Non-Standard Structure Flow Measurement Evaluation using the Flow Rate Indexing Procedure - QIP

FINAL REPORT

September 2006

Prepared for

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Water Conservation Field Services Program
United States Bureau of Reclamation
Mid-Pacific Regional Office
2800 Cottage Way
Sacramento, CA 95825
Grant Agreement No. 02FG200130

Cost Shared by

California State University Agricultural Research Initiative (CSU ARI)
Project Number 05-3-021

by

ITRC
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EXECUTIVE SUMMARY

The Irrigation Training and Research Center (ITRC) of California Polytechnic State University, San Luis Obispo performed this research study on behalf of the U.S. Bureau of Reclamation, Mid-Pacific Region. Additional funding was provided by the California State University Agricultural Research Initiative. This report describes key technical elements of using hydroacoustic flow meters in irrigation applications and presents the details of the required calibration procedures.

Hydroacoustic flow measurement technology is slowly being implemented at primary flow measurement stations in irrigation districts throughout the western U.S. Hydroacoustic flow meters can be utilized in many situations where other standard open channel flow measurement devices (such as a Replogle flume) will not work. However, these advanced electronic devices must be properly designed, installed and calibrated in order to give accurate flow measurement data. Hydroacoustic pipe flow meters of several different types are also used in irrigation pumping plants.

This report details the proper installation and calibration techniques for hydroacoustic meters. Initially, it was felt that the hydroacoustic meters could be used as a calibration device for rating non-standard structures. After some early field testing, it was evident that hydroacoustic meters required a detailed calibration procedure and specific flow conditions. Therefore, in this report the fixed-unit hydroacoustic meters were treated as non-standard measurement devices.

The calibration procedure developed as part of this study is called the *Flow Rate Indexing Procedure (QIP)*. The QIP can be completed by a professional technician with a boat-mounted Acoustic Doppler Profiler (ADP) or a standard current meter (e.g., a Price AA Current Meter). Once the QIP has been used to properly calibrate a hydroacoustic flow meter, the device can then measure and record the flow rate and volume in a channel to within +/-6% of actual values (assuming maintenance issues are regularly addressed).

The QIP approach was followed at a number of sites discussed in this report to demonstrate the field results from hydroacoustic flow meters. As a result of carrying out the QIP, flow measurement stations calibrated through this project have shown marked improvements in accuracy. On average, the discrepancy at the sites that had the full a QIP completed was cut approximately in half (from ±13.5% to ±5%). In addition, ITRC demonstrated the detailed techniques of the process and trained four (4) individuals who are now performing field measurements using the ADPs.

Evaluating the application and function of ADP boats was an important component of this study. At Merced Irrigation District, ITRC was able to compare the accuracy of the ADP boats to a Replogle flume, which is considered one of the most accurate open channel flow measurement devices (when designed and installed correctly). The flow rate discrepancy ranged from 1% to 4% depending on the profiler used and the flow conditions on the date of the investigation. Overall, the volumetric discrepancy was less than 1% over a 2-month period. ITRC concludes that the ADP boats are providing good discharge measurements in real world applications, which justifies using these devices as a "standard" for the future indexing of non-standard structures.

However, during this study the ADP boats in some cases had problems with pond weeds/moss and moving sediment along the channel bottom. The manufacturers have recently developed software for the ADPs to help address this issue based on the ISO/USGS procedure termed the "Midsection Method" (stationary measurement). ITRC now strongly recommends utilizing this procedure for measuring discharge when using ADP boats.

There are still several issues that remain for future analysis. The following topics need to be more thoroughly addressed for future installations:

1. At this time, field calibration is necessary for hydroacoustic devices. Optimally, pre-installation calibration by the manufacturer or a secondary source would be completed for common configurations so that "out-of-the-box" accuracy would not be suspect.
2. The precise factors affecting calibration constants of the hydroacoustic meters are not well understood. For example, it is known that stage has a major impact on flow readings, but it is not completely understood what effect fluctuating water levels can have on the constants and if there is a way to minimize the impact in certain situations.
3. As with any flow measurement device, accuracy appears to be highly dependent upon having smooth uniform flow at the meter (parallel flow lines). If long straight upstream channel sections are not available, another question is whether it may be possible to "condition" the upstream flow to create a better flow pattern.
4. It remains unclear what aspect ratios (width/depth) should be used in choosing between bottom-mounted units and side-mounted units over a range of conditions.
5. The intricacies of installation and initial software setup in terms of users' input information have not been analyzed as a function of calibration. For example, could adjustments to the "blanking distance" and zone of sampling have significant impact on calibration?
6. Irrigation district personnel are generally not hydraulic engineers and will require pragmatic training and field support to know how to correctly use advanced electronic devices.

Table 1 summarizes the deployment of equipment and field data collection used in the development of index velocity ratings at the 16 cooperating water agencies. ITRC has worked closely with these districts to extensively evaluate major flow measurement sites. This study would not have been possible without the cooperation of the districts and agencies. Funding provided through the Agricultural Research Initiative of the California State University (CSU/ARI) allowed expansion of this project to include the participation of non-CVP contractors.

Table 1. Summary of field data collection, index velocity ratings, and discharge rating development at study locations

Water Agency	SonTek/YSI Argonaut SL	SonTek/YSI Argonaut SW	Telog Water Level Monitoring System	Full Index Velocity Rating Procedure
Mid-Pacific Region:				
AgTac Center		√		√
Alta Irrigation District		√	√	
Anderson-Cottonwood Irrigation	√			
Banta-Carbona Irrigation				
Biggs West Gridley Irrigation		√√		
Contra Costa Water District	√		√	√
Klamath Irrigation District	√√√			
Merced Irrigation District			√√	
Patterson Irrigation District	√		√√	√
Sutter-Mutual Water Company	√			
Tulare Irrigation District	√√	√	√√√√√	√√
Tulelake Irrigation District		√		
Other Areas:				
Colorado River Indian Tribes	√			√
Lower Colorado River Authority	√			√
Paradise Valley Irrigation	√			√
Yuma Co. Water Users Assoc.	√			√

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DEFINITIONS & NOMENCLATURE

Acoustic Doppler Flow Meter – Stationary flow measurement device installed either on the side or bottom of a canal or pipeline. It utilizes Doppler technology (sound waves transmitted into the water) to obtain velocities at multiple locations along a flow profile.

Acoustic Doppler Profiler (ADP) – An acoustic Doppler device used for current metering. Typically it is installed on a small boat that can be moved across the channel perpendicular to the flow. The sensor obtains velocities at multiple points in a vertical profile at any single location. Thus, as the boat is pulled across the channel the device obtains velocities and depth information throughout the entire channel profile.

Discrepancy – Calculation of the difference between a tested measurement device compared to a standard device with a known better accuracy. For example, the percent discrepancy in discharge for each ADP boat reading compared to the installed hydroacoustic meter was calculated by using the following relationship:

$$\text{Discrepancy (\%)} = \frac{\text{measured - standard}}{\text{standard}} \times 100$$

Where,

standard = Flow rate obtained from the ADP boat
measured = Flow rate obtained from non-standard structure site (SonTek SL)

Hydroacoustic Device – Blanket term used to describe any device utilizing acoustic Doppler technology.

QIP – Flow Rate Indexing Procedure. 'Q' is a typical abbreviation for flow rate.

Non-Standard Structure – Refers to any structure in a canal that is used to estimate flow rate but does not have a known water depth (stage) to flow rate relationship. Examples of the types of non-standard structures include submerged weirs, simple rated channel sections, unusually shaped overflow structures, and hydroacoustic meters.

Stage – A specific water level at a specific flow rate on a standard or non-standard structure. Each water level (stage) should represent a different flow rate. If a stage has multiple flow rates because of issues downstream (backwater effects), the structure itself should not be used for flow measurement.

QA/QC – Quality Assurance/Quality Control

INTRODUCTION

This report summarizes the results of a performance evaluation conducted to investigate hydroacoustic rating techniques in irrigation canal systems. Standardized field procedures and technical specifications have been developed for rating measurement points obtained with hydroacoustic flow meters. Multiple demonstration sites at water agencies were included in this study. Water managers and users of advanced electronic flow measuring devices can improve the cost effectiveness, accuracy, and quality control of discharge records, even at sites with complex flow conditions, by observing these recommended guidelines.

The Irrigation Training and Research Center (ITRC) of California Polytechnic State University, San Luis Obispo performed this technical study on behalf of the U.S. Bureau of Reclamation, Mid-Pacific Region. Refer to **Table 1** for a full list of water agencies who participated in this study. Additional funding was provided through the Agricultural Research Initiative of the California State University (CSU/ARI) to include the participation of districts that do not have long-term federal contracts. The CSU/ARI funding represented about 1/3 of the project.

Background

Irrigation districts, farmers, and other agricultural and environmental water users need to accurately measure the rate and volume of flows at key points in their water distribution and delivery systems. A major component of the best management practices and water conservation efforts being promoted by the U.S. Bureau of Reclamation is the need for better water measurement. There is potential for a large number of existing structures in irrigation canal systems that could be rated affordably by using hydroacoustic flow meters.

Traditional techniques used to develop a rating curve at non-standard structures are prohibitive in most locations due to various reasons, limiting the number of sites with good measurement capabilities. In addition, rating a non-standard structure in the field requires following a tedious and laborious procedure. Flow data has to be collected manually using a hand-held current meter to determine discharge(s) at each specific water level (stage); this is a repetitive task and requires readings and calculations at multiple points to find the total flow. This type of rating could take up to 15 man-days and require undesirable changes in canal operation in order to cause necessary flow conditions during data collection. Changes in canal operation are difficult to manage as the water demand schedule is likely to be different than the conditions needed for data collection.

Another method of obtaining accurate discharge records is to install new measurement structures using standard engineering designs. However, this is can be impractical in many cases because of the considerable expense for civil works, design, new hardware, training, maintenance, etc. The cost to a water agency for the design and construction of a medium-size device such as a Replogle flume to handle 50-100 cfs is at least $50,000 or more, if one realistically considers the internal staff time involved and expenses associated with high quality equipment and building materials. Furthermore, one must also take into account the recurring costs for regular O&M of permanent monitoring stations.

Rating Non-Standard Structures

The initial goal of this study was to show that an acoustic Doppler flow meter (also called a 'hydroacoustic' device) could be installed temporarily near a non-standard structure. Flow rate and water level data would then be collected from the Doppler flow meter and compared to the water level (stage) data over the non-standard structure. Then a rating curve for the non-standard structure could be developed and the Doppler flow meter could be removed.

However, early in the study it was determined that this was not a feasible technique. Non-calibrated data from the hydroacoustic device was not accurate enough to use for rating. In effect, the non-calibrated hydroacoustic flow meter behaves just like another non-standard structure that also needed to be calibrated.

An example of this is shown in the following figure. A SonTek Argonaut SW was placed upstream of a Replogle flume located at Southern California Edison's AgTAC Center in Tulare, California. Replogle flumes provide very accurate flow measurement data if designed and installed correctly, and therefore can be considered a reasonably accurate standard device. The raw Doppler data showed significant discrepancies at low and high flow rates with average discrepancy of ±27% (refer to **Figure 1**).

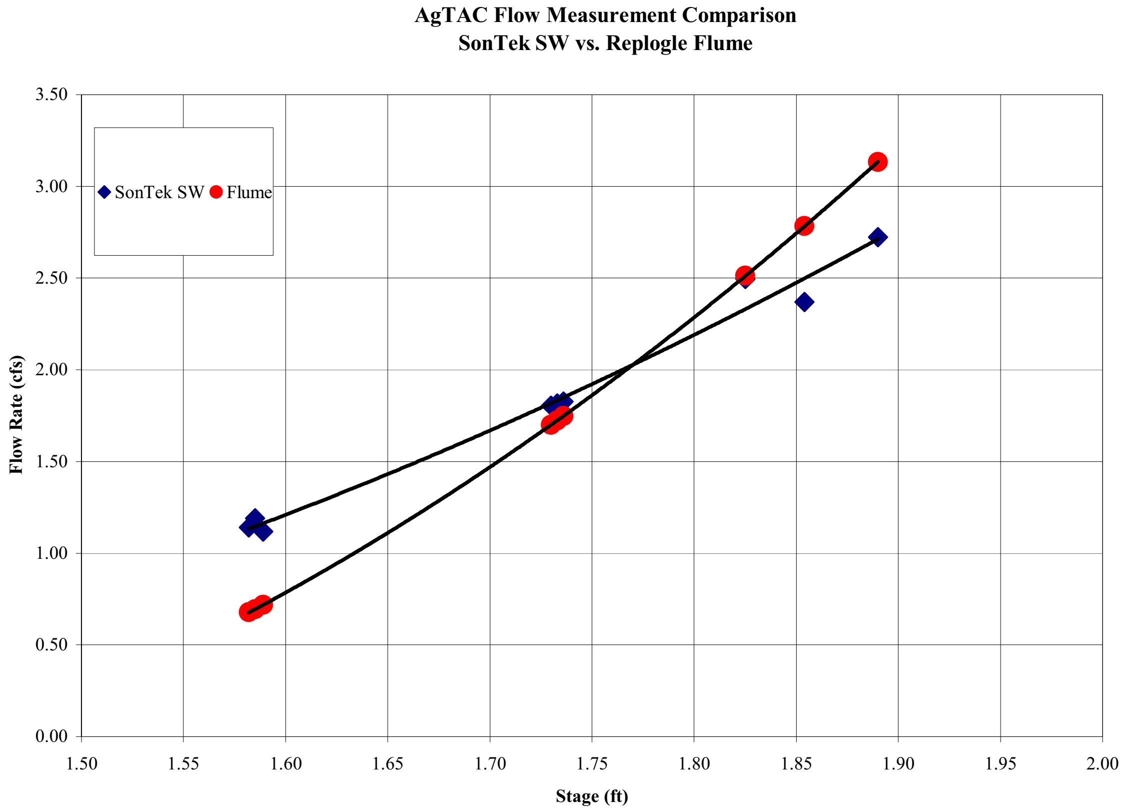

Figure 1. Non-calibrated SonTek SW data compared to Replogle flume flow rate data in the AgTAC demonstration canal

Once it was determined that a hydroacoustic flow meter could not be simply installed in a canal "out-of-the-box" and utilized immediately, ITRC modified the objectives of this study. The goal of the study was updated to incorporate an analysis of an alternative approach where a hydroacoustic meter would be used to obtain accurate discharge and stage information that could then be used to rate the non-standard structure. Therefore, ITRC focused efforts on fine tuning calibration procedures for hydroacoustic flow meters. The result was the Flow Rate Indexing Procedure (QIP).

The following figure represents the previous SonTek SW data after it had been adjusted using the QIP process. The QIP adjustment resulted in a dramatic improvement in the accuracy of the hydroacoustic device when compared to the Replogle Flume. The average discrepancy dropped to an acceptable level of ±5% and the resulting R-squared value was above 0.98, which indicates good correlation.

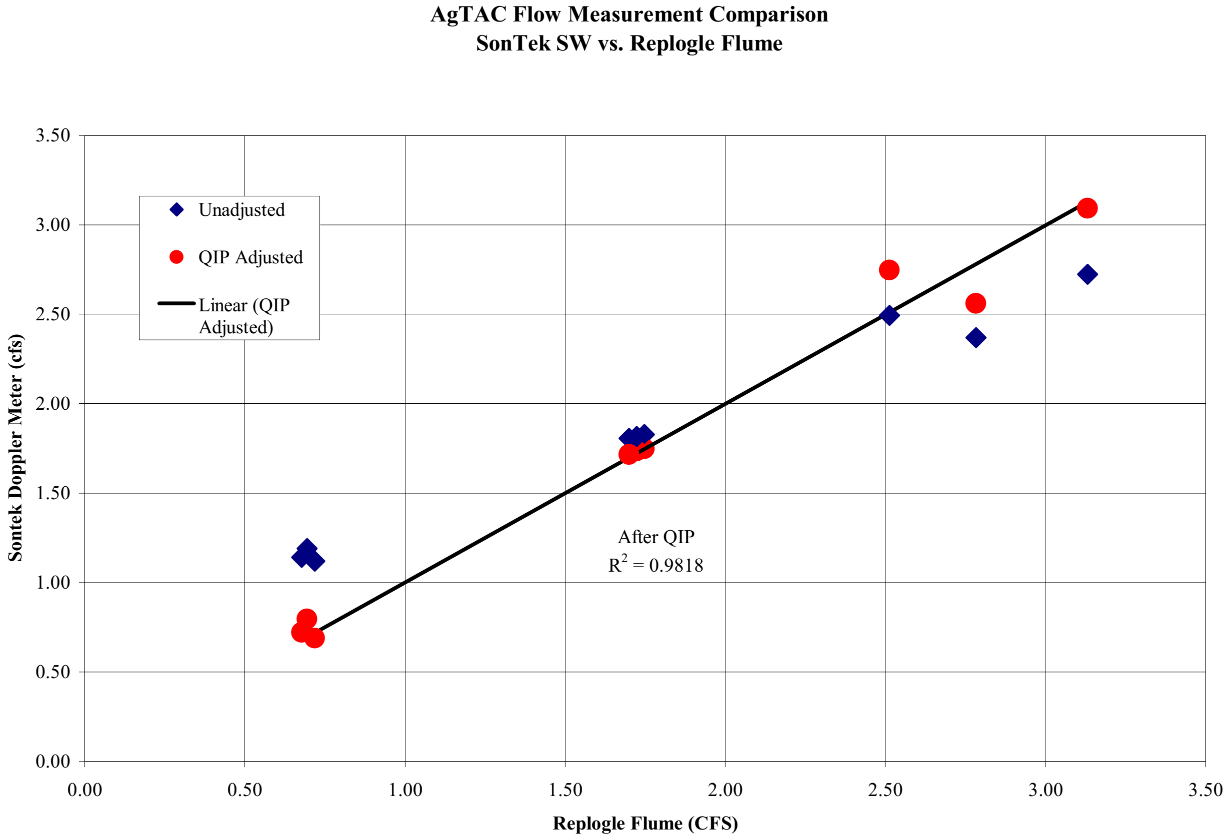

Figure 2. SonTek SW data calibrated using the QIP process compared to Replogle flume flow rate at the AgTAC demonstration canal

Research Objectives

This study evaluated the performance of advanced electronic flow measurement devices and technologies in field applications at water agencies throughout California. ITRC investigated the feasibility of using these hydroacoustic technologies for developing rating curves by deploying equipment and conducting field data collection at multiple demonstration sites. The devices were deployed in different configurations at places identified as key measurement points by the cooperating water agencies.

This research had three key objectives:

1. To prepare and evaluate standardized, step-by-step instructions for developing accurate and reliable discharge records. The steps outlined at each demonstration site are intended to illustrate the necessary components for producing accurate index velocity ratings. The final set of QIP specifications is contained in **Attachment A**. Observations from the field work helped to refine the specifications and are provided in this report as practical information for other users.

2. To use the procedures included in this report to train a user to install and index an acoustic Doppler flow meter properly. The ideal user would have experience with many hydroacoustic flow meters and have the appropriate equipment necessary to index a site. ITRC conducted demonstrations for USBR hydrologists Kevin Kibby, John Rasmussen, and Mark Niblack, as well as Donnie Stinnet, the Water Master of Joint Water District in Sacramento Valley, on how to properly install, maintain, calibrate, and index a site using a SonTek Argonaut SL for the demonstration.

3. To analyze data collected from the acoustic Doppler flow meters compared to a standard device (Replogle flume), in order to evaluate how the meters provided accurate results once a site has been indexed using ITRC procedures. Several sites, including Merced Irrigation District and Patterson Irrigation District, were selected for the further analysis.

Acoustic Doppler Profilers and Velocity Meters

ITRC has worked with manufacturers and users of high-precision acoustic Doppler flow meters for several years to improve their field performance by incorporating important design and software features that make them more user-friendly and robust. The instruments used in this study have been deployed successfully in many irrigation applications and represent industry standard specifications.[1] The sensors at the demonstration sites were calibrated prior to deployment at the measurement facilities located at the ITRC's Water Delivery Facility.

[1] Reference to any specific process, product or service by manufacturer, trade name, trademark or otherwise does not necessarily imply endorsement or recommendation of use by either California Polytechnic State University, the Irrigation Training and Research Center, or the United States Bureau of Reclamation. No party makes any warranty, express or implied and assumes no legal liability or responsibility for the accuracy or completeness of any apparatus, product, process or data described previously.

The SonTek/YSI Argonaut Side Looking (SL) 1.5-MHz Doppler flow meter measures 2D horizontal water velocity using the physical principle termed the Doppler shift. The Argonaut SL is designed for side-looking operation from underwater structures such as channel walls. The location and sampling size where the velocity measurements are collected (cell length) are adjustable based on user-selected parameters up to a range of 70 feet. The start of the measurement area can be extended away from the instrument to avoid signal contamination due to boundaries or mounting structures. The Argonaut acoustic sensors, receiver electronics, temperature sensor, pressure sensor and processor are configured in pressure housing.

The orientation of the sensors and a photograph of the Argonaut SL are shown in **Figure 3**.

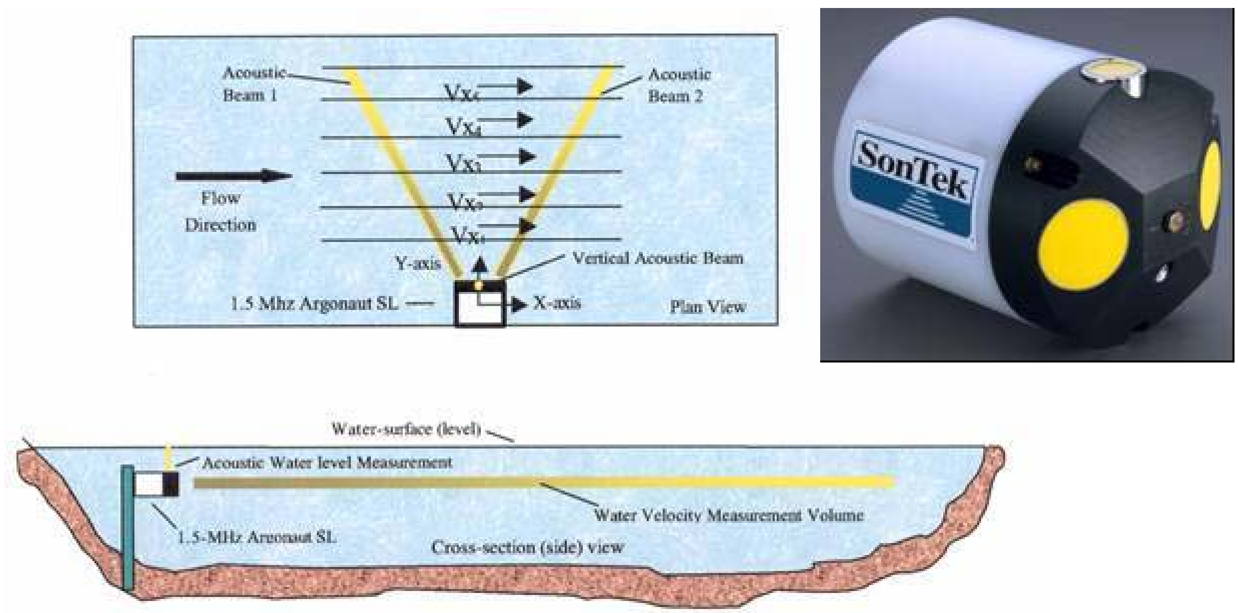

Figure 3. SonTek/YSI Argonaut SL ultrasonic Doppler flow meter

The Argonaut SL transducers measure the change in frequency of a narrow beam of acoustic signals in order to compute along-beam velocity data. Beam velocities are converted to XYZ (Cartesian) velocities using the known beam geometry of 25° off the instrument axis. A vertical beam is used for water level measurement. The optional internal flow computation feature provides the ability for the user to enter an index velocity rating into the sensor's firmware memory. The Argonaut SL units deployed at the demonstration sites have features that are SCADA compatible.

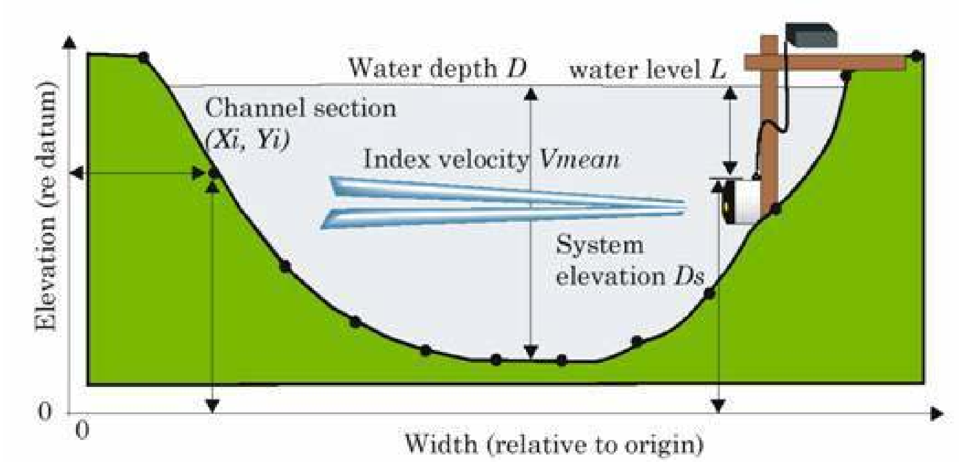

Figure 4. SonTek/YSI Argonaut SL channel geometry for internal flow computations

At some demonstration sites Argonaut Shallow Water (SW) devices were deployed in conjunction with the Telog Level Tracker water level monitoring system. The operating principles and applications of these devices are described later in this report.[2]

For this study, ITRC utilized the leading Acoustic Doppler Profiler (ADP) discharge measurement systems designed for hydrological applications – the SonTek/YSI RiverSurveyor and the RD Instruments StreamPro. Both units are shown in **Figure 5**. These boat-mounted profilers collected discharge records concurrently with the Argonaut SL and SW units. Water velocities and depths were measured at different flow rates.

Figure 5. Boat-mounted Acoustic Doppler Profilers collecting flow rate and cross-sectional measurements in irrigation canals

The discharge measurements obtained from the RiverSurveyor and StreamPro were analyzed for QA/QC purposes and used in the computation of index velocity ratings at each site due to their ability to measure flow rate within ±2% of actual values.

[2] Additional technical reports and papers are available to download at www.itrc.org.

Technical Approach and Project Components

This section summarizes the details of the technical approach followed in the study. The procedure for collecting velocity and stage datasets and performing regression analysis is relatively straightforward. The large internal memory of modern datalogger and sensor systems means the measurement devices can be set up and left in the field for several months to collect data at user-specified intervals, which can then be analyzed using ordinary office programs such as Microsoft Excel.

The Flow Rate Indexing Procedure (termed '*QIP*') developed by ITRC consists of data analysis in addition to deploying field equipment and recording site parameters. The mathematical process describing the rating for a site is given a brief explanation here to illustrate the basic technique that is used with the new hydroacoustic technologies. **Figure 6** shows a typical calibration curve using current meter readings. The time needed to collect this type of data in the field is considerable and usually involves disrupting normal operations.

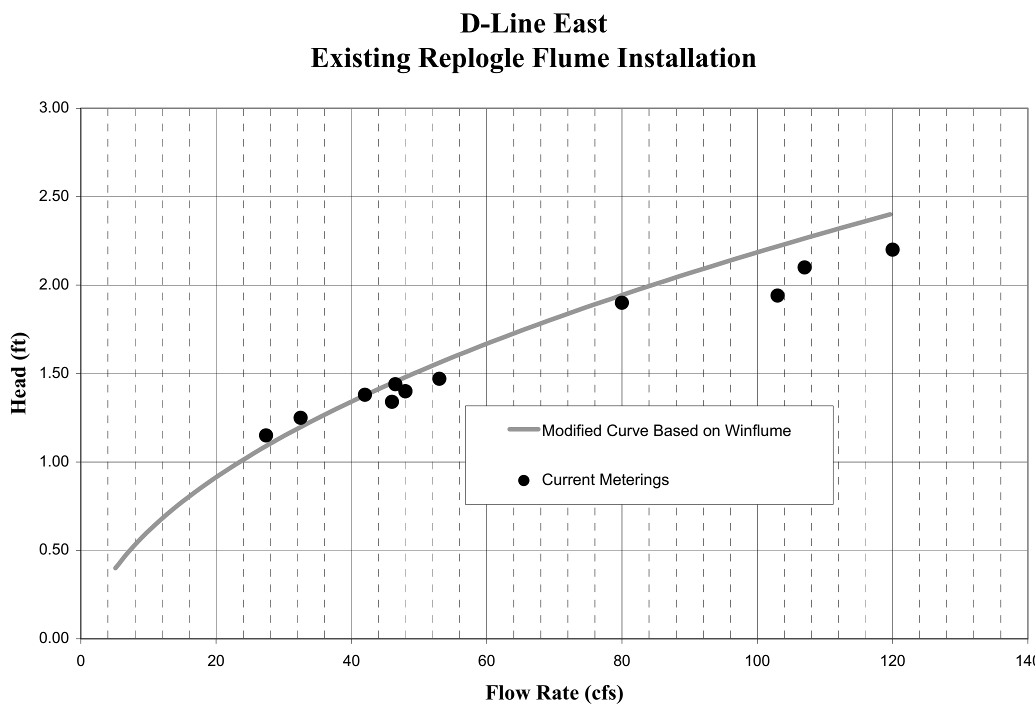

Figure 6. Plot of current metering data and head-discharge curve

The recommended calibration guidelines for a non-standard site using current metering data are as follows:

- A wide range in the measured flow rate is required. At least a 2:1 ratio in the flow rates should be used to create the dataset.
- A minimum of 10 values should be measured across the entire flow rate range.
- Data should be plotted on a log-log scale graph (**Figure 7**). Such a graph is a standard option in programs such as Microsoft Excel.

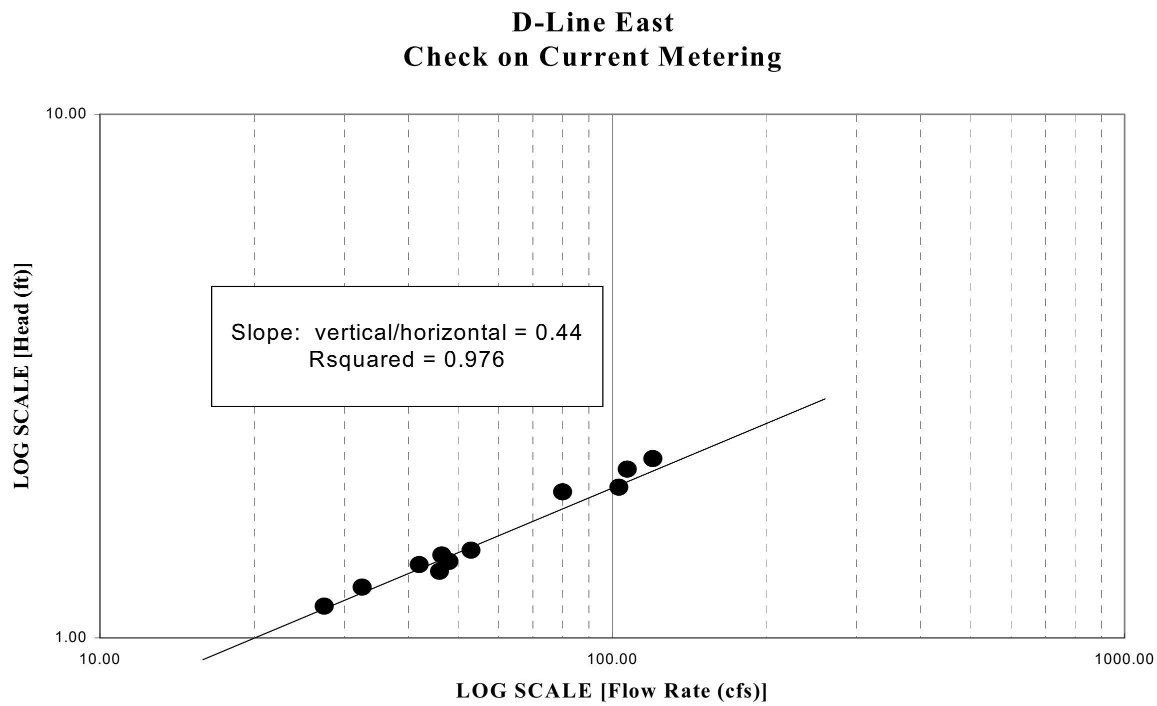

Figure 7. Example log-log plot of current meter data

The data should plot out as a line (not a curve) with a slope between 0.4 and 0.67. A spreadsheet program can be used to determine the equation of the line, and the equation should be of the form:

$$H = KQ^x$$

where "x" is a value between 0.4 and 0.67

The regression coefficient (r^2) should be better than **0.96** to ensure confidence in the results.

Figure 8 shows a sample of long-term flow data collected with an acoustic Doppler flow meter.

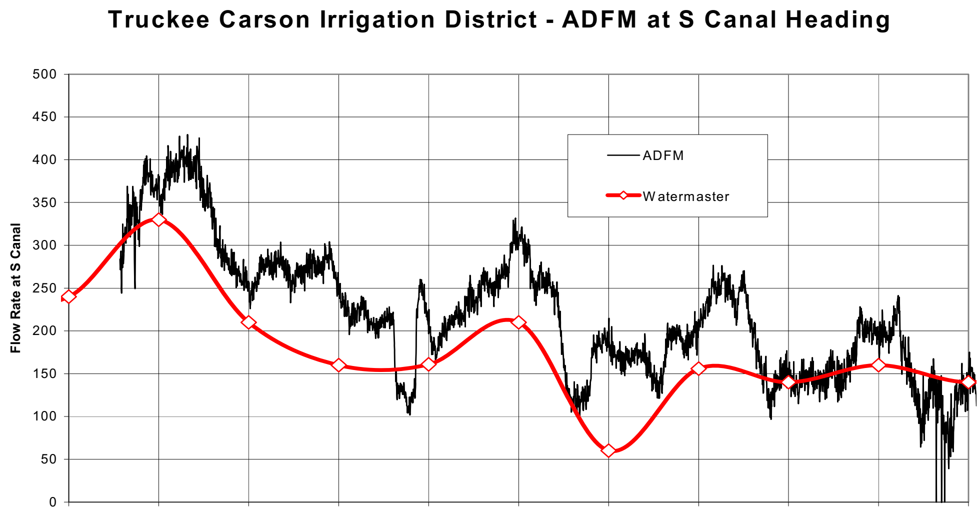

Figure 8. Plot of flow data collected by an acoustic Doppler flow meter

Recommended Site Conditions for Hydroacoustic Devices

The physical setting of hydroacoustic devices and the flow conditions at the site have a major impact on the potential accuracy of discharge records. This deserves special consideration in indexing applications when hydroacoustic flow meters are being used to rate another structure. Before deployment of a device such as the Argonaut SL or SW, the site must be evaluated according to recommended conditions. Users should refer to the manufacturer's specifications for detailed information on particular requirements for environmental protection, power supply, etc. for different models.

The following guidelines outline the required characteristics of a site for hydroacoustic devices such as the Argonaut SL.

1. The location of the device must be at least ten widths of the canal away from bends or turbulences ensuring a good, even velocity distribution.

2. The device must be located at a concrete-lined section of the canal that has been properly surveyed. The concrete section provides a stable stage-area rating.

3. The device must be installed on a secure, movable mounting bracket for easy removal of the sensors for maintenance. Even more important, the mounting bracket must be designed so that when the device is placed back into the canal, it returns to the exact same location and horizontal angle.

4. A trash deflector must be installed around the device to prevent trash, algae, and weeds from collecting on or around the sensors.

5. A calibration procedure, such as the Flow Rate Indexing Procedure (QIP), must be completed.

FLOW RATE INDEXING PROCEDURE

Hydroacoustic flow meters are high-precision instruments that can very accurately measure the velocity of water in the section of flow being sampled. The water velocity measured by stationary hydroacoustic flow meters should be proportional to the actual mean channel velocity. The mean channel velocity is usually determined by current metering, or using an Acoustic Doppler profiler (ADP). Through extensive experience, ITRC has found that it is rare that the hydroacoustic flow meter will provide reasonably accurate flow readings without calibration. The Flow Rate Indexing Procedure (QIP) will be discussed in detail in this section as the recommended calibration procedure for hydroacoustic flow meters.

Hydroacoustic flow meters are appropriate in many situations where, for example, the flow conditions are too complex for traditional devices. The flow rate is computed internally by devices such as the Argonaut SL flow meter by the firmware using a programmed stage-area rating and the index water velocity ($Q = V \times A$). The user can input an indexing equation into the unit with the deployment software based on the results of the QIP process.

In QIP applications, the measured velocity is sampled and recorded in programmed time intervals concurrently by both the device being calibrated (e.g., a SonTek Argonaut SL at the head of a lateral canal), and a second profiling device that produces an accurate discharge measurement such as an ADP or current meter. Mean channel velocities can also be obtained from current metering as long as the time periods are the same.

The data for multiple pairs of mean velocity and index velocity data collected over a range of flow rates are analyzed using regression techniques, with and without multi-parameter ratings to account for the effect of stage. The resulting equation of the index velocity rating is necessary in order to use the internal flow computational feature on hydroacoustic flow meters or for post-processing data from temporary deployments. The results of this study indicate that implementing the index velocity rating improved the average error of the demonstration sites by over 6%.

Major Steps in the Flow Rate Indexing Procedure - QIP

The major steps in the Flow Rate Indexing Procedure (QIP) are outlined in this section. The complete specifications are contained in **Attachment A**.

During an indexing session, the technician follows a set of standard procedures to collect data from the different sensors for a specified time period. Following the recommended guidelines for deployment of hydroacoustic flow meters is essential. The dataset for each measurement period is comprised of:

1. Mean velocity in the standard cross-section
2. Average measured velocity from the hydroacoustic flow meter
3. Average stage

The following major steps outline the procedure for developing an index velocity rating:

1. A hydroacoustic flow meter is installed in the canal with the appropriate deployment settings and mounting bracket. Site selection is an important consideration and the diagnostic guidelines provided in the manufacturer's technical documentation should be carefully observed. These diagnostic parameters include an assessment of the signal strength and standard deviation for a given set of operating conditions.
2. The channel is accurately surveyed and a stage-area rating is developed. The same standard cross-section is used every time indexing data is collected. Elevations for the cross-section points are in terms of stage referenced to the station datum.
3. The average stage during the discharge-measurement period is recorded. A secondary water level monitoring device may be utilized to provide quality assurance data (as was done in this study).
4. Discharge measurements are made near the hydroacoustic flow meter site while the instrument is sampling and recording velocity and stage. Historically, discharge measurements have often been done with a Price AA current meter. However, discharge records obtained from acoustic Doppler profilers (ADPs) are faster with comparable accuracy. If an ADP is used, ITRC strongly recommends using the "stationary measurement" technique described in the *Operation of ADPs* section of this report.
5. Mean channel velocity is derived for each individual discharge measurement by dividing the measured discharge by the channel area computed from the stage-area rating.
6. For each measurement period, the index velocities measured by the hydroacoustic flow meter are averaged.
7. Each discharge measurement yields a computed mean channel velocity and an average index velocity.
8. A regression analysis is performed to determine the equation of a plotted line using single or multi-parameter analysis to account for the effects of stage. The equation coefficient of the relation between the mean velocity and the index velocity is the "index velocity rating". User instructions for performing regression in Microsoft Excel are included in **Attachment B**.
9. Discharge is computed from the standard equation $Q = V \times A$. Velocity is computed from the regression equation(s) developed comparing the index velocity rating to the measured velocity. This can be done directly in the sensor's firmware using the instrument's deployment software so that the output of flow data is already calibrated. The index velocity rating can also be applied in post-processing using a spreadsheet. The Area is computed from the stage-area rating of the canal and the measured stage.
10. The index velocity rating procedure recommended by ITRC requires a wide spread in the measured discharge (a 2:1 ratio), usually at least 10 measurement values over the entire range of flows. The regression coefficient (r^2) must be better than 0.96 to ensure confidence in the results.

11. The validity of the index velocity rating depends on maintaining stable channel and hydraulic characteristics at the measurement site. Changes in channel conditions due to sedimentation or weed growth can invalidate an index velocity rating. Accurate discharge measurements from hydroacoustic instruments depend on regular assessments of the index equation using ADP or current metering data. Using the "stationary measurement" technique greatly enhances the accuracy of the measurement, negating effects of bottom shifting and moving weeds on the ADP.

The index velocity rating is developed by first validating that a linear relationship exists between the mean velocity and average of the sensor-measured velocity data collected during the same time period. This is done by creating a scatter plot with mean velocity as the y-axis and index velocity as the x-axis. An example scatter plot for an index velocity rating of a hydroacoustic flow meter is shown in **Figure 9**.

Linear regression produces a straight line that is the best fit for all the data points. The equation of this line is an index velocity rating with the single parameter (independent variable) of sensor-measured velocity. For some sites, the inclusion of stage as an additional regression parameter can improve the accuracy of the index velocity rating. The product of the index velocity and stage is the second independent variable in the multiple regression. Stage may have a significant impact depending on channel geometry, channel roughness, the set points of downstream structures, stability of the velocity profile, etc.

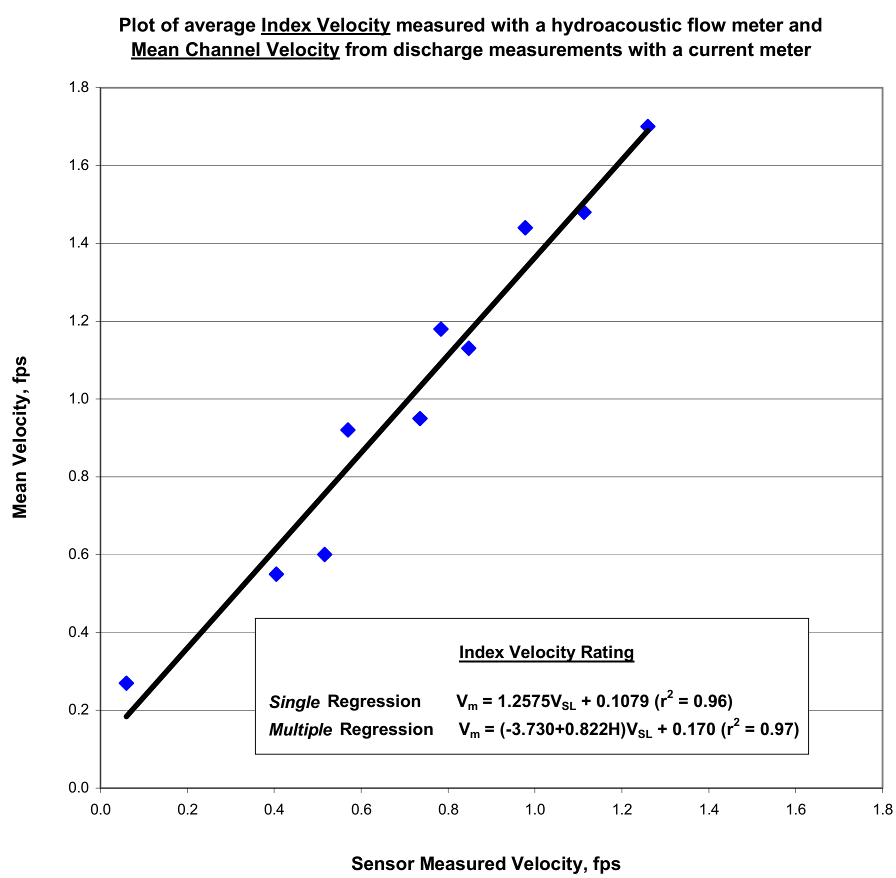

Figure 9. Example scatter plot of an index velocity rating for single and multiple linear regression ($r^2 \geq 0.96$)

Operation of Acoustic Doppler Profilers

Acoustic Doppler Profiler (ADP) instruments mounted to small boats were used to collect discharge data at the demonstration sites where an index velocity rating was developed. ITRC has conducted field validation of the systems manufactured by SonTek/YSI and RD Instruments used in this assessment, including the RiverSurveyor (SonTek/YSI) and the StreamPro (RDI).

The ADP instruments were mounted in tethered boats attached to a pulley system. The field evaluation of different boat designs included the Riverboat manufactured by OceanScience (www.oceanscience.com).

Refer to the Quick Start Guides in **Attachments C** and **D** for instructions on deploying the units and ensuring quality control of collected field data.

Recommended Guidelines

Site Characteristics, Equipment and Personnel

Before discharge data is collected at a site using an ADP, information describing the site conditions, date, personnel, equipment, and versions of software and firmware used should be entered on the *Acoustic Doppler Profiler Field Measurement Form* (USGS form 9-275).

The key issues to consider when selecting the proper location for the standard measurement cross-section are:

- The maximum water depth for the entire cross section must not exceed the maximum profiling range of the system:
    - SonTek/YSI RiverCat 3.0 MHz: 6 m (19.7 ft)
    - RDI StreamPro 2.0 MHz: 2 m (6.6 ft)
- Select an area of relatively uniform and steady flow. Avoid areas with a significant number of eddies or turbulence.
- The cross-section should have gradual changes in depth.
- Flow along the canal banks should be low or close to zero.

Additional data that should be collected at a site includes:

- The cross-sectional area of the site, accurately surveyed
- The discharge of the canal, measured using a Price AA or Pygmy meter
- Rating curve or tables of any measurement structure nearby in the canal

Changes in Water Level

The water level from a pressure sensor or staff gauge height should be obtained before and after each measurement session and entered into the space provided on the front of the field note sheet. An average gauge height and discharge then can be calculated and entered into the space provided on the upper part of the field note sheet.

A temporary setup such as the Telog Water Level Monitoring System should be installed upstream of the non-standard structure to accurately measure water level changes during the data collection period.

Depth of ADP Sensor in the Water

After the ADP is mounted and deployed on the boat and prior to each measurement, the depth of the ADP in the water should be measured and recorded. The depth of the ADP is the vertical distance from the water surface to the center of the transducer face. When measuring the ADP depth, make sure that the roll and the pitch of the boat are similar to the roll and pitch during the discharge measurement. Data is collected with a sensor depth that is 1 to 3 inches below the surface of the water.

Assessment of Bedload Movement

Assessment of stream/channel bed movement is necessary before a discharge measurement can be made, because the vessel velocity relative to the channel bed is also measured and used to calculate the actual water velocity. Because of variability of bedload movement across the channel, it may be necessary to check for bed movement at several (3-5) locations across the channel to ensure that the bed is stable. Maximum potential for bed movement occurs in the region of maximum water velocities.

Speed and Maneuvering of the Boat

The boat should be stationary at the start and end of the measurement period and a few profiles should be collected during these stationary periods. The average boat speed for each transect should be less than or equal to the average water speed. Slow, smooth boat movements are desirable. Under certain conditions it may not be possible to keep the boat speed less than the water speed. As a result, additional transects should be made.

Edge Distance Measurement

Edge distances for estimation of edge discharge must be measured using an electronic-distance measuring device, a tagline, or some other accurate measuring device.

The edge locations must be determined prior to beginning the data collection. Typically, edge measurement is taken as close to the shoreline as can be measured and still read valid data (i.e., an ensemble that contains a minimum of two good depth cells). Start and stop points for the stream/channel edges can be marked on the tether line.

Stationary Measurement

During the course of this evaluation, ITRC determined that traditional operation of the ADP devices showed inconsistent velocity readings under certain conditions. Basically, in real world applications, irrigation canals have sediment, weeds, and other issues that make them dynamic systems. Even concrete lined sections can have sediment deposits that create issues.

SonTek/YSI and RD Instruments modified their software so that a new method of operation could be used with the ADP devices. The software allows a tagline to be set up and measurements taken on measured intervals (each interval is called a panel). This method is termed "stationary measurement" or "section-by-section" (based on USGS/ISO "Mid-Section Method"). Because the development of this method was not completed until after most of the site work for this project was completed, the method was not utilized at most of the sites discussed in this report. Nevertheless, ITRC strongly recommends that the stationary measurement method be utilized in the future with the ADPs. **Attachment G** contains more information on the stationary measurement method.

While similar in many ways to a traditional discharge measurement, stationary measurement offers users several unique advantages:

- More data points to ensure data accuracy: with a conventional measurement, velocity is typically measured at only one or two points in each vertical. The ADP boat measures the velocity profile at many points in each vertical. These data points are then averaged to provide a much more accurate and reproducible measurement of the mean velocity for that panel.
- Real-time data QA/QC for data confidence: the coefficient of variation of the mean velocity is computed in real time, which provides the user with immediate feedback regarding fluctuations in mean velocity at that station. Utilizing this information, the user can adjust the measurement time to obtain the best possible velocity measurement.
- Save time and money: with ADP measurement, water depth is obtained at the same time as the water velocity. This means the user no longer needs to stop to record the depth at each station. This function can represent a significant savings of time over the course of each discharge measurement.

Stationary Discharge Measurement

The following are recommended guidelines for collecting discharge measurements using the stationary software for the boat-mounted ADP:

- Only one transect has to be completed under steady-flow conditions at each site to ensure a valid determination of discharge.
- If any one of the panel measurements differs from previous panel measurement by more than 10% (possible outlier), it should first be evaluated to determine if there is any reason to justify an additional measurement of the panel section. The stationary measurement can vary between each panel; however, if there is a noted discrepancy the single panel measurement can simply be replaced.

- After the discharge measurement has been made, each raw data file should be reviewed using the "Playback" mode to ensure that:
    a. The data is complete
    b. The data does not include any bad ensembles
    c. Depths and velocities do not exceed the prescribed limits set for the instrument in use
    d. The data does not include velocities spikes (i.e., stream velocities = ambiguity velocities)

- If a raw data file contains bad velocity ensembles or velocities spikes, the measurement should be repeated.

Measurement Assessment

An overall assessment of the resulting average discharge measurement should be made in the field at the end of the measurement session. This assessment is based on:

- Qualitative judgment of conditions encountered in making the measurement
- Quantitative evaluation of the individual transects
- Completeness of the measurement in terms of the percentage of the total cross-sectional area
- Conditions such as turbulence, eddies, reverse flows, surface chop, and proximity of the instruments to ferrous objects

The average value and standard deviation(s) of the discharge measurement and the coefficient of variation (CV) should be calculated. If the CV is greater than 5%, additional transects should be made.

DISTRICT SUMMARIES

The results of field data collection and regression analysis conducted at water agencies in the Mid-Pacific Region are discussed in the site visit reports in **Attachment E** for each demonstration site. This section summarizes the work completed at each site. Field data collection and data analysis were done according to the specifications in the ITRC Flow Rate Indexing Procedure (QIP).

Full Index Velocity Ratings

The following summaries describe districts at which ITRC conducted full velocity rating procedures for calibration of their acoustic Doppler flow meters. In addition, the acoustic Doppler flow meter was used to develop a rating curve for a non-standard structure at Contra Costa WD and Tulare ID. Individual district reports with detailed procedures can be found in **Attachment E**. An error analysis summary for the following sites can be found in **Table 2**.

Colorado River Indian Tribes (CRIT)

An index velocity rating was developed to relate the mean channel velocity to the velocity measured by a SonTek Argonaut SL located in the CRIT Main Canal. A total of 8 measurements over a range of low, medium, and high flows were obtained using current metering and ADP boats to develop a proper index velocity rating. ITRC was able to complete the index velocity rating for the SonTek.

Contra Costa Water District

A SonTek Argonaut SL flow meter was installed in the Contra Costa Canal upstream of an existing ultrasonic flow meter (**Figure 10**). The Argonaut was installed in September 2003. The ADP boats collected discharge data from September 2003 through September 2005 to develop an index velocity rating for both flow measurement devices. Data from the Argonaut SL was collected with the hope of developing a water level-to-flow relationship. However, this was not possible because of backwater effects.

The demonstration site at the Pumping Plant No. 2 in the Contra Costa Canal is shown in **Figure 10**.

Figure 10. SonTek/YSI Argonaut SL deployed at Pumping Plant No. 2, Contra Costa Water District

Lower Colorado River Authority (LCRA) Lake Plant Site

A simple linear canal index velocity rating and a multiple regression index velocity rating were developed for the LCRA Lake Plant site. A current meter was used to develop the velocity index rating for a recently installed SonTek Argonaut. The site was current metered 11 times from April 2002 through May 2003. The raw data produced a discrepancy of ±9.9% when comparing the flow rate measured by the SonTek to the standard current meter measured flow rate. ITRC index ratings of the same data produced an average discrepancy of ±3.7% in rated flow rate compared to the standard current meter measured flow rate with both the linear and multiple regression techniques.

In addition to the Lake Plant Site, ITRC provided QIP analysis and recommendations for 4 additional LCRA hydroacoustic sites.

Paradise Valley Irrigation District

A simple linear canal index velocity rating and a multiple regression index velocity rating were developed for a SonTek site in Paradise Valley ID (USBR in Montana). The site was current metered 8 times between July 2002 and August 2003. The raw data produced a ±12.7% average discrepancy when comparing the flow rate measured by the SonTek to the standard current meter measured flow rate. ITRC index ratings of the data recorded from this site produced a ±6.6% and a ±6.9% average discrepancy in rated flow rate compared to the standard current meter measured flow rate with the simple linear and multiple regression procedures, respectively.

In addition to Paradise Valley ID, ITRC provided QIP analysis on 4 additional hydroacoustic sites in Montana for the USBR.

Tulare Irrigation District

Tulare ID has installed two Argonaut SL flow meters at the Rocky Ford site in order to rate two non-standard structures. ITRC installed Telog water level recorders at each Argonaut SL site and at the site of the non-standard weir structures. The instruments became fully operational in August 2004. The ADP boats collected discharge data at 13 different flow rates at the upstream site and 17 at the downstream site to develop index velocity ratings for the installed instruments. After calibration of the sensors, an accurate rating curve was developed for the two non-standard structures.

Figure 11. SonTek RiverSurveyor collecting flow data at the Rocky Ford site

Yuma County Water Users' Association (YCWUA) West Main Canal

A SonTek Argonaut Side-Looking (SL) flow meter was installed in the YCWUA West Main Canal. The site was current metered 10 times from November 2003 to May 2004. The canal index velocity rating derived from a multiple regression analysis provided the best results at the YCWUA West Main Canal.

Summary Error Analysis

The index velocity ratings developed at each of the demonstration sites were used to compute the discharge and compare it to the mean discharge collected with the RiverSurveyor and RD Instruments StreamPro. The average error at each site is shown in **Table 2** for the raw, linear regression, and multiple regression flow rates.

The percent discrepancy in discharge for each current meter reading (or ADP boat reading) was calculated using the following relationship:

$$\text{Discrepancy (\%)} = \frac{\text{measured - standard}}{\text{standard}} \times 100$$

where, standard = flow rate obtained from ADP boat or current meter in these cases
measured = flow rate obtained from non-standard structure or device (SonTek SL for example)

The average error shown in **Table 2** was computed based on the average of the absolute value of the percent error calculated at each discharge measurement. The values in **Table 2** reinforce the recommendation that calibration of acoustic Doppler flow meters using QIP process is necessary.

Table 2. Average percent discrepancy (+/-) computed at each QIP site and the regression analysis R-Squared values

		Percent Discrepancy (+/-)		
Site	**Number of Current Meter Readings Taken**	**Raw SonTek Data**	**Flow Calculation with Linear Regression**	**Flow Calculation with Multiple Regression**
CRIT Main Canal	8	5.9%	5.3%	2.8%
Contra Costa Water District	5	13.3%	4.6%	4.3%
LCRA Lake Plant Site	11	9.9%	3.7%	3.7%
Paradise Valley ID (Montana)	8	12.7%	6.6%	6.9%
Tulare ID upstream site	14	14.7%	6.3%	4.5%
Tulare ID downstream site	14	6.1%	6.0%	4.2%
Yuma Co. WUA West Main Canal	10	32.0%	11.0%	9.4%

	Regression R-Squared Values*	
Site	**Linear Regression**	**Multiple Regression**
CRIT Main Canal	0.983	0.990
Contra Costa Water District	0.993	0.998
LCRA Lake Plant Site	0.992	0.992
Paradise Valley ID (Montana)	0.930	0.947
Tulare ID upstream site	0.871	0.916
Tulare ID downstream sit[1]e	0.622	0.805
Yuma Co. WUA West Main Canal	0.960	0.966

*Note: these values for R-Squared are based on the velocity. These values improve dramatically if they are based on flow rates.

Other Site Visits

The following district summaries describe index ratings that either are works-in-progress, did not require the full 8-10 measurements, or where the ADP may have been used for purposes other than rating a stationary acoustic Doppler device. Site visit reports for each of the following districts can be found in **Attachment F**.

AgTAC Center

A SonTek Argonaut SW flow meter was installed in the Southern Edison AgTAC Center demonstration canal. The instrument was installed in February 2004 and has a display unit. The Argonaut SW measures flow down the canal and can be compared to flow rates measured by a Magnetic flow meter upstream or a Replogle flume downstream in the same canal. The sensor was calibrated to the Magnetic meter using the ITRC index velocity rating.

Alta Irrigation District

A SonTek Argonaut SW flow meter and a Telog water level recorder were installed in an Alta ID canal at an upstream location of an existing non-standard structure. The instrument was installed in July 2004 and removed in August 2004. The ADP boats were used to collect discharge data in July and August 2004 to start developing an index velocity rating for the installed instrument. However, while the SonTek was collecting data, the battery and solar panel were stolen from the site. Because of the data loss, an index velocity rating and the non-standard structure rating curve could not be developed in the allotted time frame.

As part of the July 2004 ITRC Flow Measurement class (which includes flume design, an introduction to electronic flow devices, and calibration of the electronic flow devices) a site visit was conducted to the Alta ID SonTek installation. Participants were introduced to the field installation and a demonstration of the acoustic Doppler profiling boats **(Figure 12)**.

Figure 12. Location of the installed SonTek SW, ADP boat measurement, and non-standard structure

Anderson Cottonwood Irrigation District

A SonTek Argonaut SL flow meter was installed in an Anderson Cottonwood ID canal downstream of existing rated sites. The instrument was installed in September 2003 and is still recording data. ITRC staff assisted a USBR hydrologist with the collection of the first index velocity rating point needed to calibrate the SonTek. The USBR hydrologist is continuing to collect data using a SonTek ADP boat to complete the index velocity rating.

The sites of the sensor installation and the rated section are shown in **Figure 13.**

Figure 13. Location of the installed SonTek SL and SCADA system at ACID

Banta-Carbona Irrigation District

Pump efficiency tests were conducted at Banta-Carbona ID at Pumping Plant No. 2. The flow rates were measured in October and November of 2004 for all 6 pumps at different head conditions. The ADP RDI boat collected discharge data that was used for pump efficiency tests. Cross-sectional area information was not provided by the ADP boats due to the difficulty of surveying the site, and since this was a temporary procedure.

The demonstration of the ADP device in the Banta-Carbona main canal is shown in **Figure 14**.

Figure 14. RDI StreamPro measuring flow rate at Pumping Plant No. 2, BCID

Biggs-West Gridley Irrigation District

Two Argonaut SW flow meters were installed in the Biggs-West Gridley ID canal system using a concrete and plastic lined measurement section shown in **Figure 15**. The instruments were installed in 2005. ITRC assisted a USBR hydrologist with collecting the first index rating point using an ADP boat. The USBR is collecting discharge data using ADP boats to develop an index velocity rating for both the installed instruments. Cross-sectional area information was surveyed by Biggs-West Gridley ID engineering staff.

Figure 15. Two installation types for Argonaut SWs at Biggs West Gridley ID

Klamath Irrigation District

Klamath ID has installed three Argonaut SL flow meters in the B, C, and D Canals. The ADP boats collected discharge data at the same time as the Argonaut SL to begin development of an index velocity rating for the installed instruments. The USGS and ITRC are working together to collect data for the index velocity ratings.

The typical installation of a SonTek Argonaut SL in Klamath ID is shown in **Figure 16.**

Figure 16. SonTek/YSI Argonaut SL deployed at the B (left) and D (right) Canals in Klamath ID

ITRC also checked the accuracy of an Accusonic flow meter at the head of the A Canal with the ADP boats. The flow measurement comparison between the Accusonic and the ADP was within 0.7%.

Merced Irrigation District

The mean discharge was measured using both the SonTek/YSI RiverSurveyor and RD Instruments StreamPro ADP boats just downstream of a Replogle flume of the Merced ID main canal as shown in **Figure 17**. This was done as a check for both the Replogle flume and the ADP boats. Also, Telog water level recorders were installed upstream and downstream of the Replogle flume to check for depth and submergence. No indexing or rating was done at this site.

The flow rate comparison of the RDI and SonTek ADPs to the Replogle flume is shown in **Table 3**.

Table 3. Comparison of Replogle flume (standard) flow rate with the RDI ADCP and SonTek ADP

	Average Flow Rate (cfs)			Discrepancy (%)	
Date	**SonTek**	**RDI**	**Replogle Flume**	**SonTek**	**RDI**
8/4/2004	1217	1207	1252	-3%	-4%
8/31/2005	1106	n/a	1100	1%	n/a

Figure 17. Telog Water Level Monitoring systems were deployed upstream and downstream of this large Replogle flume in the Merced ID

Patterson Irrigation District

ITRC installed a SonTek SL flow meter at Patterson ID downstream of the Replogle flume and Telog water level recorders that are located upstream and downstream of the flume, and at the Argonaut SL site as shown in **Figure 18**. The instruments were installed in 2004.

The ADP boat was used to collect discharge data on May 25, 2005 and was compared to the Replogle flume discharge measurement. **Table 4** shows the comparison of the discharge measurements. The discrepancy of -7% was due to pond weeds along the bottom of the channel causing the boat to take false readings. This is an example of why stationary measurement method should be utilized when profiling a channel with an ADP boat.

Table 4. Comparison of ADP boat data to the Replogle flume discharge measurement.

	Average Flow Rate (cfs)		Discrepancy (%)
Date	**ADP**	**Replogle Flume**	**ADP**
5/25/2005	98.5	106.4	-7%

Figure 18. RD Instruments StreamPro ADCP collecting discharge data at a Telog Water Level Monitoring station located upstream of a Replogle flume

Figure 19 shows the comparison of the calibrated SonTek SL and Replogle flume flow rates over a two-month period. The results showed a volumetric discrepancy of -0.7% over the time period (using the flume as the standard). It is important to note that in this case the hydroacoustic meter and the Replogle Flume gave very close readings after the QIP was utilized.

It is critical to note that the actual accuracy that we are often interested in is the volume and not the instantaneous flow rate. In this case, the volumetric discrepancy is very small.

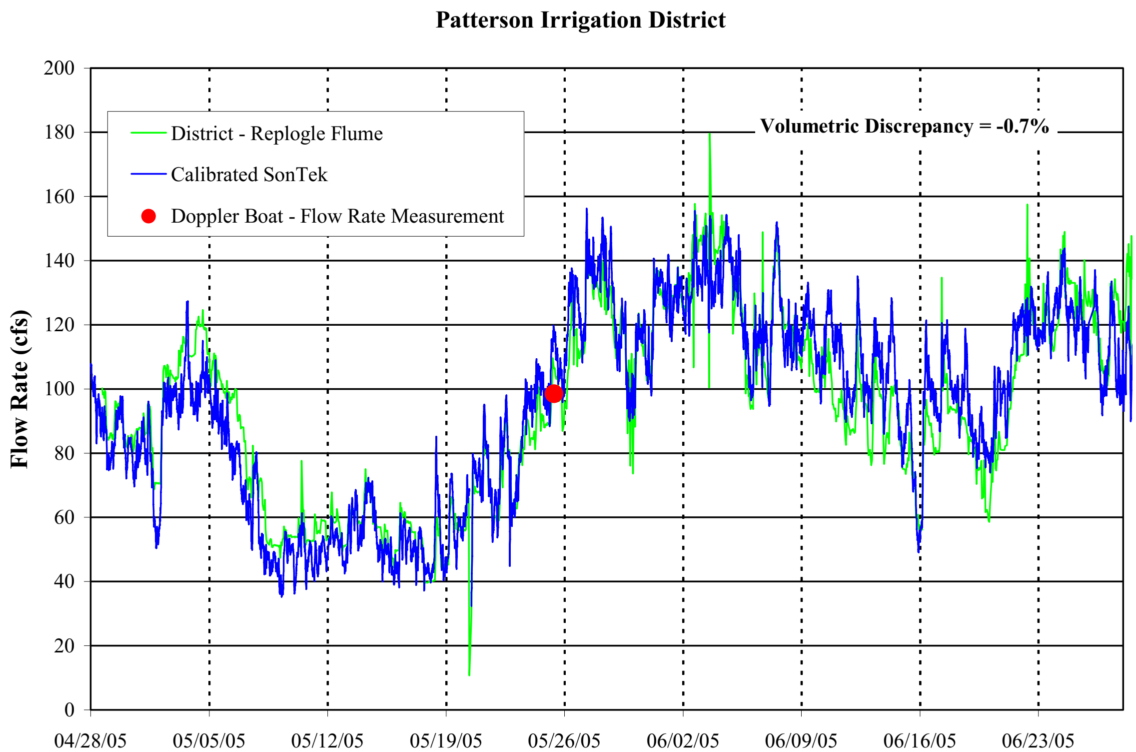

Figure 19. Flow rate comparison of the SonTek SL and the Replogle flume data at Patterson Irrigation District

Sutter-Mutual Water Company

Sutter-Mutual WC has installed an Argonaut SL flow meter downstream of the Tisdale Pumping Plant. ITRC also installed Telog water level recorders at the Argonaut SL site. The instrument was installed in September 2004. ITRC assisted a USBR hydrologist with utilizing ADP boats to collect discharge data for developing an index velocity rating for the installed instrument. The USBR hydrologist is in the process of collecting the remaining data to complete the index velocity rating.

Tulelake Irrigation District

Tulelake ID upgraded the flow measurement station in Drain 10 by installing the SonTek Argonaut SW in 2004 in a fully submerged pipe. The district is in the process of connecting the SonTek to the district's SCADA system at the headquarters office. ITRC is in the process of collecting discharge data using the ADP boats to develop an index velocity rating for the installed instrument. **Figure 20** shows the ADP boat collecting discharge data.

Figure 20. RDI StreamPro collecting flow data at the Tulelake ID site

Sacramento Valley Site Visits – Stationary Measurement Method

Near the end of the project new software was developed allowing users of the RDI and SonTek ADP boats to conduct discharge measurements using the Stationary Measurement Method (or Section-by-Section method). ITRC conducted multiple site visits throughout the Sacramento Valley utilizing this software. A detailed description of the method and results can be found in **Attachment G**.

CONCLUSIONS

Accurate flow measurement is one of the most important components of irrigation district management and operation. Hydroacoustic meters are improving flow measurement accuracies in canals where it is not possible to install a more traditional or standard flow measurement device such as a Replogle flume. However, these devices cannot simply be installed in a site and be expected to provide accurate data. ITRC has developed procedures for calibration of hydroacoustic meters called the Flow Rate Indexing Procedure (QIP). Through this project ITRC has been able to adjust and fine tune the QIP by working with 16 irrigation districts throughout the western U.S.

The acoustic Doppler profiling (ADP) boats were an important component of this study. At Merced ID, ITRC was able to compare the accuracy of the ADP boats to a Replogle flume which is considered one of the most accurate open channel flow measurement devices. The discrepancy ranged from 1-4% depending on the profiler used and the date of the investigation. ITRC concludes that the ADP boats are providing good discharge measurements in real world applications which justifies using these devices as a "standard" for indexing non-standard structures when used properly. The accuracy of the ADP discharge is improved further by using the stationary (section-by-section) software that has been recently developed and is strongly recommended by ITRC.

After the QIP is conducted at hydroacoustic meter sites, accuracy is improved significantly. Flow rate discrepancy was reduced in this study from an average of ±13.5% for the raw data, to ±6.2% and ±5.1% using the linear and multiple regression techniques, respectively.

There are a number of issues that still remain for further investigation:

1. Neither researchers nor manufacturers have yet developed a satisfactory pre-installation calibration procedure. These units must all be field calibrated.
2. We do not completely understand how the calibration constants will be impacted by factors such as changing water levels. For example, it may be that the calibration will be much simpler if a constant water level can be maintained regardless of the flow rate.
3. The accuracy appears to be highly dependent upon having parallel flow lines past the measurement device. If long straight upstream canal sections are not available, it may be possible to "condition" the flow rate upstream of the devices to artificially create a better flow pattern.
4. It is unclear what aspect ratios (width/depth) should be used in choosing between bottom-mounted units and side-mounted units.
5. Questions remain regarding the proper "blanking distance" and zone of sampling that is best for good calibration.
6. Irrigation district personnel are generally not hydraulic engineers and will require pragmatic training and field support to know how to use the new devices.

These issues can be overcome with additional (i) research, (ii) demonstration, and (iii) training.

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ATTACHMENT A

CANAL FLOW RATE MEASUREMENT GUIDELINES FOR HYDROACOUSTIC METERS

Canal Flow Rate Measurement Guidelines – ITRC 2005
Hydroacoustic Meters

Hydroacoustic Meters - A Hydroacoustic flow meter provides remote velocity sampling and integrated flow measurement based on the physical principle called the Doppler shift. The sensors can either project a continuous or pulsed beam of acoustic signals at angles above the horizontal position of the sensor. Flow velocity is calculated by averaging the measured variations in sound frequency reflected back from particles in the water. Depth is measured with a ceramic-based pressure transducer integrally mounted in a surface mount velocity sensor and the device calculates the flow rate.

Continuous beam Dopplers send out a continuous signal with one transmitter and measure signals returning from debris anywhere and everywhere along the beam with a receiver (Figure 1). The measured velocities of the particles are resolved to a mean velocity that can be related to a channel velocity.

Pulsed or profiling Dopplers transmit encoded pulses with the carrier frequency along multiple beams. The meters are able to target specific locations, and only measure these reflected signals. This allows the velocity distribution in a water column to be profiled. These instruments are generally more complex and expensive when compared to continuous Doppler systems.

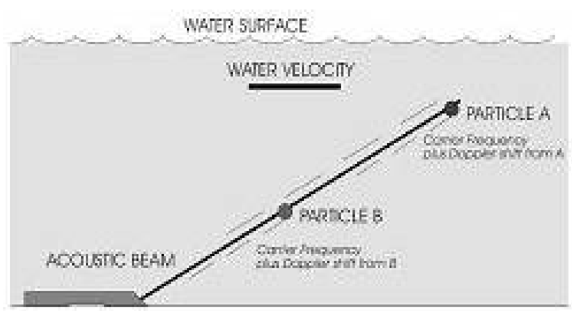


Figure 1. Principle of operation of a continuous beam Doppler flow meter

In general, there are three categories for Hydroacoustic meter installations, which can be loosely defined as small, medium and large flow measurement sites. The low-cost Hydroacoustic meters (less than $3,000) are being widely accepted for small flow rates up to 50 cfs. The most expensive Hydroacoustic meters (about $20,000) seem to be accepted for high flow rate sites up to 5,000 CFS. The following diagram is a guideline for using Hydroacoustic meters in canals. Note again that the main difference is in the size of the canal to be measured.

Examples of Hydroacoustic Flow Meters in Canals
ITRC Ratings as of January 2005

	Mace Agriflo	Sontek SW	Sontek SL	MGD ADFM
Primary Canal Application	small canals	small to medium	medium	large
Cost - sensor only	$3,000	$6,500	$10,000	$20,000
Flow range	1-50 cfs	10-100 cfs	50-500 cfs	200-5000 cfs
Location	bottom	bottom	side	bottom
Aspect ratio (top width to depth)	less than 5:1	less than 10:1	greater than 5:1	less than 10:1
Ease of Installation	☺☺☺☺	☺☺	☺	☺
Data Access through RTU	☺	☺☺☺☺	☺☺☺☺	☺
Durability	☺☺	☺☺☺	☺☺☺	☺☺
Accuracy (initial)	☺	☺☺☺	☺☺☺	☺☺☺☺
Ease of Field Calibration	☺☺	☺☺☺	☺☺☺☺	☺☺☺
Visual Display on the Unit	☺☺☺☺	☺	☺	☺☺
Units in US Irrigation Districts	50	15	25	30

There are significant differences in the performance of the Hydroacoustic meters. The more expensive meters definitely have more "out of the box" accuracy. This means that if they are installed in a good measurement site the time and energy to calibrate the unit can be significantly less.

The following guidelines outline the required characteristics of a site for hydroacoustic devices:

- The sensor must be installed at least ten widths of the canal away from bends or turbulences.
- Must be located at a concrete-lined section of the canal that is well surveyed.
- Must be installed on a secure, movable arm for easy removal of the sensors for maintenance.
- A trash deflector must be installed around the device.
- A calibration procedure, such as the Flow Rate Indexing Procedure (QIP), must be completed.
- Because of the maintenance concerns, and the need to calibrate the devices, it can be a very good idea to install a walking bridge over the device, which would allow an operator to sweep silt away from the device occasionally, and provide a current metering site

During a QIP calibration session, the technician follows a set of standard procedures to collect data from the different sensors for a specified time period. Following the recommended guidelines for deployment of hydroacoustic flow meters is essential. The dataset for each measurement period is comprised of:

- Mean velocity in the standard cross-section using a standard device such as a boat-mounted profiler as described in a later section.
- Average measured velocity from the hydroacoustic flow meter
- Average stage

The following is a brief summary of the steps for conducting a QIP:

1. A hydroacoustic flow meter is installed in the canal with the appropriate deployment settings and mounting bracket. Site selection is an important consideration and the diagnostic guidelines provided in the manufacturer's technical documentation should be carefully observed. These diagnostic parameters include an assessment of the signal strength and standard deviation for a given set of operating conditions.
2. The channel is accurately surveyed and a stage-area rating is developed. The same standard cross-section is used every time indexing data is collected. Elevations for the cross-section points are in terms of stage referenced to the station datum.
3. The average stage during the discharge-measurement period is recorded. A secondary water level monitoring device may be utilized to provide quality assurance data (as was done in this study)
4. Discharge measurements (current metering or use of ADP) are made near the hydroacoustic flow meter site while the hydroacoustic instrument is sampling and recording velocity and stage. Historically, discharge measurements have been done with a Price AA current meter. However, discharge records obtained from acoustic Doppler profilers (ADPs) are faster with comparable accuracy. If an ADP is used ITRC strongly recommend using the "stationary measurement" technique described in the Operation of ADPs section of this report.
5. Mean channel velocity is derived for each individual discharge measurement by dividing the measured discharge by the channel area computed from the stage-area rating.
6. For each measurement period, the index velocities measured by the hydroacoustic flow meter are averaged.
7. Each discharge measurement yields a computed mean channel velocity and an average index velocity.
8. A regression analysis is performed to determine the equation of a plotted line using single or multi-parameter analysis to account for the effects of stage. The relation between the mean velocity and the index velocity is the "index velocity rating". Users instructions for performing regression in Microsoft Excel are included in **Attachment B**.

9. Discharge is computed from the standard equation Q = V*A. (V) velocity is computed from the regression equation(s) developed comparing the index velocity rating to the measured velocity. This can be done directly in the sensor's firmware using the instrument's deployment software so that the output of flow data is already calibrated. The index velocity rating can also be applied in post-processing using a spreadsheet. The (A) area is computed from the stage-area rating of the canal and the measured stage.
10. The index velocity rating procedure recommended by the ITRC requires a wide spread in the measured discharge (a 2:1 ratio), usually at least 10 measurement values over the entire range of flows. The regression coefficient (r^2) must be better than 0.96 to assure confidence in the results.
11. The validity of the index velocity rating depends on maintaining stable channel and hydraulic characteristics at the measurement site. Changes in channel conditions due to sedimentation or weed growth can invalidate an index velocity rating. Accurate discharge measurements from hydroacoustic instruments depend on regular assessments of the index equation using ADP or current metering data. Using the "stationary measurement" technique greatly enhances the accuracy of the measurement negating effects of bottom shifting and moving weed on the ADP.

The index velocity rating is developed by first validating a linear relationship exists between the mean velocity and average of the sensor measured velocity data collected during the same time period. This is done by creating a scatterplot with mean velocity as the y-axis and index velocity as the x-axis. An example scatterplot for an index velocity rating of a hydroacoustic flow meter is shown in **Figure 2**.

Linear regression produces a straight line that is the best fit for all the data points. The equation of this line is an index velocity rating with the single parameter (independent variable) of sensor-measured velocity. For some sites, the inclusion of stage as an additional regression parameter can improve the accuracy of the index velocity rating. The product of the index velocity and stage is the second independent variable in the multiple regression. Stage may have a significant impact depending on channel geometry, channel roughness, the set points of downstream structures, stability of the velocity profile etc.

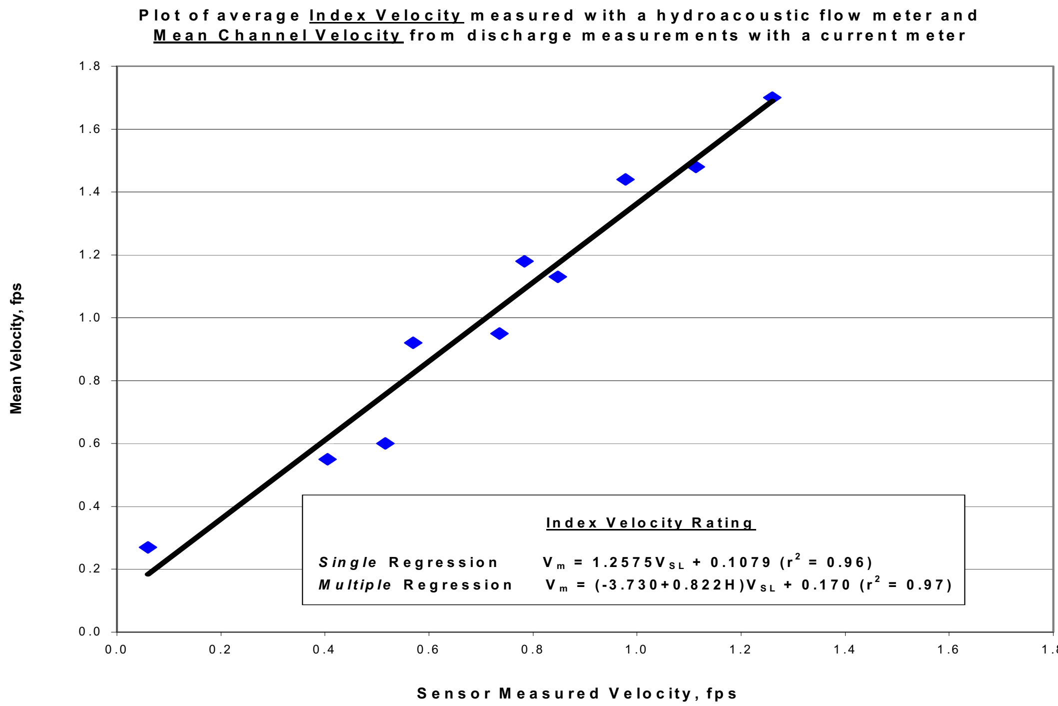


Figure 2. Example scatterplot of an index velocity rating for single and multiple linear regression ($r^2 \geq 0.96$)

There is a major difference between using a Replogle flume for flow rate control versus a Hydroacoustic meter. If the desire is to use the device to set a constant flow rate, a Replogle flume will stabilize the flow rate very quickly. A canal with a Hydroacoustic meter may take 20 minutes to an hour to stabilize depending on the canal.

One of the challenges in using a Hydroacoustic meter is the mounting of the unit. The meters are subject to blockage by moss and water weeds. Below are some examples of the new brackets that are being used for Hydroacoustics.

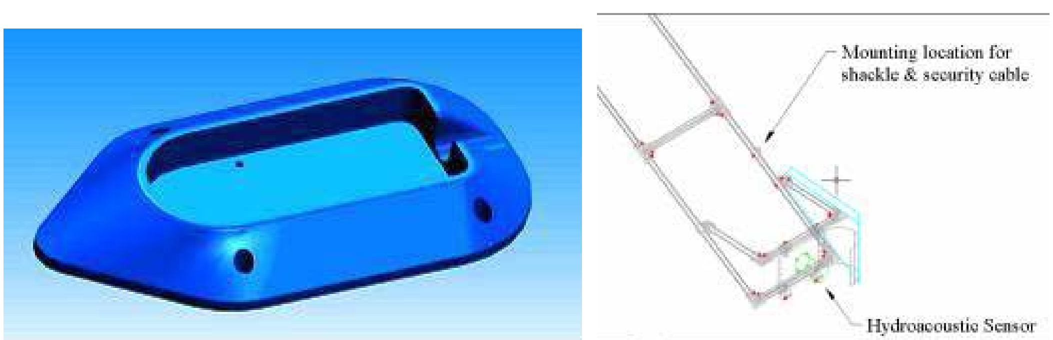
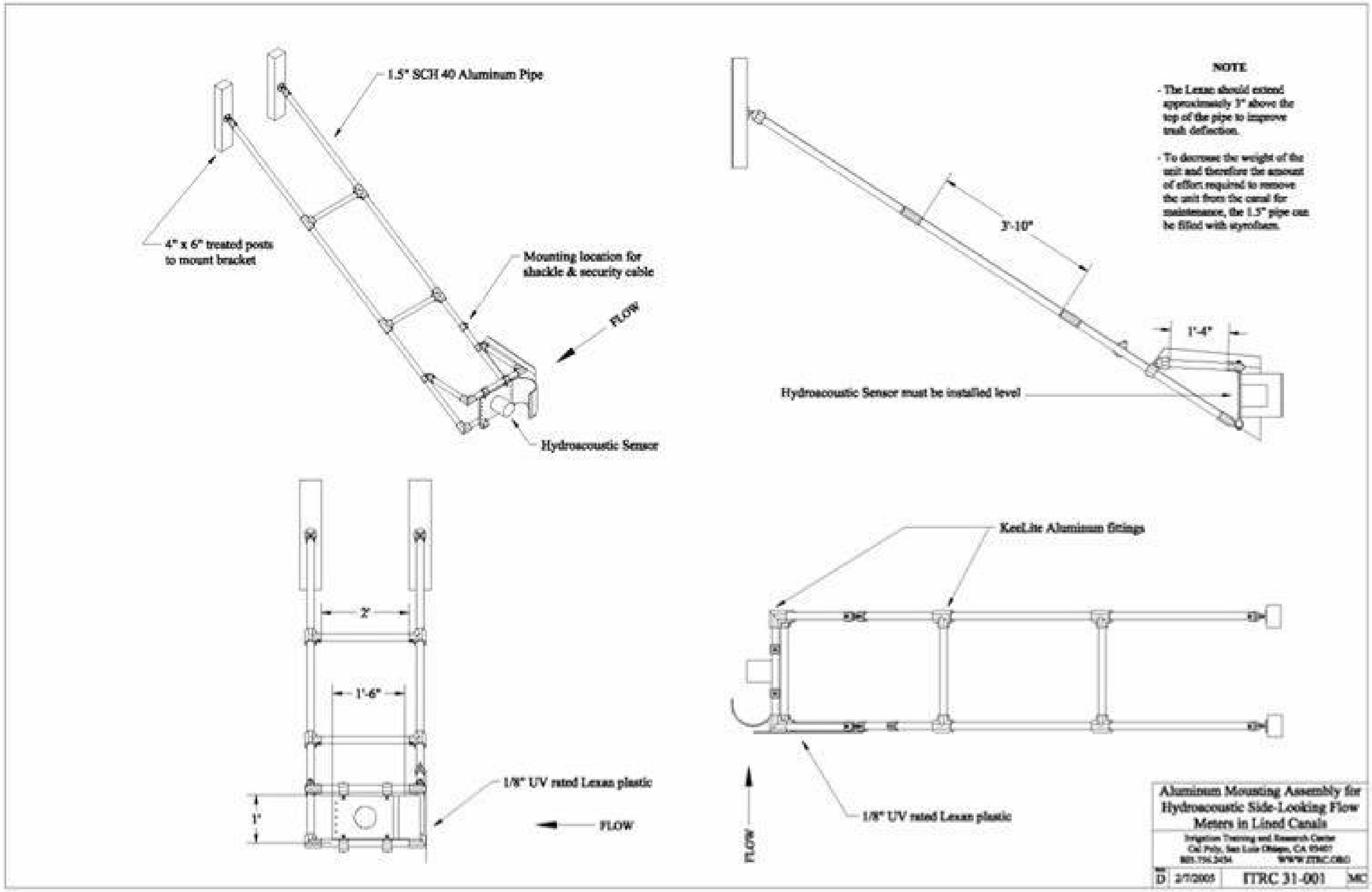
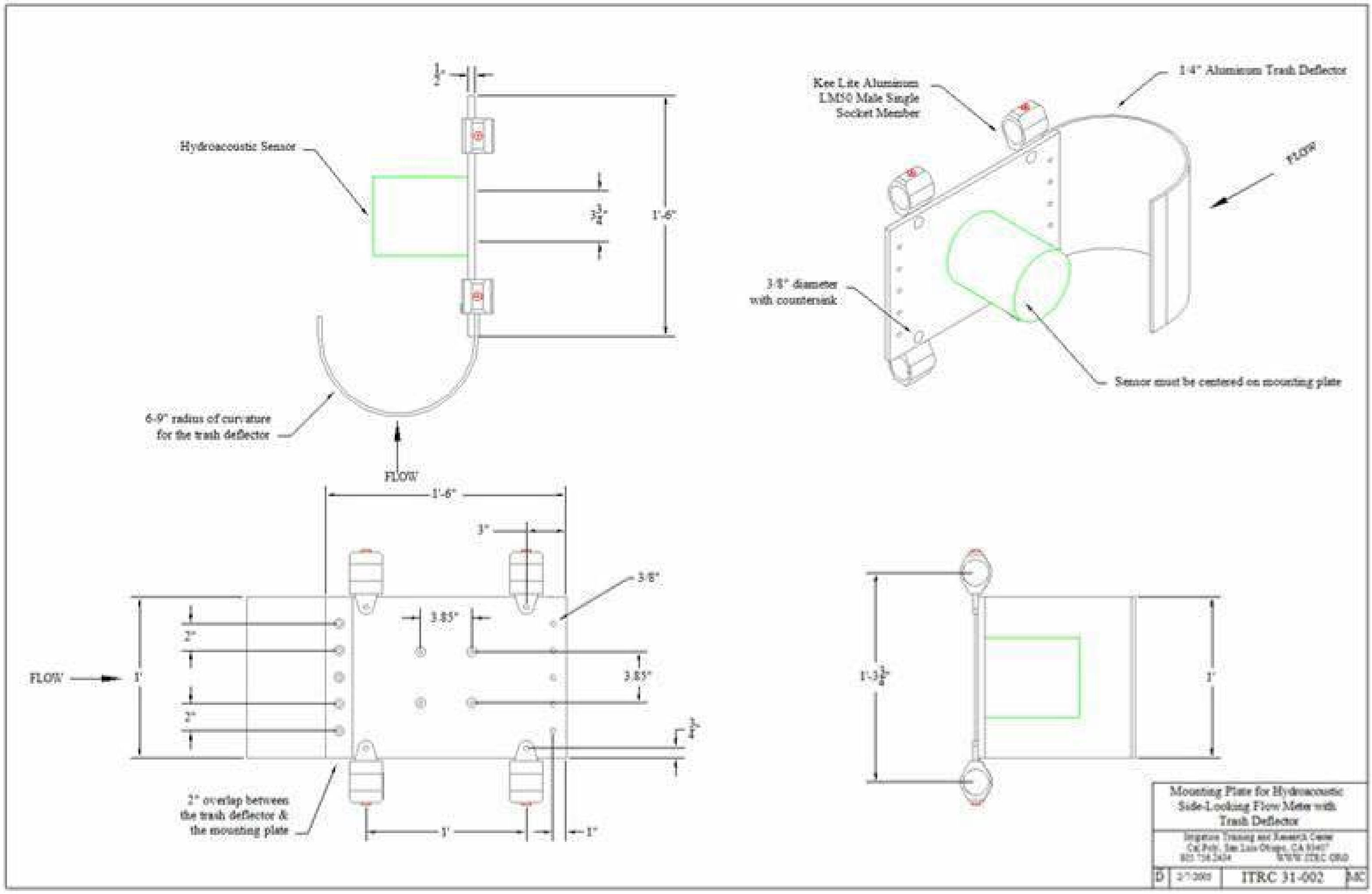
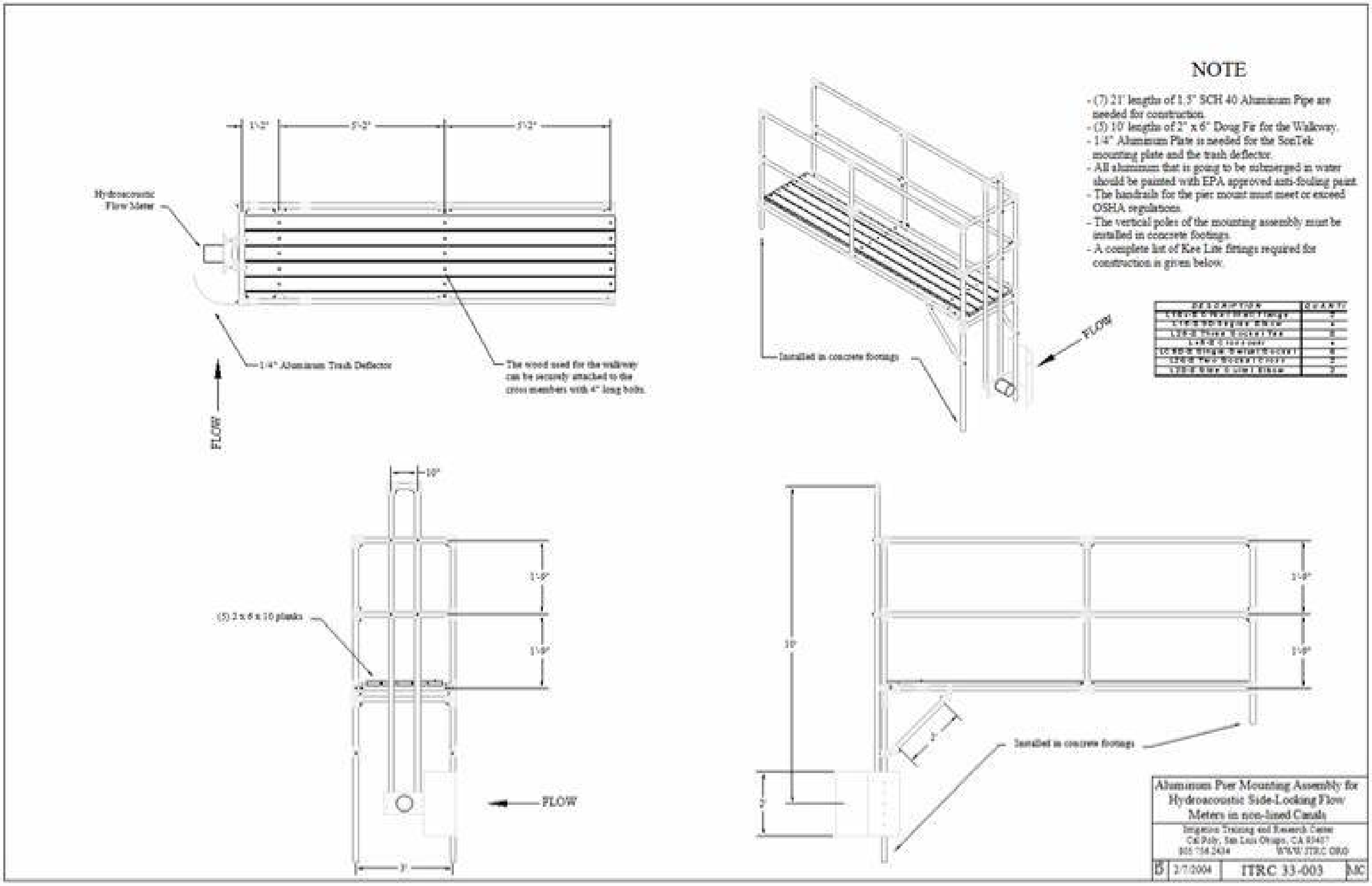


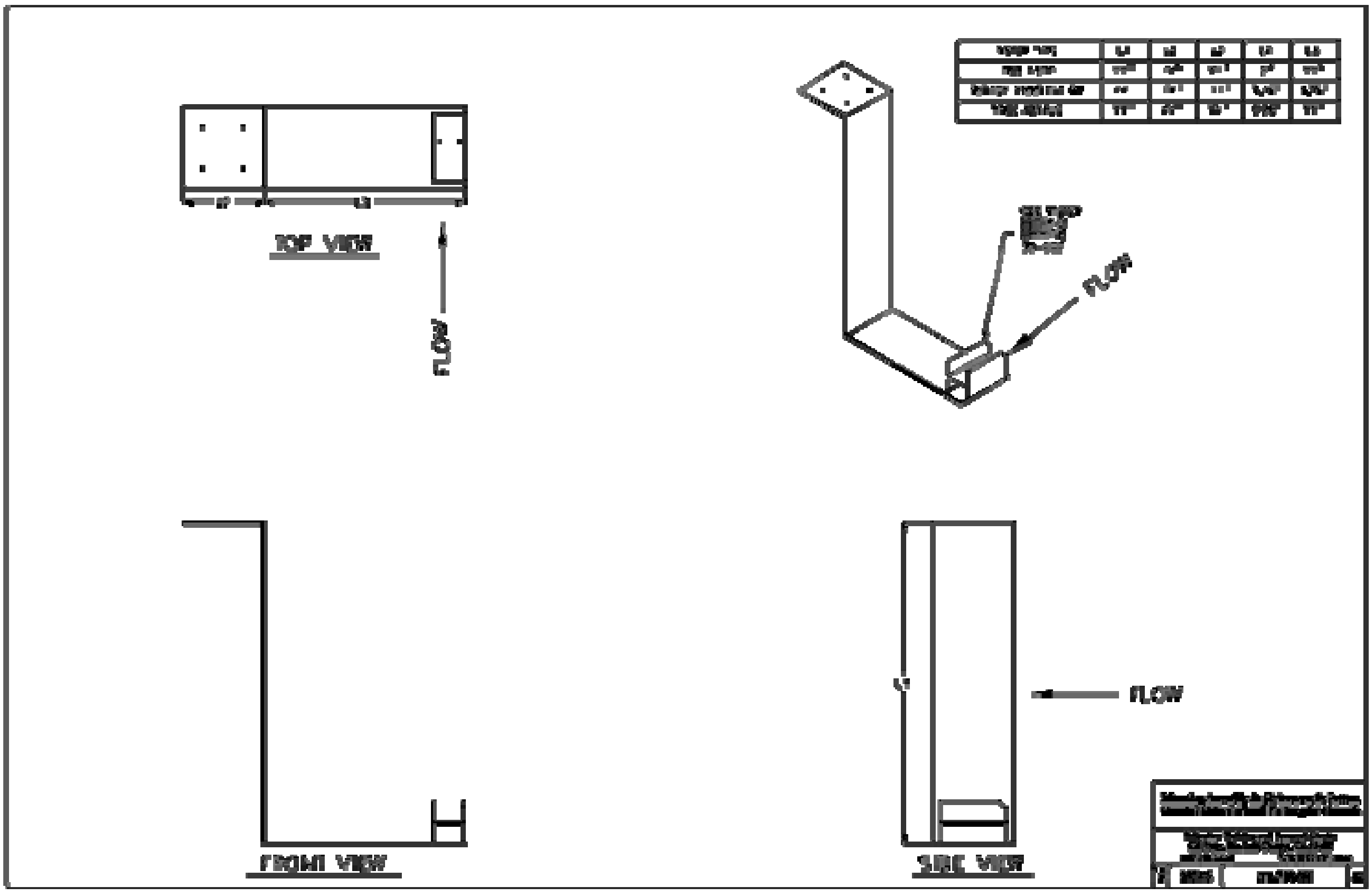
Figure 3. Examples of brackets used for Hydroacoustic meters

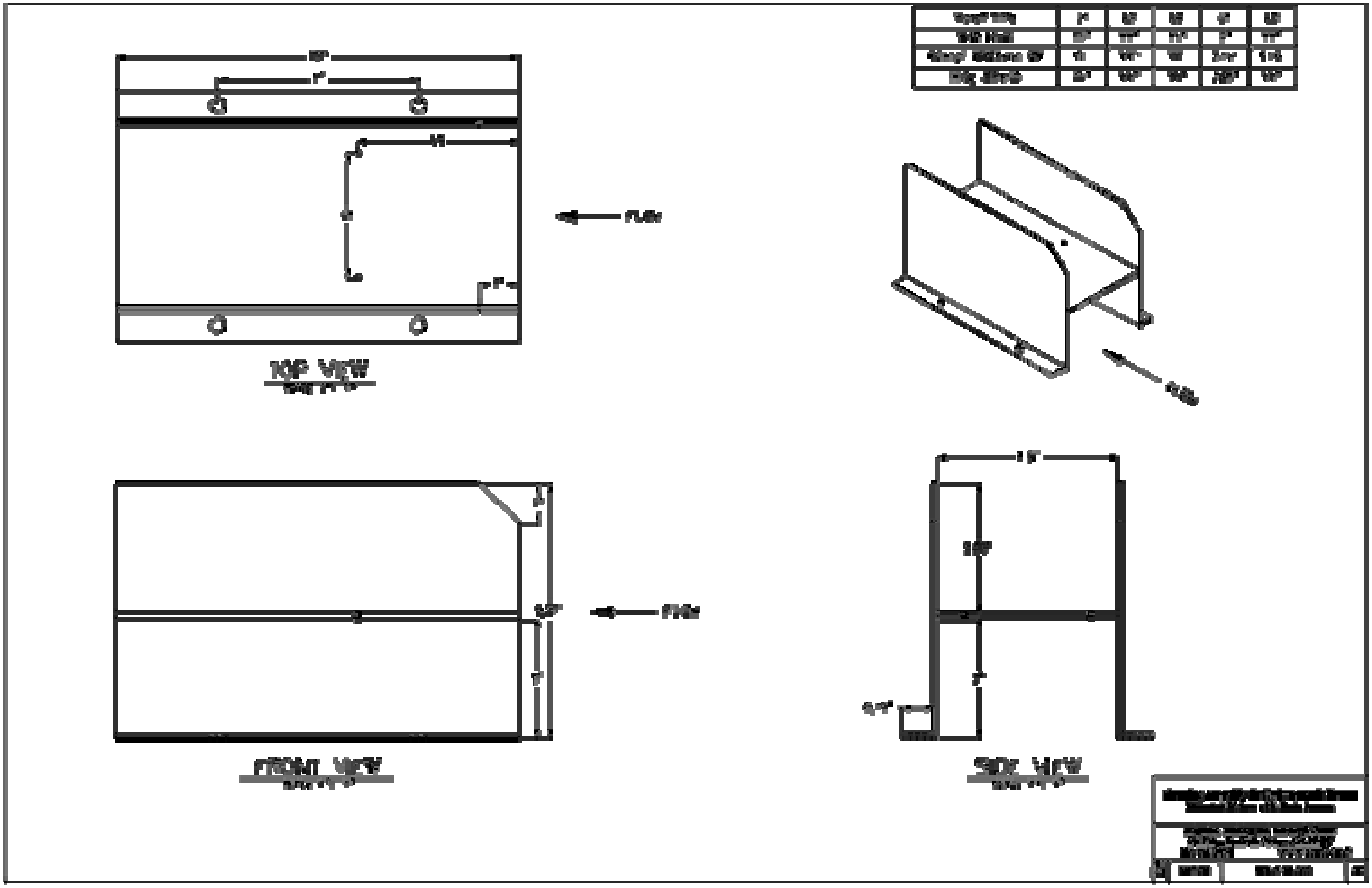
A-1. AutoCAD Drawings

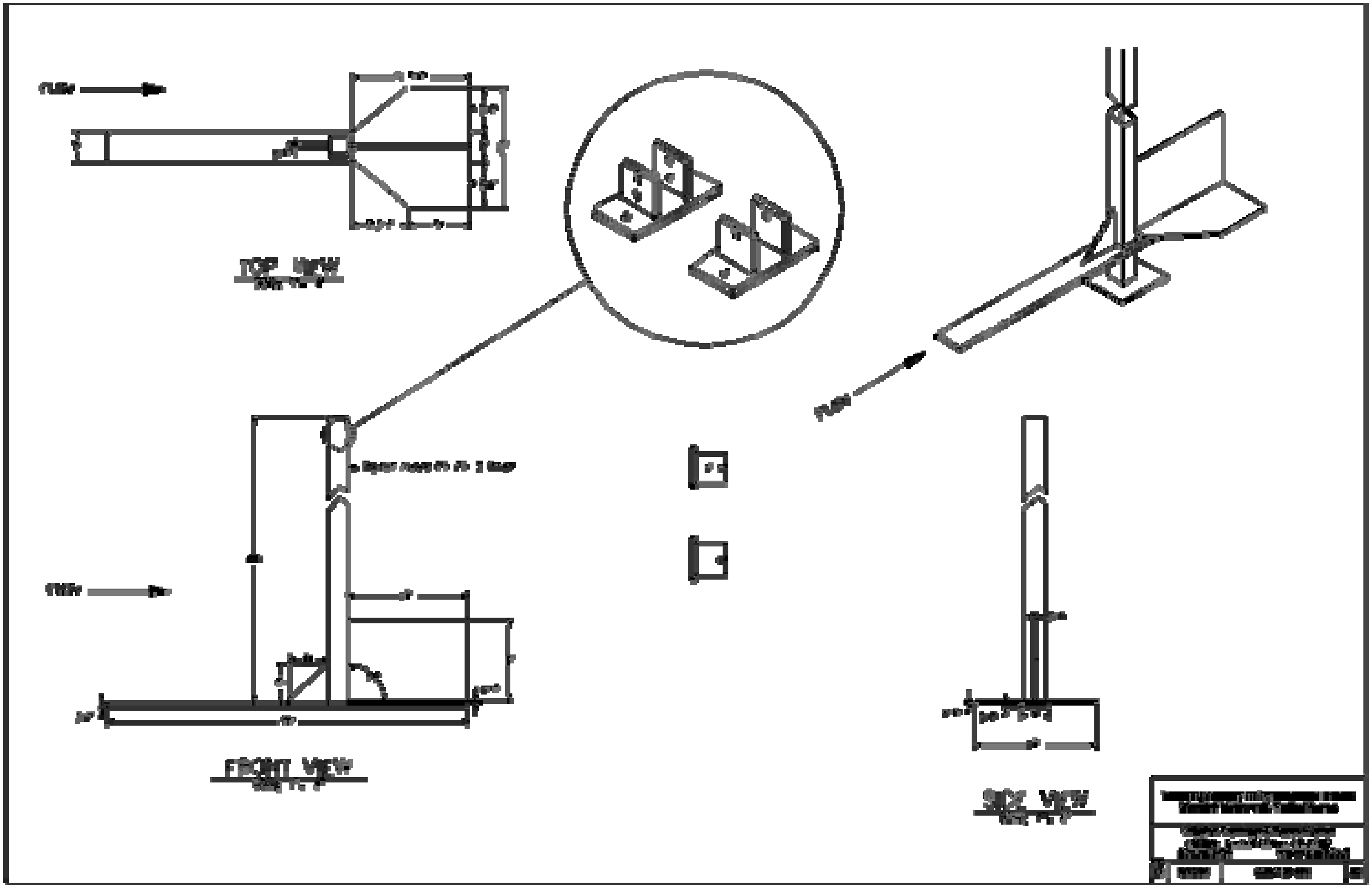

1.5" SCH 40 Aluminum Pipe
4" x 6" treated posts to mount bracket
Mounting location for shackle & security cable
FLOW
Hydroacoustic Sensor
NOTE
- The Lexan should extend approximately 3" above the top of the pipe to improve trash deflection.
- To decrease the weight of the unit and therefore the amount of effort required to remove the unit from the canal for maintenance, the 1.5" pipe can be filled with styrofoam.
3'-10"
1'-4"
Hydroacoustic Sensor must be installed level
2'
1'-6"
1'
1/8" UV rated Lexan plastic
FLOW
KeeLite Aluminum fittings
1/8" UV rated Lexan plastic
FLOW
Aluminum Mounting Assembly for Hydroacoustic Side-Looking Flow Meters in Lined Canals
D 2/7/2005 ITRC 31-001 MC


Hydroacoustic Sensor
6-9" radius of curvature for the trash deflector
FLOW
1'-6"
Kee Lite Aluminum LM50 Male Single Socket Member
1/4" Aluminum Trash Deflector
FLOW
3/8" diameter with countersink
Sensor must be centered on mounting plate
1'-6"
3"
3/8"
3.85"
3.85"
FLOW
1'
2"
2"
2" overlap between the trash deflector & the mounting plate
1'
1"
1'
Mounting Plate for Hydroacoustic Side-Looking Flow Meter with Trash Deflector
ITRC 31-002


NOTE
- (7) 21' lengths of 1.5" SCH 40 Aluminum Pipe are needed for construction.
- (5) 10' lengths of 2" x 6" Doug Fir for the Walkway.
- 1/4" Aluminum Plate is needed for the SonTek mounting plate and the trash deflector.
- All aluminum that is going to be submerged in water should be painted with EPA approved anti-fouling paint.
- The handrails for the pier mount must meet or exceed OSHA regulations.
- The vertical poles of the mounting assembly must be installed in concrete footings.
- A complete list of Kee Lite fittings required for construction is given below.
Hydroacoustic Flow Meter
1/4" Aluminum Trash Deflector
The wood used for the walkway can be securely attached to the cross members with 4" long bolts.
FLOW
1'-2"
5'-2"
5'-2"
Installed in concrete footings
(5) 2 x 6 x 10 planks
10"
1'-9"
1'-9"
3'
10'
2'
Aluminum Pier Mounting Assembly for Hydroacoustic Side-Looking Flow Meters in non-lined Canals
Irrigation Training and Research Center
Cal Poly, San Luis Obispo, CA 93407
805 756 2434 WWW.ITRC.ORG
2/7/2004
ITRC 33-003
MC


TOP VIEW
FLOW
FLOW
FRONT VIEW
SIDE VIEW
FLOW




TOP VIEW
FRONT VIEW
SIDE VIEW

A-2. Non-Standard Structure Flow Measurement Evaluation Using the Flow Rate Indexing Procedure - QIP

Non-Standard Structure Flow Measurement Evaluation Using the Flow Rate Indexing Procedure – QIP

Stuart Styles[3]

ABSTRACT

This paper summarizes the results of a performance evaluation using advanced hydroacoustic rating techniques in irrigation canal systems. Standardized field-tested procedures and technical specifications for index velocity ratings have been developed for rating measurement locations using hydroacoustic flow meters. Water managers and users of advanced electronic flow measuring devices can improve the cost effectiveness, accuracy, and quality control of discharge records, even at sites with complex flow conditions, by observing these recommended guidelines.

Keywords: flow measurement, non-standard structure, hydroacoustic flow meter, index velocity rating

Background

Irrigation districts, farmers, and other agricultural and environmental water users need to accurately measure the rate and volume of flows at key points in their water distribution and delivery systems. A key device that has traditionally been used is a Replogle Flume. This is a standard measurement device recommended by the Water Measurement Manual of the USBR (3rd Edition 2001). Some locations are not suited for a Replogle Flume due to headloss constraints. At these sites where headloss is a constraint, another option has been to use simple rating tables based on the depth of the water in the canal.

However, traditional techniques used to develop a rating curve at non-standard locations are time consuming and there are a limited number of sites with good measurement capabilities. The rating of a non-standard structure in the field requires a tedious and laborious procedure. Flow data must be collected manually using a hand held current meter to determine the discharge at a specific water level (stage). Using a current meter to determine the discharge is a repetitive task and requires readings and calculations at multiple points to find the total flow.

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As a result, there is an opportunity to apply the flow rate indexing procedure (termed "QIP") to rate a large number of existing non-standard structures. Flow rate indexing with hydroacoustic meters greatly reduces the time required to rate a structure, and the measurement accuracy is improved because of the large number of data points that can be collected by autonomous installations over a wide range of flow conditions.

Research Objectives

The Irrigation Training and Research Center (ITRC), California Polytechnic State University, San Luis Obispo performed this technical study on behalf of the U.S. Bureau of Reclamation, Mid-Pacific Region. Thirteen water agencies participated. This study evaluated the performance of advanced electronic flow measurement devices and technologies in field applications at water agencies throughout California. A key objective of this project was to prepare and evaluate standardized, step-by-step instructions for developing accurate and reliable discharge ratings. The procedures follow the approach used by Morlock (2002) with the USGS. The USGS approach is primarily used in streams and rivers. The ITRC approach is designed for irrigation canals. The ITRC investigated the feasibility of using these hydroacoustic technologies for developing rating curves by deploying equipment and conducting field data collection at nine demonstration sites. The devices were deployed in different configurations at places identified as key measurement points by the cooperating water agencies.

Procedure

ACOUSTIC DOPPLER PROFILERS AND VELOCITY METERS

The ITRC has worked with manufacturers and users of high-precision acoustic Doppler flow meters for several years to improve their performance by incorporating important design and software features that make them more user-friendly and robust. The instruments used in this study have been deployed successfully in many irrigation applications and represent industry standard specifications. The sensors at the demonstration sites were calibrated prior to deployment at the flow measurement facilities located at ITRC's Water Delivery Facility.

For this study, ITRC utilized the leading Acoustic Doppler Profiler (ADP) discharge measurement systems designed for hydrological applications – the SonTek/YSI RiverSurveyor and the RD Instruments StreamPro. Both units are shown in Figure 1. These boat-mounted profilers collected discharge records concurrently with the SonTek/YSI Argonaut Side-Looking (SL) and Shallow Water (SW) units. Water velocities and depths were measured at different flow rates. The discharge measurements obtained from the RiverSurveyor and StreamPro were analyzed and used in the computation of index velocity ratings at each site.

Figure 1. Boat-mounted Acoustic Doppler Profilers collecting flow rate and cross-sectional measurements in irrigation canals

TECHNICAL APPROACH AND PROJECT COMPONENTS

The procedure for collecting velocity and stage datasets and performing regression analysis is straightforward and the necessary fieldwork can be completed in several hours per site. The large internal memory of modern datalogger and sensor systems means the devices can be set up and left in the field for several months to collect data at user specified intervals, which is then analyzed using ordinary office programs such as Excel.

The use of hydroacoustic flow meters dramatically reduces the time required to generate a rating curve for a site by the ability to record many more data points for stage and discharge measurements in an autonomous installation. To take advantage of this feature of hydroacoustic technology, temporary demonstration units were deployed at existing non-standard structures in irrigation canal systems. Data was downloaded in the field and checked for gaps and out of range values.

The *QIP* developed by ITRC consists of data analysis in addition to deploying field equipment and recording site parameters. The mathematical process describing the rating for a site is given a brief explanation here to illustrate the basic technique that is used with the new hydroacoustic technologies. Figure 2 shows a typical calibration curve using current meter readings.

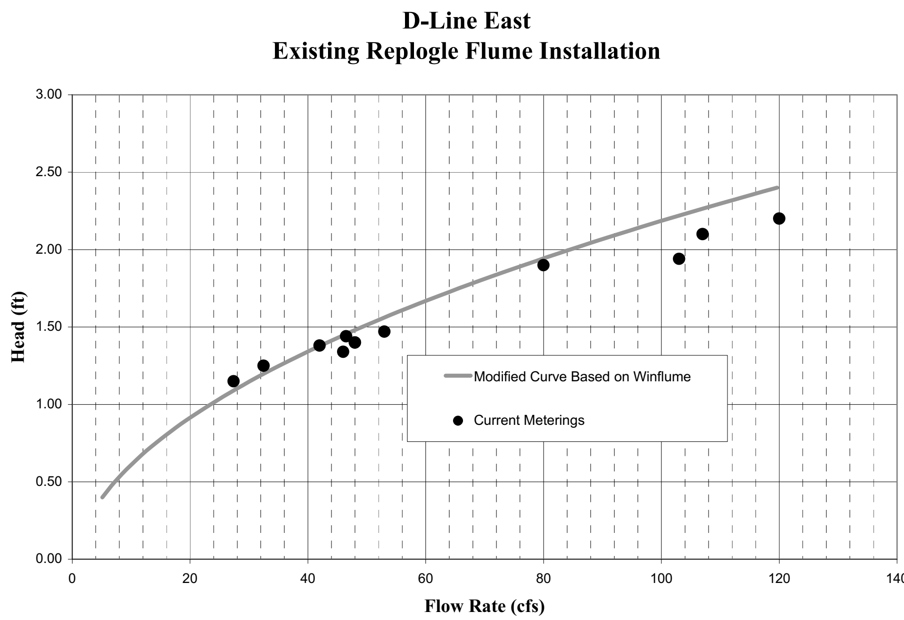


Figure 2. Plot of current metering data and head-discharge curve

The recommended calibration procedure for a non-standard site is as follows:

- A wide range in the measured flow rate is required. At least a 2:1 ratio in the flow rates should be used to create the dataset.
- A minimum of 10 values should be measured across the entire flow rate range.
- Data should be evaluated using the trendline function to evaluate the equation. The equation is in the form of a power curve. This type of graphing function is a standard option in programs such as Excel®.

The data should evaluated to determine the coefficient and exponent in the power equation listed below. The exponent should be between 0.3 and 0.7. A program such as Excel can be used to determine the equation and the regression coefficient. The equation should be of the form:

$$H = KQ^x$$

where “x” is a value between 0.3 and 0.7

The regression coefficient (r^2) must be better than **0.96** to ensure confidence in the results. This has been determined to provide the required +/-5% flow measurement accuracy of a rated site. If the data is less than 0.96, additional data points must be obtained.

RECOMMENDED SITE CONDITIONS FOR HYDROACOUSTIC DEVICES

The physical setting of hydroacoustic devices and the flow conditions at the site have a major impact on the potential accuracy of discharge records. This deserves special consideration in indexing applications when hydroacoustic flow meters are being used to rate a structure. Before deployment of a device such as the Argonaut SL or SW, the site must be evaluated according to manufacturers’ recommendations.

The following guidelines outline the required characteristics of a site for the hydroacoustic devices such as the Argonaut SL:. The sensor must be:

1. The sensor must be at least ten widths of the canal away from bends or turbulences.
2. Must be located at a concrete-lined section of the canal that is well surveyed.
3. Must be installed on a secure, movable arm for easy removal of the sensors for maintenance.
4. A trash deflector must be installed around the device.
5. A calibration procedure, such as the Flow Rate Indexing Procedure (QIP), must be completed.

FLOW RATE INDEXING PROCEDURE

Hydroacoustic flow meters are high-precision instruments that very accurately measure the velocity of water in the section of flow being sampled. The water velocity measured by hydroacoustic flow meters represents a sampled portion of the canal that can be used as an "index" for the actual mean channel velocity. Hydroacoustic flow meters are appropriate in many situations where, for example, the flow conditions are too complex for traditional devices. The flow rate is computed internally by devices such as the Argonaut SL flow meter internally by the firmware using a programmed stage-area rating and the index water velocity ($Q = V \times A$). The user can input an indexing equation into the unit with the deployment software based on the results of the QIP process.

In QIP applications, the measured velocity is sampled and recorded in programmed time intervals concurrently by both the device being calibrated (e.g., an Argonaut SL at the head of a lateral canal), and a second profiling device that produces an accurate discharge measurement such as the RiverSurveyor. Mean channel velocities can also be obtained from current metering as long as the time periods are the same.

The data for multiple pairs of mean velocity and index velocity collected over a range of flow are analyzed using regression techniques, with and without multi-parameter ratings to account for the effect of stage. The resulting equation of the index velocity rating is necessary for using the internal flow computational feature on hydroacoustic flow meters or for post-processing data from temporary deployments.

MAJOR STEPS IN THE FLOW RATE INDEXING PROCEDURE - QIP

During an indexing session, the technician follows a set of standard procedures to collect data from the different sensors for a specified time period. Following the recommended guidelines for deployment of hydroacoustic flow meters is essential. The dataset for each measurement period is comprised of:

- Mean velocity in the standard cross-section using a standard device such as a boat Dopplers described previously.
- Average measured velocity from the hydroacoustic flow meter
- Average stage

The following major steps outline the procedure for developing an index velocity rating:

1. A hydroacoustic flow meter is installed in the canal with the appropriate deployment settings and mounting bracket. Site selection is an important consideration and the diagnostic guidelines provided in the manufacturer's technical documentation should be carefully observed.
2. The channel is accurately surveyed and a stage-area rating is developed. The same standard cross-section is used every time indexing data is collected. Elevations for the cross-section points are in terms of stage referenced to the station datum.
3. The average stage during the discharge-measurement period is recorded. A secondary water level monitoring device may be utilized to provide quality assurance data (as was done in this study).
4. Discharge measurements are made near the hydroacoustic flow meter site while the instrument is sampling and recording velocity and stage.
5. Mean channel velocity is derived for each individual discharge measurement by dividing the measured discharge by the channel area computed from the stage-area rating.
6. For each measurement period, the index velocities are averaged.
7. Each measurement yields a computed mean channel velocity and an average index velocity.
8. A regression analysis is performed to determine the equation of a plotted line using single or multi-parameter analysis to account for the effects of stage. The relation between the mean velocity and the index velocity is the "index velocity rating".
9. Discharge is computed from the standard equation Q = VA. (V) Velocity is computed from the application of the index velocity rating to the measured velocity. The (A) area is computed from the stage-area rating of the canal and the measured stage.
10. The index velocity rating procedure recommended by ITRC requires a wide spread in the measured discharge (a 2:1 ratio), usually at least 10 measurement values over the entire range of flows. The regression coefficient (r^2) must be better than 0.96 to ensure confidence in the results.
11. The validity of the index velocity rating depends on maintaining stable channel and hydraulic characteristics at the measurement site. Changes in channel conditions due to sedimentation or weed growth can invalidate an index velocity rating. Accurate discharge measurements from hydroacoustic instruments depend on regular assessments of the index equation using ADP or current metering data.

The index velocity rating is developed by first validating that a linear relationship exists between the mean velocity and average of the sensor-measured velocity data collected during the same time period. This is done by creating a scatterplot with mean velocity as the y-axis and index velocity as the x-axis (Figure 3).

Linear regression produces a straight line that is the best fit for all the data points. The equation of this line is an index velocity rating with the single parameter (independent variable) of sensor-measured velocity. For some sites, the inclusion of stage as an additional regression parameter can improve the accuracy of the index velocity rating. The product of the index velocity and stage is the second independent variable in the multiple regression. Stage may have a significant impact depending on channel geometry, channel roughness, the set points of downstream structures, stability of the velocity profile etc.

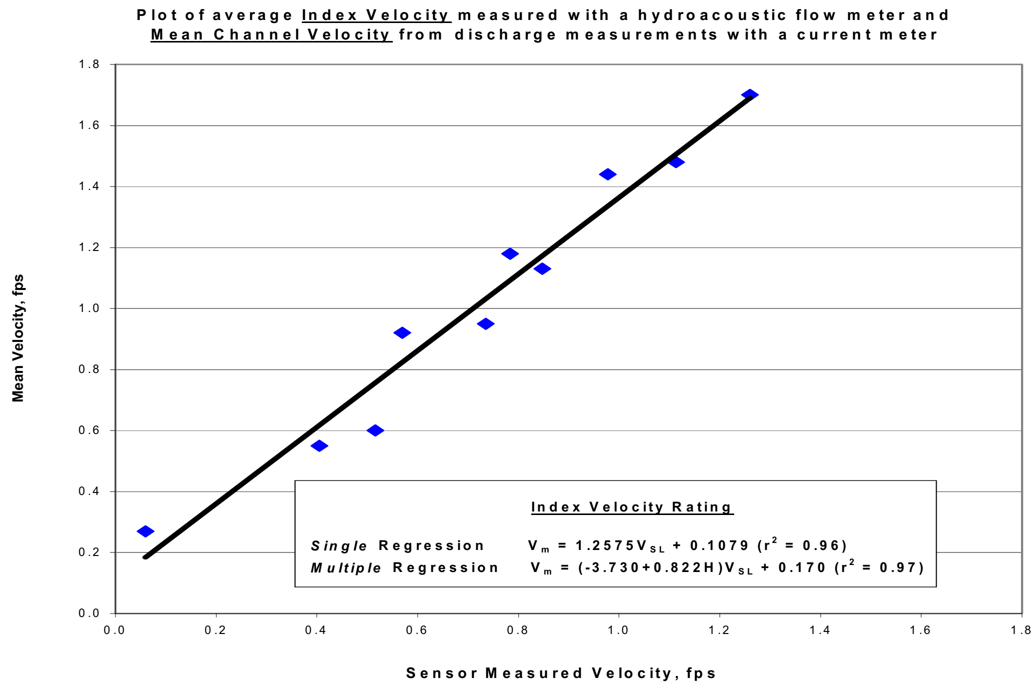


Figure 3. Example scatterplot of an index velocity rating for single and multiple linear regression ($r^2 \geq 0.96$)

SUMMARY DISCREPANCY ANALYSIS

The index velocity ratings developed at each one of the demonstration sites were used to compute the discharge and compare to the mean discharge collected with the RiverSurveyor and RD Instruments Stream Pro.

The percent discrepancy in discharge was calculated using the following relationship:

$$\text{Discrepancy (\%)} = \frac{\text{measured - standard}}{\text{standard}} \times 100$$

Where,

standard = Flow rate obtained from ADP boat or current meter in these cases
measured = Flow rate obtained from non-standard structure or device (SonTek SL for example)

		Average Discrepancy (+/-)		
Site	**Number of Current Meter Readings Taken**	**Raw SonTek Data**	**Flow Calculation with Linear Regression**	**Flow Calculation with Multiple Regression**
CRIT Main Canal	8	5.9%	5.3%	2.8%
Contra Costa Water District	5	13.3%	4.6%	4.3%
LCRA Lake Plant Site	11	9.9%	3.7%	3.7%
Paradise Valley ID (Montana)	8	12.7%	6.6%	6.9%
Tulare ID upstream site	14	14.7%	6.3%	4.5%
Tulare ID downstream site	14	6.1%	6.0%	4.2%
Yuma Co. WUA West Main Canal	10	32.0%	11.0%	9.4%

Summary

The ITRC's QIP technique has been successfully used to rate non-standard structures by indexing flow rates with hydroacoustic meters. This method greatly reduces the time required to rate a structure, and improves the measurement accuracy by collecting a large amount of data by autonomous installations over a wide range of flow conditions. Standardized, step-by-step instructions have been prepared for developing accurate and reliable discharge ratings.

References

Morlock, S.E., H.T. Nguyen, and J.H. Ross. 2002. Feasibility of Acoustic Doppler Velocity Meters for the Production of Discharge Records from U.S. Geological Survey Streamflow-Gaging Stations. U.S. Geological Survey, Water-Resources Investigations Report 01-4157. Denver, Colorado.

U.S. Bureau of Reclamation. 2001. Water Measurement Manual – A Guide to Effective Water Measurement Practices for Better Water Management. United States Department of the Interior. Bureau of Reclamation. Third Edition. Denver, Colorado.

ATTACHMENT B

CANAL VELOCITY INDEXING AT COLORADO RIVER INDIAN TRIBES (CRIT)

Canal Velocity Indexing at Colorado River Indian Tribes (CRIT) Irrigation Project in Parker, Arizona using the SonTek Argonaut SL

Authors: Dr. Stuart Styles P.E., Mark Niblack, Beau Freeman

Abstract

An index velocity rating was developed for a SonTek/YSI Argonaut Side-Looking (SL) ultrasonic Doppler flow meter installed in the Main Canal of the Colorado River Indian Tribes (CRIT) Irrigation Project in Parker, Arizona. Velocity data collected concurrently with the ultrasonic flow meter and conventional current meter were compared using linear regression techniques. The rating equation for this installation provides a reasonably accurate means of computing discharge. This project was completed by the Irrigation Training and Research Center (ITRC), California Polytechnic State University, San Luis Obispo, working under a technical assistance contract for the Water Conservation Office, United States Bureau of Reclamation (USBR), Yuma, Arizona and the California Energy Commission (CEC).

The procedure used in the evaluation included multiple measurements over a range of low, medium, and high flows. This approach verified the validity of discharge measurement through analysis of coefficients of determination and by comparison of discharges computed from the ratings to measured discharges.

Introduction

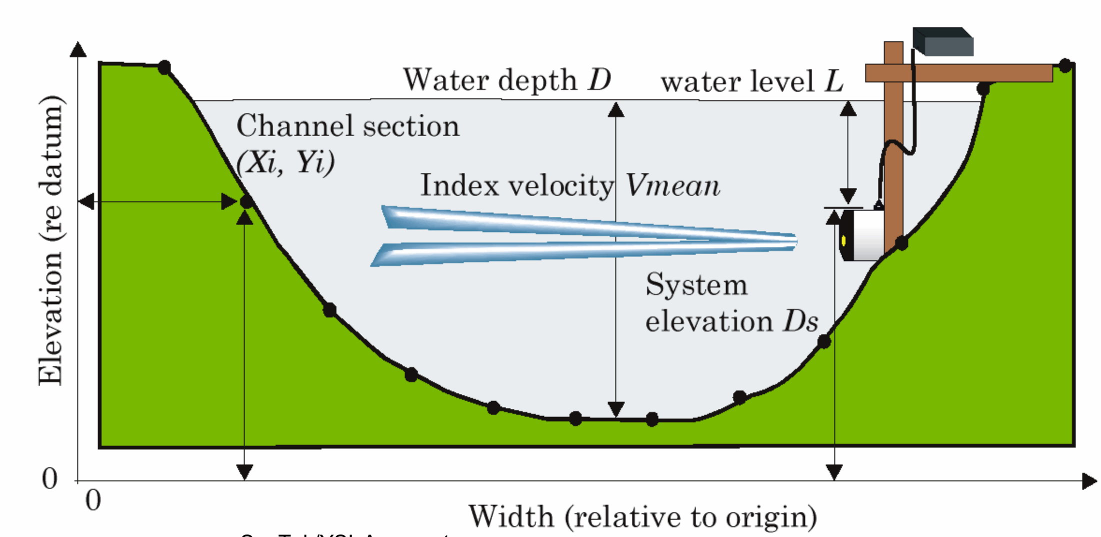
This paper is a summary of an application of the Index Velocity Rating Procedure for a SonTek/YSI Argonaut™ Side-Looking (SL) 1.5-MHz acoustic Doppler current meter. The Argonaut SL has the ability to perform internal discharge computations as the product of mean channel velocity and cross-sectional area. The index coefficients for establishing the empirical velocity relationship in a channel are determined through regression analysis. Computing flow with the internal flow algorithm requires the user to input a specific velocity equation and the channel geometry defined by up to 20 cross-sectional points (x-y pairs).

The discharge and velocity measurements presented in this paper were collected in the Colorado River Indian Tribes (CRIT) Main Canal. Current metering was done following procedures established by the USBR in their Water Measurement Manual (USBR 2001). The actual Argonaut SL measured velocity values are used to illustrate the index velocity rating technique and the development of an equation to accurately produce discharge records using hydroacoustic instruments. The process discussed in this paper is a modification of the procedure outlined by the USGS for indexing (USGS 2002).

Utilizing electronic flow rate measurement equipment that can cost less than 10 percent of a large concrete flume is attractive economically. However prior to the use of this indexing procedure, there was much uncertainty of the overall accuracy in the use of a flow meter such as the Argonaut SL in some irrigation canal applications.

Basic Operation Principle

The SonTek/YSI Argonaut SL measures 2-dimensional horizontal water velocity in an adjustable location and size of the sampling volume using the physical principle termed the Doppler shift. The Argonaut transducers measure the change in frequency of a narrow beam of acoustic signals in order to compute along-beam velocity data. Beam velocities are converted to XYZ (Cartesian) velocities using the known beam geometry of 25° off the instrument axis.



source: SonTek/YSI Argonaut Operation Manual

Figure 1. SonTek/YSI Argonaut SL channel geometry for internal flow computations

Basic Deployment Instructions

Before deployment of the Argonaut SL, the site must be prepared to achieve a high level of accuracy of the device. The following guidelines outline the required characteristics of a site for the Argonaut SL.

1. The location of the device must be ten widths of the canal away from bends or turbulences as to have good horizontal velocity distribution.

2. The device must be located at a concrete-lined section of the canal that is well surveyed.

3. The device must be installed on a removable arm for easy removal of the device for maintenance.

4. A moss deflector must be installed around the device to prevent trash or organic matter from collecting on or around the device.

5. A calibration procedure, like the one discussed in this paper, must be completed.

To determine an index velocity rating, concurrent mean channel velocity and Argonaut SL measured velocities are required. The following steps outline the basic procedures one follows in collecting velocity and stage data for developing an index velocity rating. The result is a dataset comprised of i) a mean velocity, ii) average Argonaut SL velocity, and iii) average stage.

1. An Argonaut SL is installed with the appropriate deployment settings and mounting bracket. Site selection is an important consideration and the diagnostic guidelines provided in the manufacturer's technical documentation should be carefully observed. These diagnostic parameters include an assessment of the signal strength and standard deviation for a given set of operating conditions.

2. The channel is accurately surveyed and a stage-area rating is developed. Elevations for the cross-section points are in terms of stage referenced to the station datum.

3. Discharge measurements (Price AA current metering or comparable device) are made near the Argonaut SL site while the instrument is sampling velocity.

4. The average stage during the discharge-measurement period is recorded.

5. Mean channel velocity is derived for each individual discharge measurement by dividing the measured discharge by the channel area computed from the stage-area rating.

6. For each discharge measurement, Argonaut SL measured velocities are averaged for the discharge-measurement period. For the Argonaut SL, the velocity x-component or the computed velocity vector can be used for the measured velocity.

7. Each discharge measurement yields a computed mean channel velocity and an average Argonaut SL velocity.

8. The index velocity rating procedure recommended by the ITRC requires a wide spread in the measured discharge (a 2:1 ratio), usually at least 10 measurement values over the entire range of flows. The regression coefficient (r^2) must be better than 0.96 to assure confidence in the results.

This discussion does not attempt to provide a detailed description of all the technical issues involved with the deployment of the instrument for a desired level of accuracy. The performance of the Argonaut SL depends on considerations such as the influence of boundary interference, proper alignment with the flow, appropriate settings of the averaging and sampling intervals, and cell size. A further limitation in the operation of the Argonaut SL is the aspect ratio, which is defined as the ratio of the measurement range to height. Range is horizontal distance from the instrument and height is the vertical distance to the surface or bottom. It is strongly recommended to use the Argonaut SL for aspect ratios greater than 5:1. It is not recommended for aspect ratios less then 5:1. A bottom-mounted unit looking toward the water surface is recommended for those applications.

Measurement Results

A total of eight discharge measurements were collected in the CRIT Main Canal. The measured stage, computed mean channel velocity determined by current meter, and the Argonaut SL measured velocity are summarized in **Table 1.**

Table 1. CRIT Main Canal Current Meter and Argonaut SL Velocity Measurements

No.	Stage, feet	Current Meter Velocity, fps	Argonaut SL Velocity, fps
1	11.80	1.19	1.29
2	12.20	1.19	1.39
3	11.30	2.05	2.08
4	11.30	1.97	2.09
5	11.80	3.00	2.95
6	11.80	2.97	3.06
7	10.50	1.48	1.42
8	10.50	1.47	1.42

Index Velocity Rating Development

An index velocity rating is developed in this section to relate the mean channel velocity to the velocity measured by the Argonaut SL in the CRIT Main Canal. For some operating conditions, the index velocity relation may be linear, while in other situations the relation may be best expressed as curvilinear or a compound curve (USGS 2002). In each instance, the user should assume that stage might be a significant factor in the accurate prediction of mean channel velocity. This situation where the relationship between mean velocity and Argonaut measured velocity is affected by stage is handled by performing a multiple linear regression.

If the relation between the mean channel velocity and the measured Argonaut SL velocity is linear, it can be represented by a linear equation as follows:

$$V_m = xV_{SL} + C$$

where,

V_m = computed mean velocity
V_{SL} = average measured Argonaut SL velocity during one measurement period
x = velocity coefficient
C = constant

The first step in determining whether a linear relation exists is to plot mean velocity (y-axis) and Argonaut SL velocity (x-axis). **Figure 2** is a graph of the velocity dataset for the CRIT Main Canal in **Table 1**.

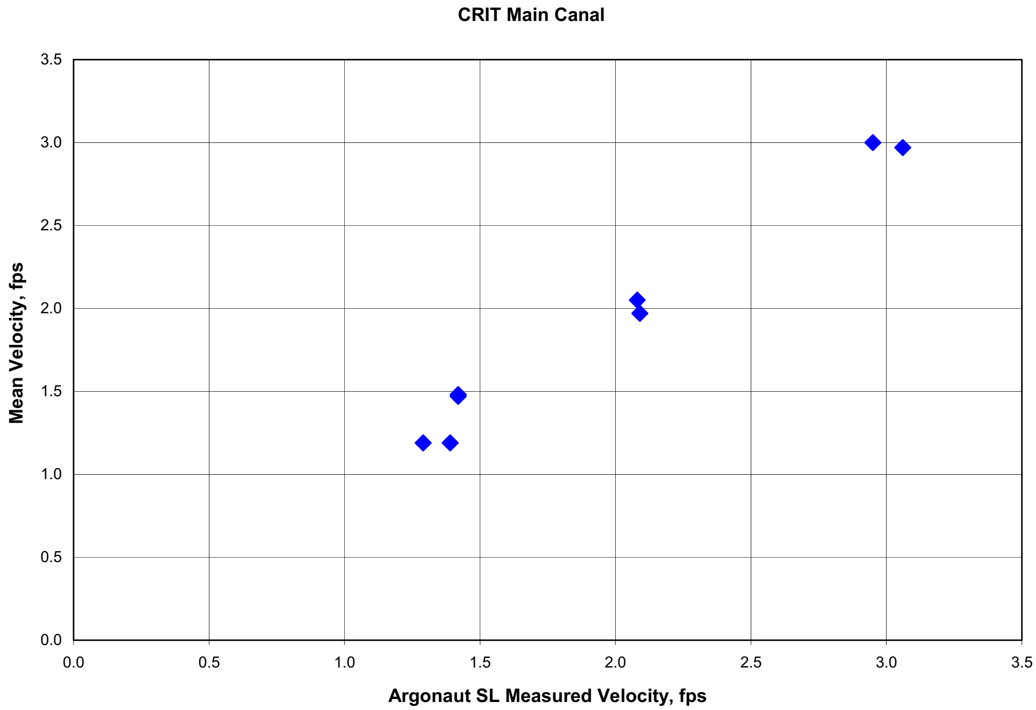


Figure 2. Mean velocity and Argonaut SL velocity from discharge measurements in the CRIT Main Canal

The next step is to derive the linear equation and compute the coefficient of determination (r^2). The r^2 value indicates what percentage of the variation in mean velocity can be explained by the variation of Argonaut SL velocity.

A simple method for determining the equation coefficient and constant along with the r^2 value is the linear regression tool in Excel® spreadsheets.

The linear index velocity rating equation determined for the CRIT Main Canal dataset in **Table 1** is shown below:

$$V_m = 1.015V_{SL} - 0.077$$

Figure 3 shows the index velocity rating from least-squares regression. The r^2 value of 0.98 indicates that 98 percent of the variation in the mean velocity can be explained by the variation in the Argonaut SL velocity.

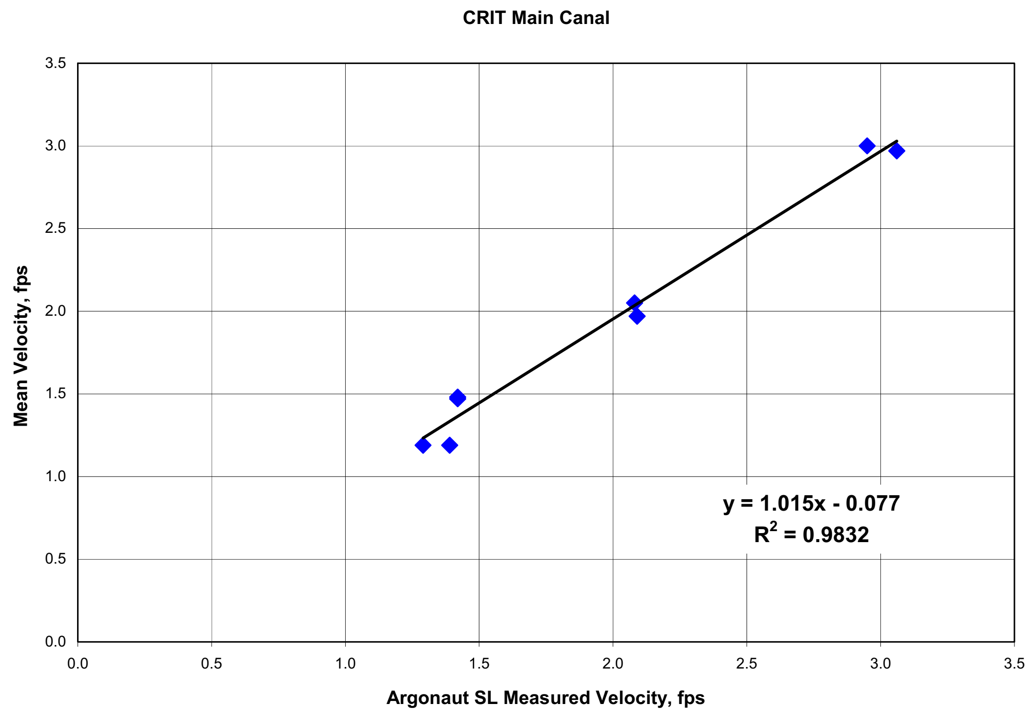


Figure 3. Index velocity rating using simple linear equation (r^2 = 0.98)

The above analysis assumed that the Argonaut SL measured velocity is the only parameter to consider when determining the index velocity rating. However depending on the site's hydraulic conditions, stage may be a significant factor in the prediction of mean channel velocity using a side-looking acoustic Doppler velocity instrument.

An equation that relates both the Argonaut SL velocity and stage to mean velocity is:

$$V_m = V_{SL}(x + yH) + C$$

where,

V_m = computed mean velocity
V_{SL} = average measured Argonaut SL velocity during one measurement period
x = velocity coefficient
y = stage coefficient
H = stage
C = constant

The values of the coefficients and constant in the index velocity equation can be determined from the multiple linear regression analysis where mean velocity is the dependent variable and the independent variables are the Argonaut SL measured velocity and the product of measured velocity and stage.

Using multiple regression analysis, the equation and r^2 value determined for the CRIT Main Canal dataset in **Table 1** assuming that stage is a factor is:

$$V_m = V_{SL}(1.995 - 0.080H) - 0.192$$
$$r^2 = 0.99$$

Figure 4 shows the relationship between the mean velocity and the computed index velocity using multiple linear regression.

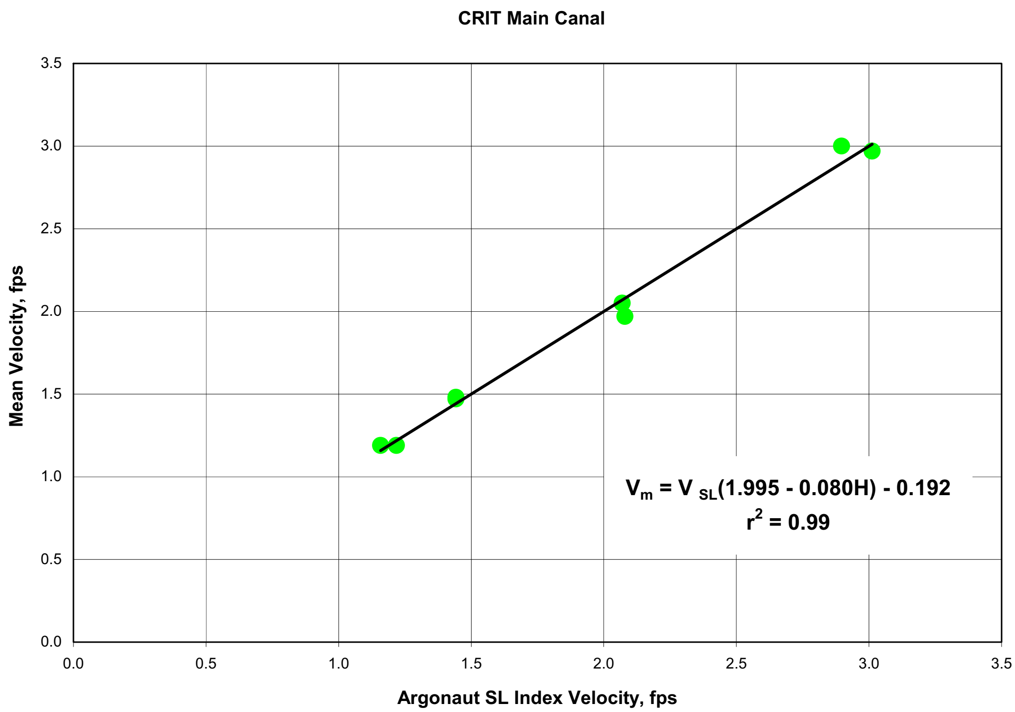


Figure 4. Index velocity rating using multiple regression equation

<u>Results</u>

Table 2 summarizes the computed discharge using both index velocity equations and the percent error relative to the current meter measurements. The flow rate (Q = VA) was computed using the index velocity and channel area based on the measured stage and a bottom width of 25 ft and side slope of 1:1.

Table 2. Discharge (cfs) and percent discrepancy using simple linear regression and multiple regression with stage

No.	Current meter discharge, cfs	Simple linear equation no stage		Multiple regression with stage	
		cfs	Discrepancy	cfs	Discrepancy
1	514	535	4.1%	503	-2.1%
2	540	605	12.1%	553	2.4%
3	841	834	-0.8%	849	0.9%
4	805	839	4.2%	853	6.0%
5	1318	1267	-3.9%	1258	-4.6%
6	1304	1315	0.9%	1308	0.3%
7	562	509	-9.5%	538	-4.3%
8	547	509	-7.0%	538	-1.7%

Conclusion

The index velocity rating determined using the multiple linear regression analysis with stage is generally closer to the discharge measured with a current meter. The percent error of the index velocity for the simple linear equation and the multiple linear regression equation is approximately ±10% and ±6%, respectively. In other words, the inclusion of stage as a factor in determining the index velocity rating for this particular dataset improved the accuracy by about ±4%. It is recommended to always include stage in the development of an Index Velocity Rating Procedure. The final equation can be readily programmed into the instrument for use with the internal flow computations option.

Figure 5. SonTek/YSI Argonaut SL installed in a canal

Due to the inherent problems in using current metering as the reference flow rate, future evaluations will be done using other rapid measurement techniques. The issues with current meters include; poorly defined cross-sections, fluctuating flow rates, moss hanging on meter, etc. Potential technologies include using the portable Doppler meters that can be mounted to boats and rapidly determine the flow rate in a canal.

References

USBR - Bureau of Reclamation. 2001. Water Measurement Manual – A Guide to Effective Water Measurement Practices for Better Water Management. United States Department of the Interior. Bureau of Reclamation. Third Edition. Denver, Colorado.

USGS - Morlock, S.E., H.T. Nguyen, and J.H. Ross. 2002. Feasibility of Acoustic Doppler Velocity Meters for the Production of Discharge Records from U.S. Geological Survey Streamflow-Gaging Stations. U.S. Geological Survey, Water-resources Investigations Report 01-4157. Denver, Colorado.

Disclaimer

ATTACHMENT C

PROCEDURE FOR USING ACOUSTIC DOPPLER CURRENT PROFILERS (ADPS)

IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, California 93407
Tel: (805) 756-2434 Fax: (805) 756-2433 www.itrc.org

TECHNICAL MEMORANDUM

Date: April 30, 2004

To: Dr. Stuart Styles, ITRC Director

From: Ben Burgoa, ITRC Engineer

Subject: Procedures for Measuring Canal Discharges Using RDI StreamPro and SonTek/YSI RiverSurveyor Acoustic Doppler Profilers

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This memo contains the procedures for measuring canal discharges using RD Instruments StreamPro Acoustic Doppler Current Profiler (ADCP) and SonTek/YSI RiverSurveyor Acoustic Doppler Profiler (ADP). The Irrigation Training and Research Center (ITRC) acquired these two units to investigate the usefulness of the ADP in calibration of non-standard, flow measurement structures. This project is funded by the Water Conservation Office of the United State Bureau of Reclamation, Mid Pacific Region.

Discharge Measurement Procedure using Acoustic Doppler Current Profilers (ADCPs or ADPs)

ADCP Units

ADCP units should be assembled and tested following manufacturers' specifications (Appendix 2 and 3). A pre-field inspection must be made to ensure that the instrument is functioning correctly. Instruments should utilize the most recent software and firmware.

The portable HP- iPAQ and Palm i705 handheld units should be kept plugged at all times. Also, portable computers should utilize the most recent software programs.

Site Characteristics, Equipment, and Personnel

Before discharge data is collected using the ADCP, information describing the site, date, personnel, equipment, and versions of software and firmware used should be entered on the *Acoustic Profiler Discharge Measurement note sheet* (Appendix 1)

The key issues to consider when selecting the location of your measurement cross-section are:

- The maximum water depth for the entire cross section must not exceed the maximum profiling range of the system:
  - SonTek/YSI RiverCat 3.0 MHz: 6 m (19.7 ft)
  - RDI StreamPro 2.0 MHz = 2 m (6.6 ft)

- Select an area of relatively uniform and steady flow. Avoid areas with a significant number of eddies or turbulence
- The cross-section should have gradual changes in depth
- Flow along the canal banks should be low or close to zero

Additional data should be collected at the site:

- The cross-sectional area of the site should be surveyed or drawings should be provided by the District
- The discharge of the canal should also be measured using Price AA or Pygmy meter
- Rating curve of the structure

Changes in Water Level

The water level or gage height from a staff or pressure sensor should be obtained before and after each measurement and entered into the space provided on the front of the field note sheet. An average gage height and discharge then can be calculated and entered into the space provided on the upper part of the field note sheet.

A Telog datalogger and Druck transducer system should be installed upstream of the non-standard structure to monitor water level during the test.

Depth of ADCP sensor in the water

After the ADCP is mounted and deployed on the boat and prior to each measurement, the depth of the ADCP in the water should be measured and recorded. The depth of the ADCP is the vertical distance from the water surface to the center of the transducer face. When measuring the ADCP depth, make sure that the roll and the pitch of the boat are similar to the roll and pitch during the discharge measurement.

Adjust the sensor depth so that it is 1 to 3 inches below the surface of the water.

Assessment of Bedload Movement

Assessment of stream/channel bed movement is necessary before a discharge measurement can be made, because the vessel velocity relative to the channel bed is also measured and used to calculate the actual water velocity. Because of variability of bedload movement across the channel, it may be necessary to check for bed movement at several (3-5) locations across the channel to ensure that the bed is stable. Maximum potential for bed movement occurs in the region of maximum water velocities.

1. Bed movement can be assessed by holding the boat for at least 10 minutes at a fixed location within the channel while a series of ensembles or profiles is collected.
2. If the bed is stable, the “Ship Track” display will indicate no significant movement of the vessel.
3. If the “Ship Track” indicates a gradual movement of the vessel in the upstream direction, an alternate site should be sought.

Speed and Maneuvering of the Boat

The boat should be stationary at the start and end of the measurement and a few profiles should be collected during these stationary periods. Noted that, the average boat speed for each transect should be less than or equal to the average water speed. Slow, smooth boat movements are desirable. Under certain conditions it may not be possible to keep the boat speed less than the water speed. As a result, additional transects should be made.

Edge Distance Measurement

Edge distances for estimation of edge discharge must be measured using an electronic-distance measuring device, a tagline, or some other accurate measuring device.

The edge locations must be determined prior to beginning the data collection. Typically, edge measurement is taken as close to the shoreline as can be measured and still read valid data (i.e. an ensemble that contain a minimum of two good depth cells). Start and stop points for the stream/channel edges can be marked on the tether line.

Discharge Measurement (Old Procedure – Prior to "Stationary Measurement" Method)

1. At least four transects (two in each direction) must be made under steady-flow conditions at each site to ensure a valid determination of discharge.
2. If any one of the first four or more transects differs from the calculated discharge average by more than 5% (an outlier), it should first be evaluated to determine if there is any reason to justify discarding the data point.
    a. If a transect is discarded, another should be made so that the discharge measurement is calculated from the average of at least four transects.
    b. If there is no justifiable reason for discarding the transect, four additional transects should be made and all of them (8 transects), including the outlier, should be averaged to determine discharge.
3. It may be necessary to use individual transects as discrete measurements of discharge under rapidly varying flow conditions. However, whenever possible, a pair of reciprocal transects should be made to reduce directional biases.
4. After the discharge measurement has been made, each raw data file should be reviewed using the "Playback" mode to ensure that:
    a. The data is complete,
    b. The data does not include any bad ensembles,
    c. Depths and velocities do not exceed the prescribed limits set for the instrument in use, and
    d. The data does not include velocities spikes (i.e. stream velocities = ambiguity velocities).
5. If a raw data file contains bad velocity ensembles or velocities spikes, the measurement should be repeated until at least four complete measurements with no bad data have been obtained.

Measurement Assessment

An overall assessment of the average discharge measurement should be made after the completion of the transects composing the measurement. This assessment is based on:

1. Qualitative judgment of conditions encountered in making the measurement
2. Quantitative evaluation of the individual transects
3. Completeness of the measurement in terms of the percentage of the total cross-sectional area
4. Conditions such as turbulence, eddies, reverse flows, surface chop, and proximity of the instruments to ferrous objects

The average (Q) and standard deviation(s) of the discharge measurement and the coefficient of variation (CV) should be calculated (100*s/Q). If the CV is greater than 5%, additional transects should be made.

References

Lipscomb, S. W. 1995. Quality Assurance Plan for Discharge Measurements Using Broadband Acoustic Doppler Current Profilers. U.S.G.S. Open File Report 95-701.

Office of Surface Water Technical Memorandum No. 2002.02. Policy and Technical Guidance on Discharge Measurement using Acoustic Doppler Current Profiler.

Simpson, M.R. 2001. Discharge Measurement Using a Broad-Band Acoustic Doppler Current Profiler. U.S.G.S. Open-File Report 01-1.

SonTek/YSI. 2002. RiverSurveyor: Read Me First. File Date 09-09-2002.

Appendix C-1

USGS Water Resource Division - Acoustic Profiler Discharge Measurement Notes

9-275-XXX
05/10/2001

Sta. No.____________

U.S. DEPARTMENT OF THE INTERIOR
Geological Survey
Water Resources Division
Acoustic Profiler Discharge Measurement Notes

Meas. No. ________
Processed by ______
Ck'd by __________

Sta. Name____
Date_____________, **20**___ **Party** ____
Width __________ Area ___________ Vel. ___________ G.H. ___________ Disch. ___________________

Profiler Water Temp. ______°C at _______ Rated area: __________ Index Velocity ____________
Profiler S/N:______ Mfgr: __________ Freq. ______ Firmware:_______ SoftwareVer. ____________

		Other commands:	
DepthCellSize			
No. of Cells			
Blanking Distance			
Water Mode			
Ambiguity Vel.			
Water pings			
Bottom pings			

Profiler Depth ____________
Config. file ______________
Deployment ______________
Moving Bed ______________
Moving Bed Present: Y N
Diag. Test ________________
Diag. Test Errors: Y N

Boat/Motor Used _________________ ADCP Time to WT ☐ @ _______ GPS: _______________
Mag.Var. 1)_______2)_______3)_______4)_______Avg: _______ Comp. Cal.: ______________

GAGE READINGS						
Time					Inside	Outside
Weighted MGH						
GH correction						

Samples collected: water quality, sediment, biological, other:___________________
Measurements documented on other sheets: water quality, aux./base gage, other:
____

Rain gage serviced/calibrated ______
____

Weather ____________________
Wind Spd. _______ Dir._________
Air Temp. ______°C at________
Water Temp.______°C at________
Specific. Cond: _______________
Checkbar/chain found ______________
Changed to

Wading, cable, ice, boat, upstr., downstr., side bridge, _______ft., mi. upstr., downstr. of gage.

Cross section: ____

Control: ____

Gage operating: _______________ Record removed: Y or N Filename: ______________________

Battery voltage: ___________ Intakes/Orifice cleaned/purged: _______________________________
Bubble-gage psi: Tank _________, Line_________; Bubble rate _______/min.

CSG checked: ________ HWM height on stick _______ Ref elev _________ HWM elev_________

Remarks: ____

Canal Cross-Section

COMPUTATION NOTES

Beginning		Ending		Discharge					
				Estimated	Measured	Estimated			Total
Ensemble number	Distance added	Ensemble number	Distance added	Top	Middle	Bottom	Left	Right	
Mean						Mean			
Estimation Top ________________							Range (max-min)÷Mean (%) : ________________		
Method Bottom _____________				Power Law Exponent: ____________________			Measured Q as percent of total __________________		

MEASUREMENT NOTES

LEFT BANK: Sloping Vertical Other: ______ RIGHT BANK: Sloping Vertical Other: ______

Transect Number	Start Bank	Time	Distance	Ending Distance	Time	Total Discharge	Remarks

Notes:

Appendix C-2
Site Setup

Site Preparation

After the site is selected, a set of stakes and pulleys will be installed on each side of the canal (Figure 3-1). The constructed transect should be perpendicular to the canal. A nylon rope will be installed between the pulleys. The rope should be taut (i.e. without slack) across the canal.

The boat will be assembled following manufacturer instructions and tested before being placed in the canal. The boat will be tied to the rope and placed in the water carefully.

Figure 3-1. Boat placed correctly in the water

The starting and ending points should be determined according to manufacturer instructions, and the edge distances measured. A piece of tape should be placed on the rope to indicate the starting and ending points of the transects (Figure 3-2).

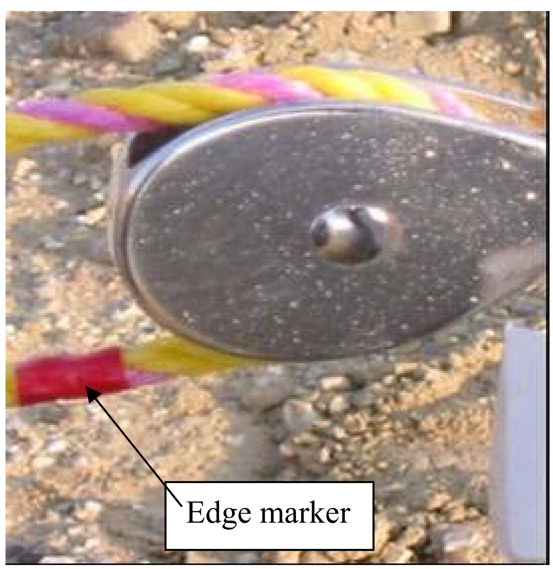
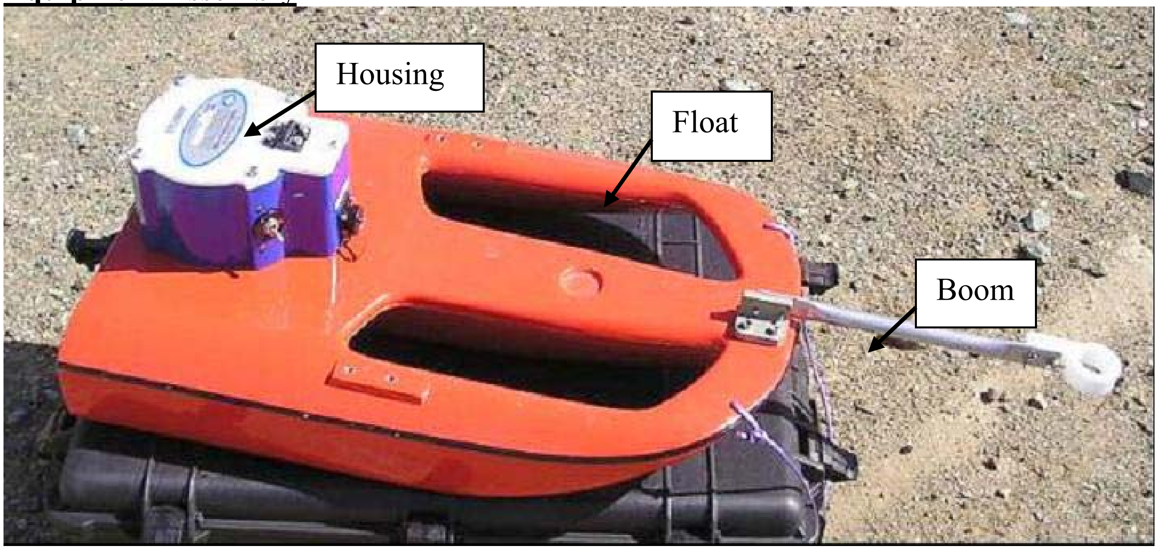


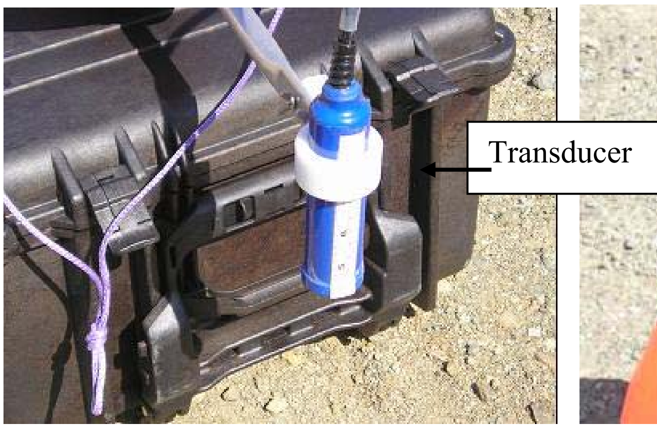
Figure 3-2. Tape on rope marking start and end points

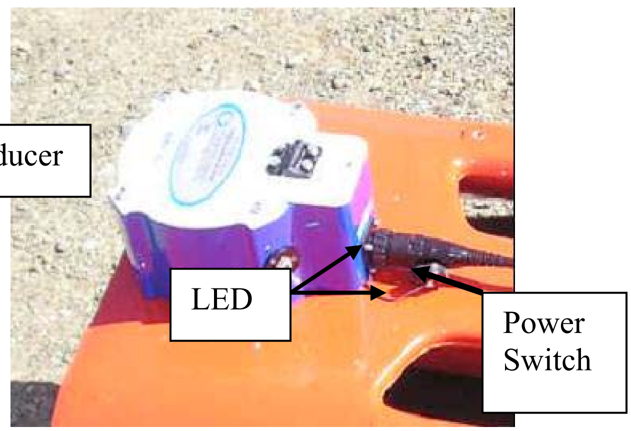
Appendix C-3
RDI StreamPro Quick Start Guide

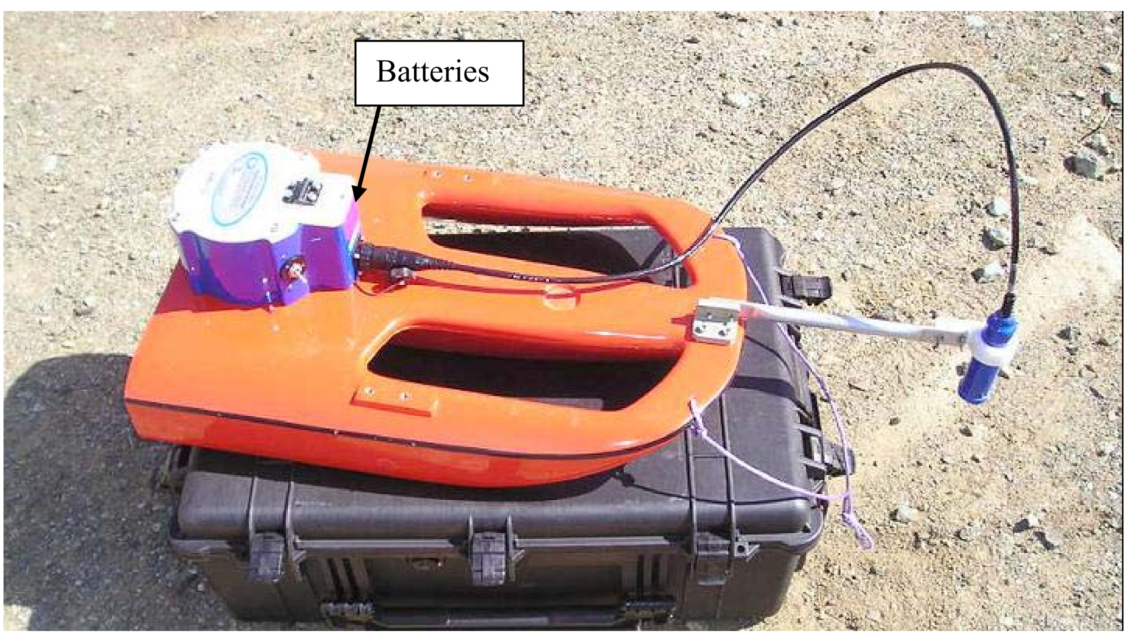
StreamPro Quick Start Guide

Equipment Assembly









Stream Pro ADCP Discharge Measurement

1. Turn on the iPAQ communication
   a. Tap the Blue Tooth icon located in the lower right corner of the iPAQ at the **Start** screen.
   b. **Turn on** the Bluetooth communication. The blue LED on the iPAQ should light
2. Testing the StreamPro
   a. Turn the On power to the StreamPro ADCP. The Yellow LED indicates power is on
   b. Start StreamPro application and select RDI StreamPro icon. The Blue LED on the StreamPro ADCP indicates that the connection is made
   c. Load the factory default configuration file
      i. Tap the **Setup** tab
      ii. Tap **Configuration File**
      iii. Select **Factory Default**; you should see the message "Factory Defaults Loaded"
   d. Run the Self-Test
      i. Tap the **Test** tab
      ii. Tap **Instrument**
      iii. Tap **Self-Test**
      iv. View test results ("PASS")
3. Data Collection with StreamPro
   a. Note: Create a folder for each site, preferably in the iPAQ storage card; create a configuration file and enter data file prefix for that site; put the configuration file in the folder created. All subsequent data files will be saved to that folder
   b. Configuring the StreamPro (page 20)
      i. Change Default Setting
         1. Tap the **Setup** tab
         2. Tap **Configuration File**
         3. Tap **Change Settings**
         4. **Accept** when done with the changes
      ii. Change units
         1. Tap the **Setup** tab
         2. Tap **Units**
         3. Select **SI** or **English**
      iii. Save Configuration File As
         1. Tap the **Setup** tab
         2. Tap **Configuration File** and **Save As**
         3. Rename file and save in My Documents folder
         4. Tap **OK**
   c. Measure start and stop points for the stream edges
      i. Note: You must determine the edge location prior to beginning data collection. Typically, edge measurements are taken as close to the shoreline as can be measured and still read valid data. Ensembles that contain a minimum of two good depth cells are considered valid data. You should read the ***Site Setup*** section
      ii. Start Test

1. Select the **Test** tab
2. Tap **Instrument** and **Start Pinging**
3. The number of good depth bins is displayed on the bottom-right corner of the screen
4. Slowly move the StreamPro closer to the shore until a minimum of two good depth cells are located
5. Mark this location by placing a tape on the rope (*Starting Point*)
6. Measure and record the distance between the boat's location and the physical edge of the canal (*Edge Distance*)
7. Repeat this process at the far bank to locate the *stopping point* of the transect

d. Collecting Data
   i. Move the StreamPro ADCP to the start point
   ii. In StreamPro, select the **Data Collection** tab
   iii. Tap the **Transect Start** button to initiate data recording
   iv. Enter the **Edge** Distance when prompted
   v. Select **OK** to accept the distance
   vi. Note: The **Left Edge** is the left bank of the canal when facing downstream
   vii. Hold the boat position while the StreamPro records good edge measurements "**Taking edge measurements. Hold position**"
   viii. StreamPro will prompt you to move the boat across the canal by displaying "**Transect in progress. Please proceed to the opposite bank**"
   ix. When the StreamPro arrives at the opposite shore, tap the **Transect Stop** button
   x. Enter the **Edge** Distance for the new shore when prompted
   xi. Select **OK** to accept the distance
   xii. The recording stops and the data file is closed
   xiii. Select the **Transect Start** button again to repeat the process in the opposite direction
   xiv. Repeat these steps to capture at least four good transects

4. Viewing History
   a. Compare Transects
      i. To view a list of the transects tap the **History** tab
   b. Discharge Summary
      i. Tap **Transects** then tap the data file to view the transect summary for each data file opened
      ii. Tap **Transect** and the tap **Compare Transects** to return to the Compare Transect screen
5. Data Playback
   a. Playing Back Collected Data
      i. Tap the **Playback** tab
      ii. Tap **File**, **Load**, displaying a list of data files available for playback
      iii. Select a raw data file for playback and tap **OK**
      iv. Popup will appear with message "File Loaded"; Tap **OK** (Note: Files are saved to the \StoragCard\RD Instruments\ProjectFile folder)

v. The slider control at the bottom of the screen can be used to walk through the file data

6. To end the program ALWAYS tap **File** at the bottom left corner of the iPAQ and then tap **Exit StreamPro**

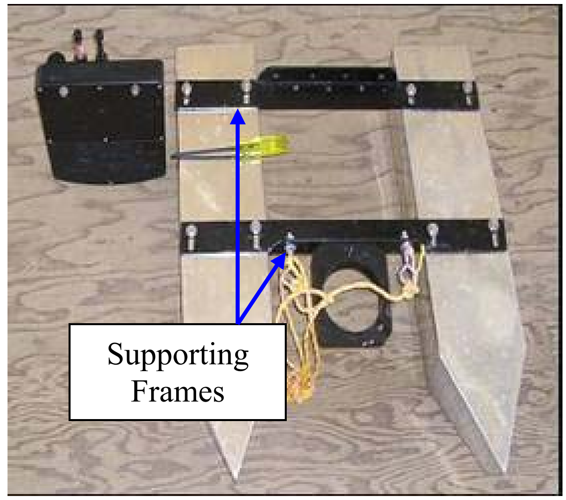
7. Moving and Copying Data Files
    a. Place the iPAQ Pocket PC in the cradle
    b. When Microsoft ActiveSync starts, click the **Explore** icon
    c. Navigate to the folder where the files were saved (Note: Files are saved to the \StoragCard\RD Instruments\ProjectFile folder)
    d. Highlight the files you want to copy or move
    e. On the **Edit** menu, select **Copy To Folder** and select the folder where the data files will be copied to the selected folder
    f. If you want to move the data files from the iPAQ Pocket PC, select **Move To Folder** and select the folder where the data files will be moved to the selected folder

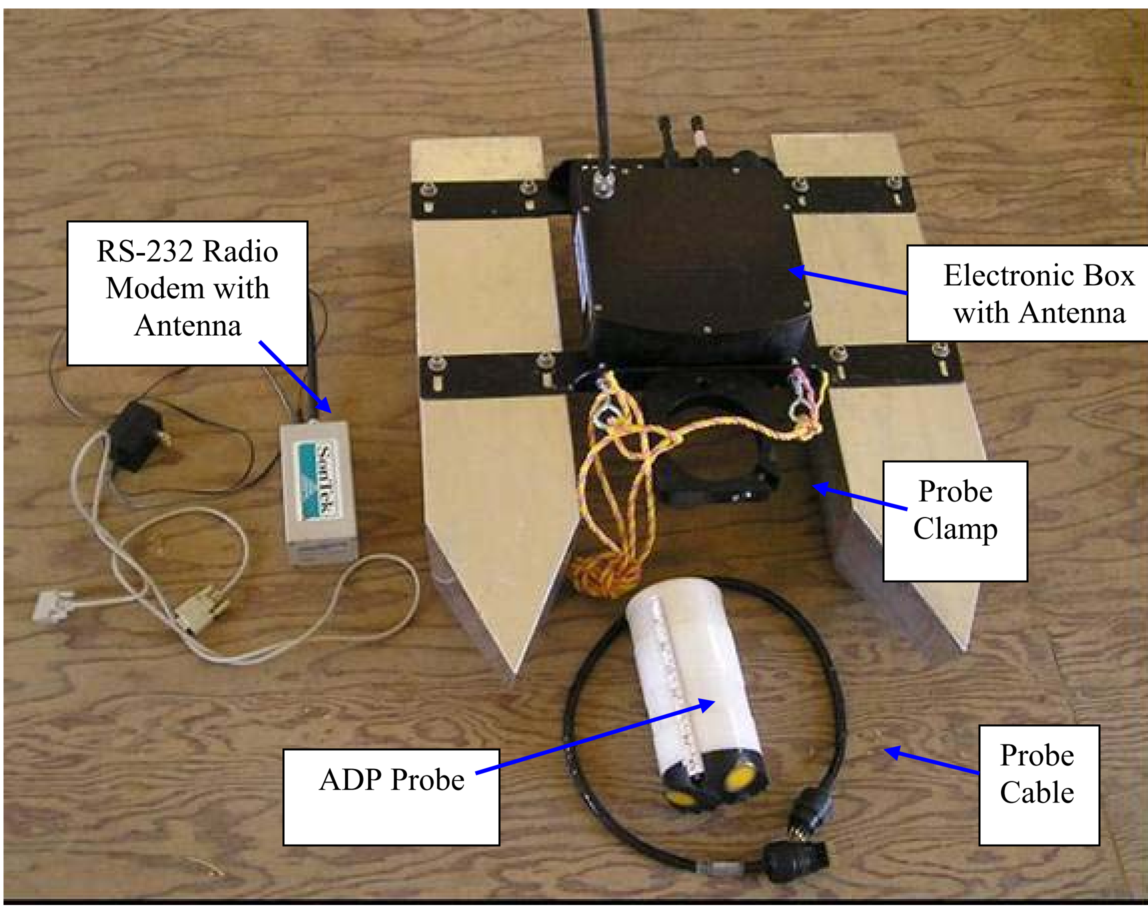
8. General Notes
    a. It is recommended to always use new batteries for each day of field testing. StreamPro runs with 8 AA batteries, which can run continuously for 16 hours
    b. USGS practice is to configure an ADCP using SI units, and then switch to English units when collecting data and playing back
    c. The iPAQ must be kept charged. Loss of power will cause loss of data in the iPAQ. The iPAQ can be charged using a USB connection to a notebook PC computer

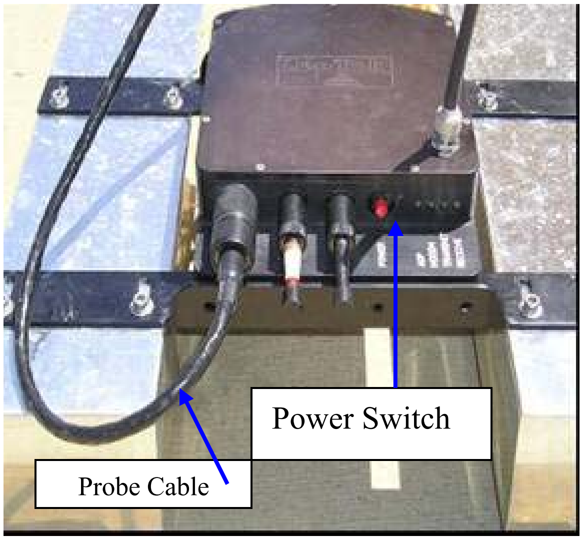
Appendix C-4
SonTek/YSI RiverSurveyor Quick Start Guide

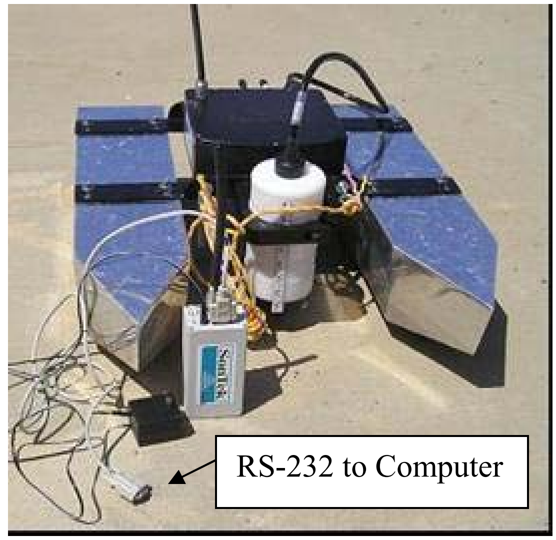
RiverSurveyor Quick Start Guide

Equipment Assembly









RiverSurveyor Discharge Measurement

1. Connecting to the system
    a. Power the RiverCat ADP
    b. Start the RiverSurveyor software (Programs/ SonTek Software/ RiverSurveyor)
    c. Connect to the RiverCat by pressing **Systems** button on the toolbar (Ctrl S)
    d. Check the status of the connection by "**click here to check**". The correct response should be "**Found**"
2. Setting up the system
    a. Set up the system by pressing "**Go to ADP user Setup"** button after connection or press "**Setup**" on the toolbar
    b. **Set System Time**
        i. Press "**Match System to Computer Time**"
        ii. Press "**Close**"
    c. Compass Calibration
        i. Click the "**Calibrate Compass**" button
        ii. Click the **Start** button to start the compass calibration
        iii. The RiverCat boat with the installed probe should be rotated through at least two complete rotations, varying pitch and roll as much as is practical (within the ± 50° sensor limit)
        iv. At the end of the calibration, press **Stop**
        v. The compass software reports a calibration score. If you receive results other than EXCELLENT, refer to the ADP manual for more information
        vi. Exit Compass Calibration by pressing the **Close** button
    d. **Basic Setting** (enter the correct values):
        i. File name: Enter prefix for all the recorded file names
        ii. To use automatic files names, enter **Enable**
        iii. Averaging Interval: (5-10 s)
        iv. Magnetic Declination: Set the magnetic declination to the appropriate value for your region (see Appendix 5)

v. Water salinity: Entered a value that is representative of the local water conditions (Fresh water = 0 ppt)
vi. Transducer depth method: Manual Option
vii. Transducer depth: Enter the measured depth of the transducer below the surface of the water

e. **Profile Range**
   i. Method 1: **Select maximum depth** will automatically set the profiling range parameters using only the maximum depth. To manually enter values for profiling range, refer to the following table

Table 5-1. Summary of River Surveyor Specifications and Configuration Frequency = 3.0 MHz (Manual page 14)

Profiling Range:	(Meters)	(Feet)
Min.	0.6	2.0
Max.	6	19.7
Cell Size		
Min.	0.15	0.5
Max.	2	6.56
Blanking Distance		
Min.	0.2	0.7
Bottom-Track Depth		
Max.	10	32.8

f. **Advanced Settings**
   i. Coordinate system: ENU
   ii. Bottom Track: YES
   iii. Recorder (internal): Disable
   iv. Temperature mode: Measured

g. Configuration Manager
   i. To save your current configuration:
      1. Type in a name for this configuration in the **Save Current Configuration** and click **Save**
   ii. To load an existing configuration:
      1. Click on **Load Configuration** or double-click the configuration name

h. Press the **OK** button to confirm any changes you have made and to start data collection
   i. A warning dialog box will be displayed if any input is in question
   ii. If you **Cancel** to exit **User Setup**, your settings will not be updated.

3. Data Collection
   a. To start collecting data from your RiverSurveyor system, press the ▶ Start button on the Playback/Record toolbar or press **F6**
      i. This will start the data collection but will not record this data to a file
      ii. This feature is designed to allow users to make sure that the system is operating correctly before starting data collection and to get feedback from the system when positioning the vessel at the start of the transect

iii. Move the vessel to the position where you want to collect data and ensure you are receiving valid (i.e. green) incoming data from all systems. Ideally there should be at least two valid cells to make a good measurement

b. To start recording data from your RiverSurveyor system press the ● Start recording button or press **F7**
   i. The Start Edge dialog will be displayed and you will be prompted to enter the bank (left or right) where you started the measurement and the distance from this bank to your current position (Left bank is the bank on the left side of the stream when looking downstream)
   ii. Enter these values and the program will start recording data to a file
   iii. Slowly move the vessel along the transect from one side of the river to the other, with a steady course and speed
   iv. When the boat is getting close to the far bank, keep track of the number of valid cells in the profile. When you are sufficiently close to the bank and still have two valid cells, stop the vessel
   v. Measure the distance to the nearest bank and then press the ● Start Recording bottom again or press **Alt F7**
   vi. You will be prompted to enter the distance you measured to the end bank
   vii. If you are finished collecting data, press the ■ Stop button or **F5**
   viii. If you are continuing with data collection, leave the system running in Play mode and move the vessel to its next position

4. Loading a RiverSurveyor Data File (xxx.adp) for Analysis
   a. Open and load data files
      i. Press the **Open** button (Ctrl O), and then locate and open the desired data file
      ii. Upon opening the file, RiverSurveyor will display the ADP File Information dialog box, which shows details about the measurement information stored in this data set
      iii. To load the entire data set – Make sure that **All Profiles** is selected, and then click **OK**
      iv. The data file will load and portions of the screen will update to show file information

Appendix C-5
Magnetic Declination for Cities in California

Magnetic Declination for Cities in California

One of the required values used by the ADP units is magnetic declination. The magnetic declination for any given location can be found on the USGS quadrangles. A website for Canada Natural Resources (www.geolab.nrcan.gc.ca/geomag/mirp_e.shtml) has a magnetic declination calculator. This calculator requires the longitude and latitude for the location and the year. Table 6-1 presents the magnetic declination in 2004 for cities in California.

Table 6-1. Calculated magnetic declination for some California cities in 2004.

Location	Longitude	Latitude	Magnetic Declination
Bakersfield	119° 00' W	35° 22' N	14° 01' E
Blythe	114° 35' W	33° 35' N	12° 41' E
Fresno	119° 46' W	36° 46' N	14° 31' E
Merced	120° 25' W	37° 20' N	14° 46' E
Redding	122° 25' W	40° 35' N	15° 58' E
Sacramento	121° 20' W	38° 40' N	15° 17' E
San Luis Obispo	120° 40' W	35° 17' N	14° 16' E
Visalia	119° 17' W	36° 20' N	14° 19' E

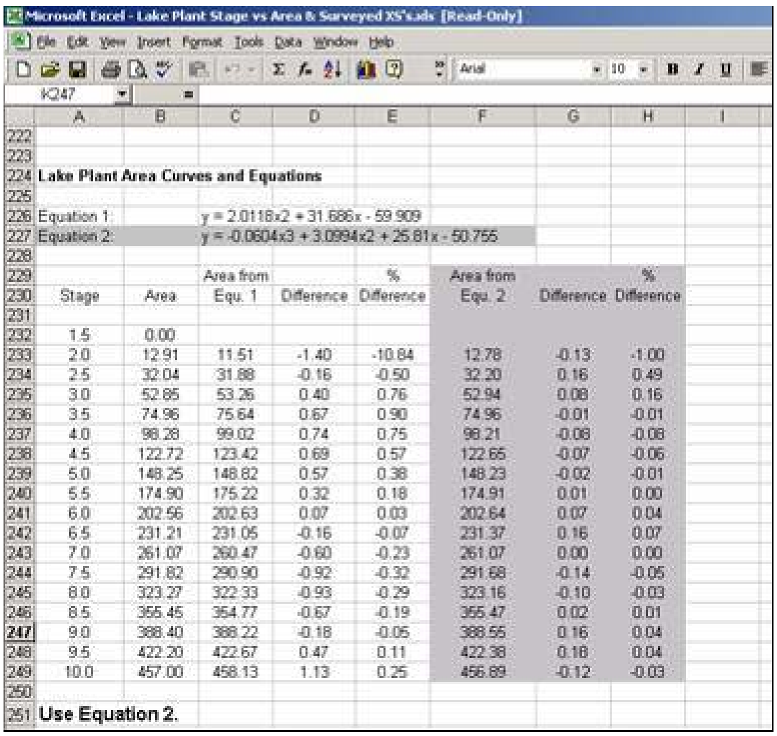
ATTACHMENT D

USER INSTRUCTIONS FOR REGRESSION ANALYSIS OF HYDROLOGICAL DATA USING EXCEL

Regression Analysis for the Flow Rate Indexing Procedure (QIP) using Microsoft Excel

The following steps illustrate an example regression analysis for developing the coefficients in the index velocity rating equation using Excel.

1. Using a new worksheet, an equation can be developed relating stage to area from the collected water level data. Enter the stage and area data in columns to create a scatterplot graph. The trendline feature can be utilized to determine the best fit equation. Going beyond a third-order polynomial is not necessary. Choose the equation the produces the least error between the equation calculated area and the actual area.


Microsoft Excel - Lake Plant Stage vs Area & Surveyed XS's.xls [Read-Only]

Lake Plant Area Curves and Equations

Equation 1: y = 2.0118x2 + 31.686x - 59.909

Equation 2: y = -0.0604x3 + 3.0994x2 + 25.81x - 50.755

Stage	Area	Area from Equ. 1	Difference	% Difference	Area from Equ. 2	Difference	% Difference
1.5	0.00						
2.0	12.91	11.51	-1.40	-10.84	12.78	-0.13	-1.00
2.5	32.04	31.88	-0.16	-0.50	32.20	0.16	0.49
3.0	52.85	53.26	0.40	0.76	52.94	0.08	0.16
3.5	74.96	75.64	0.67	0.90	74.96	-0.01	-0.01
4.0	98.28	99.02	0.74	0.75	98.21	-0.08	-0.08
4.5	122.72	123.42	0.69	0.57	122.65	-0.07	-0.06
5.0	148.25	148.82	0.57	0.38	148.23	-0.02	-0.01
5.5	174.90	175.22	0.32	0.18	174.91	0.01	0.00
6.0	202.56	202.63	0.07	0.03	202.64	0.07	0.04
6.5	231.21	231.05	-0.16	-0.07	231.37	0.16	0.07
7.0	261.07	260.47	-0.60	-0.23	261.07	0.00	0.00
7.5	291.82	290.90	-0.92	-0.32	291.68	-0.14	-0.05
8.0	323.27	322.33	-0.93	-0.29	323.16	-0.10	-0.03
8.5	355.45	354.77	-0.67	-0.19	355.47	0.02	0.01
9.0	388.40	388.22	-0.18	-0.05	388.55	0.16	0.04
9.5	422.20	422.67	0.47	0.11	422.38	0.18	0.04
10.0	457.00	458.13	1.13	0.25	456.89	-0.12	-0.03

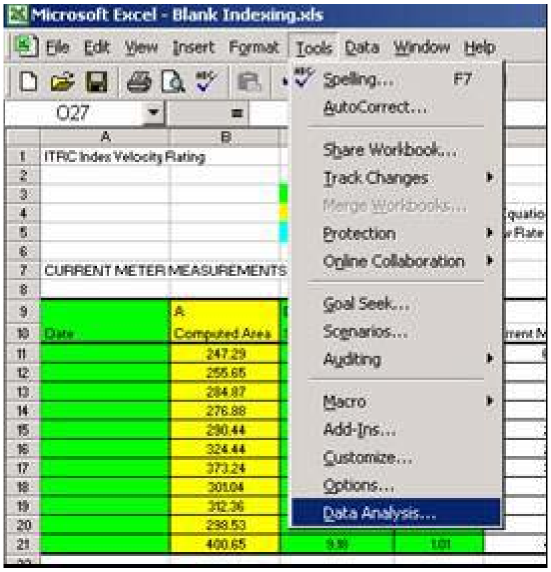
Use Equation 2.

2. The computed area and measured stage are copied to a new worksheet.

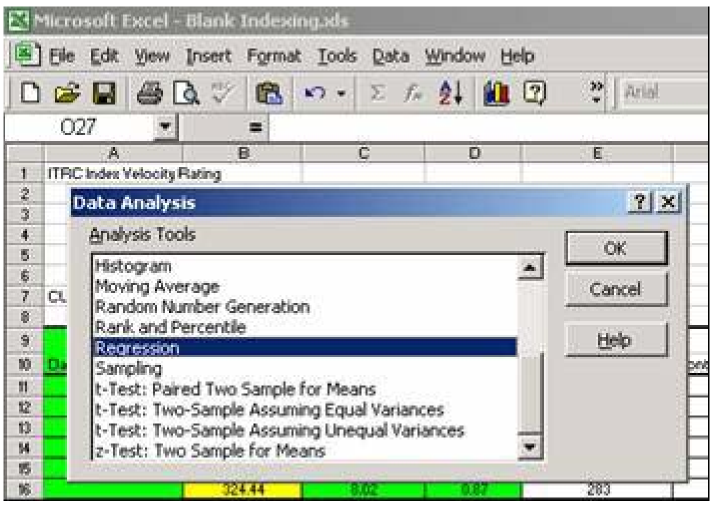
3. Enter the current meter measured mean velocity (V_{mean}) into its respective column.

4. Enter the SonTek measured velocity (V_{meas}) into its respective column.

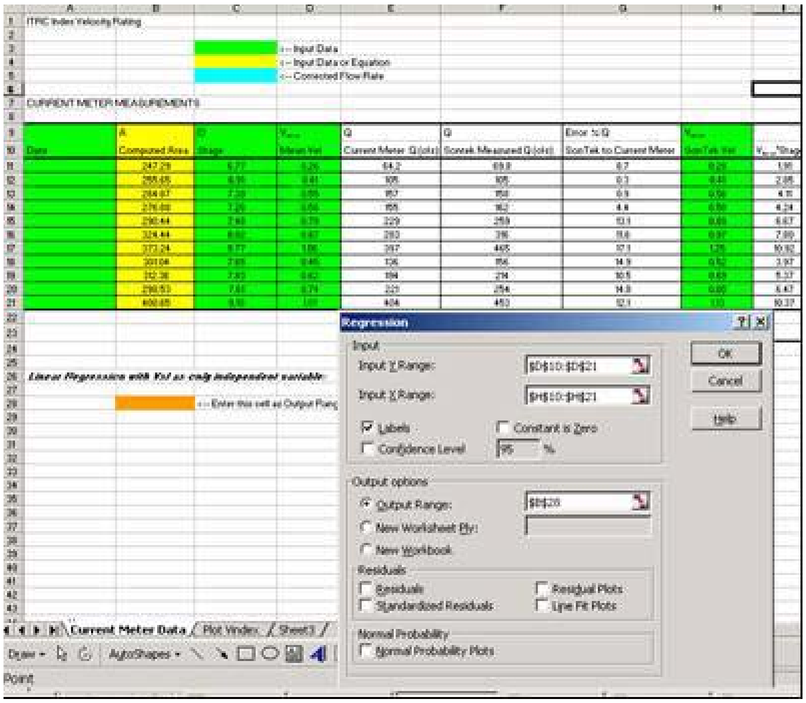
5. Go to Tools, Data Analysis. (Note: This command may not be available. If not, go to Tools, Add-Ins and check the Analysis ToolPak and press OK. You may have to restart Excel for the Data Analysis command to become available.)



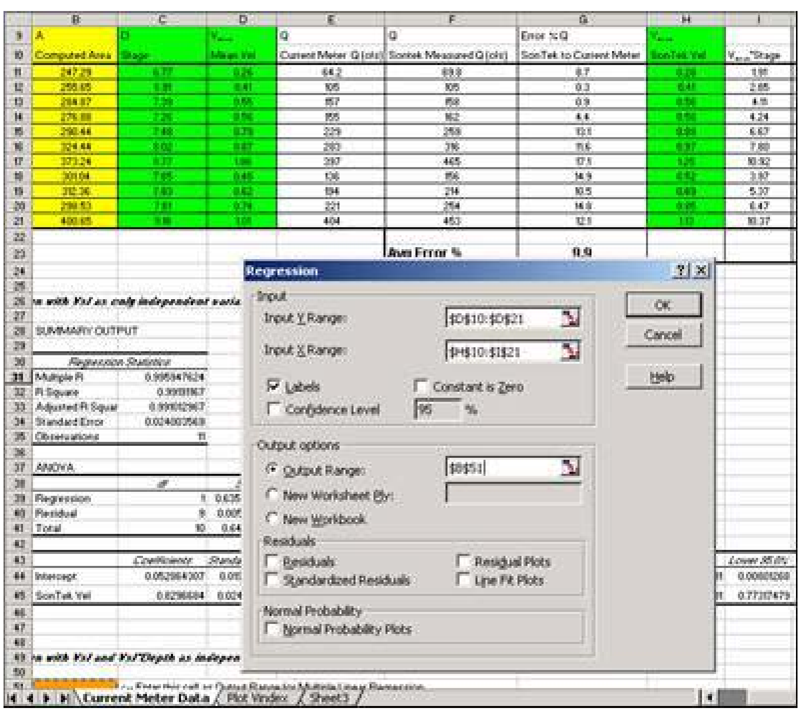
6. In the Data Analysis window select Regression and press OK.



7. For simple linear regression, enter the V_{mean} cells (including the column label) for "Input Y Range". Enter the V_{meas} cells (including the column label) for "Input X Range". Check the "Labels" box. Select "Output Range" and enter the cell directed on the spreadsheet. Press OK.



8. For multiple linear regression, follow Step 8a except enter the V_{meas} and the V_{meas}*Stage columns into "Input X Range."



9. The equation coefficients are generated in the output analysis. These are used to calibrate the SonTek unit.

	A	B	C	D	E	F	G	H	I	J
26	***Linear Regression with Vsl as only independent variable:***									
27										
28		SUMMARY OUTPUT								
29										
30		*Regression Statistics*								
31		Multiple R	0.995947624							
32		R Square	0.99191167							
33		Adjusted R Squar	0.991012967							
34		Standard Error	0.024003569							
35		Observations	11							
36										
37		ANOVA								
38			*df*	*SS*	*MS*	*F*	*Significance F*			
39		Regression	1	0.635928504	0.635928504	1103.714252	9.99048E-11			
40		Residual	9	0.005185542	0.000576171					
41		Total	10	0.641114046						
42										
43			*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
44	$V_{intercept}$ -->	Intercept	0.052864307	0.019826912	2.666290504	0.025778677	0.008012682	0.097715931	0.00801268	0.09771593
45	V_{slope} -->	SonTek Vel	0.8296684	0.024973317	33.22219517	9.99048E-11	0.77317479	0.88616201	0.77317479	0.88616201
46										
47	***Linear Regression with Vsl and Vsl*Depth as independent variables:***									
48										
49		SUMMARY OUTPUT								
50										
51		*Regression Statistics*								
52		Multiple R	0.995952307							
53		R Square	0.991920938							
54		Adjusted R Squar	0.989901247							
55		Standard Error	0.025444945							
56		Observations	11							
57										
58		ANOVA								
59			*df*	*SS*	*MS*	*F*	*Significance F*			
60		Regression	2	0.635934485	0.317967242	491.1106463	4.26021E-09			
61		Residual	8	0.005179562	0.000647445					
62		Total	10	0.641114046						
63										
64			*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
65	$V_{intercept}$ -->	Intercept	0.050668278	0.031045948	1.632041616	0.141315068	-0.020923851	0.122260408	-0.02092385	0.12226041
66	V_{slope} -->	SonTek Vel	0.847978791	0.192351594	4.408483302	0.002260981	0.404414933	1.291542649	0.40441493	1.29154265
67	StageCoef -->	Vmeas*Stage	-0.001927787	0.020058789	-0.096106852	0.92579963	-0.048183468	0.044327894	-0.04818347	0.04432789

Current Meter Data / Plot Vindex / Sheet3

ATTACHMENT E
FLOW RATE INDEXING PROCEDURE DISTRICT REPORTS

E-1: Colorado River Indian Tribes (CRIT) QIP

IRRIGATION TRAINING AND RESEARCH CENTER
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TECHNICAL MEMORANDUM

Date: 28 March 2003

To: Dr. Stuart Styles, Director ITRC

From: Beau Freeman, Senior Engineer ITRC

Subject: Index Velocity Rating Procedure for the CRIT Main Canal

Enclosed for your review is a summary of the Index Velocity Rating Procedure using 8 datasets collected in the CRIT Main Canal.

The measured stage, computed mean channel velocity determined by current meter, and the SonTek measured velocity are summarized in **Table 1.**

Table 1. CRIT Main Canal Current Meter and SonTek Velocity Measurements

No.	Stage, feet	Current Meter Velocity, fps	SonTek Velocity, fps
1	11.80	1.19	1.29
2	12.20	1.19	1.39
3	11.30	2.05	2.08
4	11.30	1.97	2.09
5	11.80	3.00	2.95
6	11.80	2.97	3.06
7	10.50	1.48	1.42
8	10.50	1.47	1.42

An index velocity rating can be developed to relate the mean channel velocity to the velocity measured by the SonTek. Multiple measurements over a range of low, medium, and high flows are required to develop a proper index velocity rating. The mean channel velocity is defined here as the measured discharge using the current meter divided by the computed channel area (using a stage-area rating). The average stage during the measurement period is recorded. The SonTek velocity measurements are averaged during the same measurement period. The result is a dataset comprised of i) a mean velocity, ii) average SonTek velocity, and iii) average stage.

If the relation between the mean channel velocity and SonTek velocity is linear, it can be represented by a linear equation as follows:

$$V_m = xV_{SL} + C$$

where,

V_m = computed mean velocity
V_{SL} = average velocity measured by the SonTek during one measurement period
x = velocity coefficient
C = constant

The first step in determining whether a linear relation exists is to plot mean velocity (y-axis) and SonTek velocity (x-axis). **Figure 1** is a graph of the velocity dataset for the CRIT Main Canal.

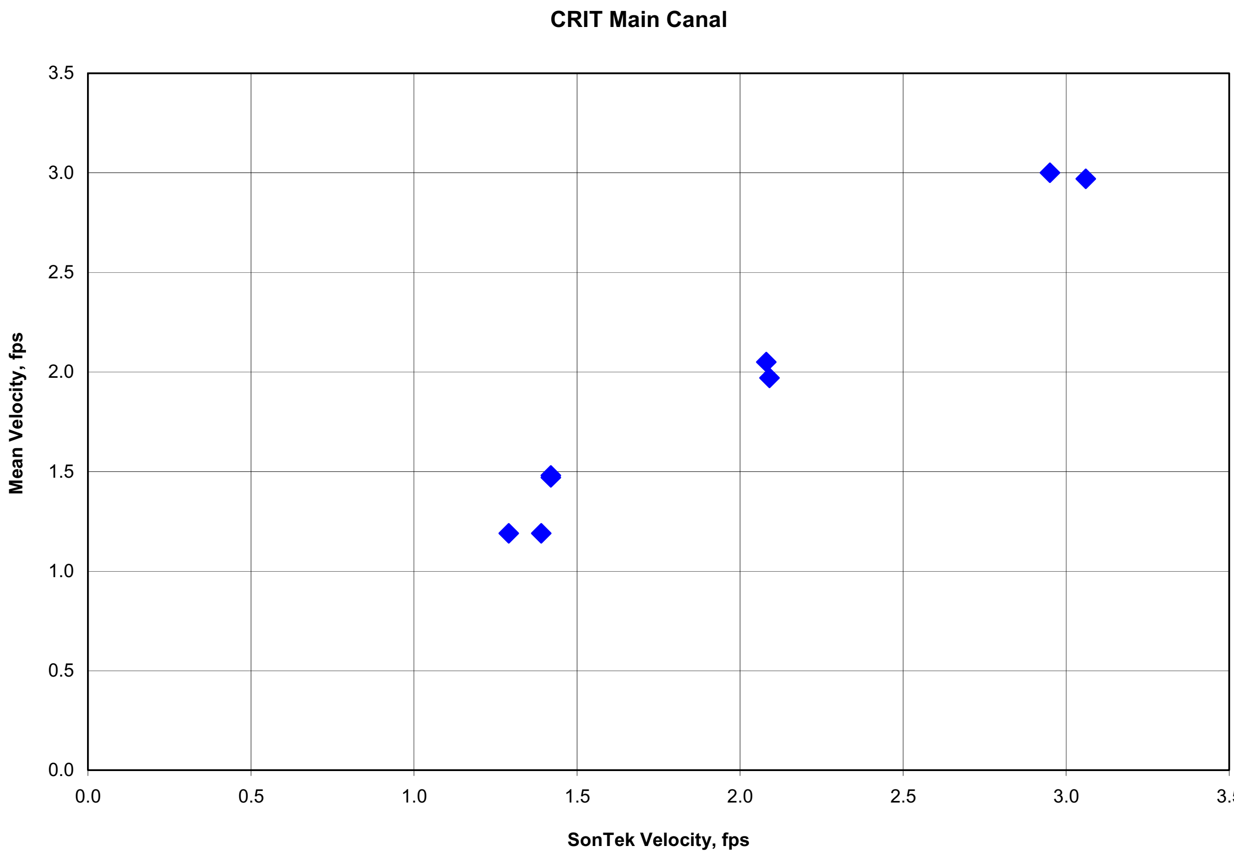

Figure 1. Mean velocity and SonTek velocity from discharge measurements in the CRIT Main Canal

The next step is to derive the linear equation and compute the coefficient of determination (r^2). The r^2 value indicates what percentage of the variation in mean velocity can be explained by the variation of SonTek velocity.

A simple method for determining the equation coefficient and constant along with the r^2 value is the linear regression tool in Excel® spreadsheets.

The linear index velocity rating equation determined for the CRIT Main canal dataset in **Table 1** is shown below:

$$\mathbf{V_m = 1.015V_{SL} - 0.077}$$

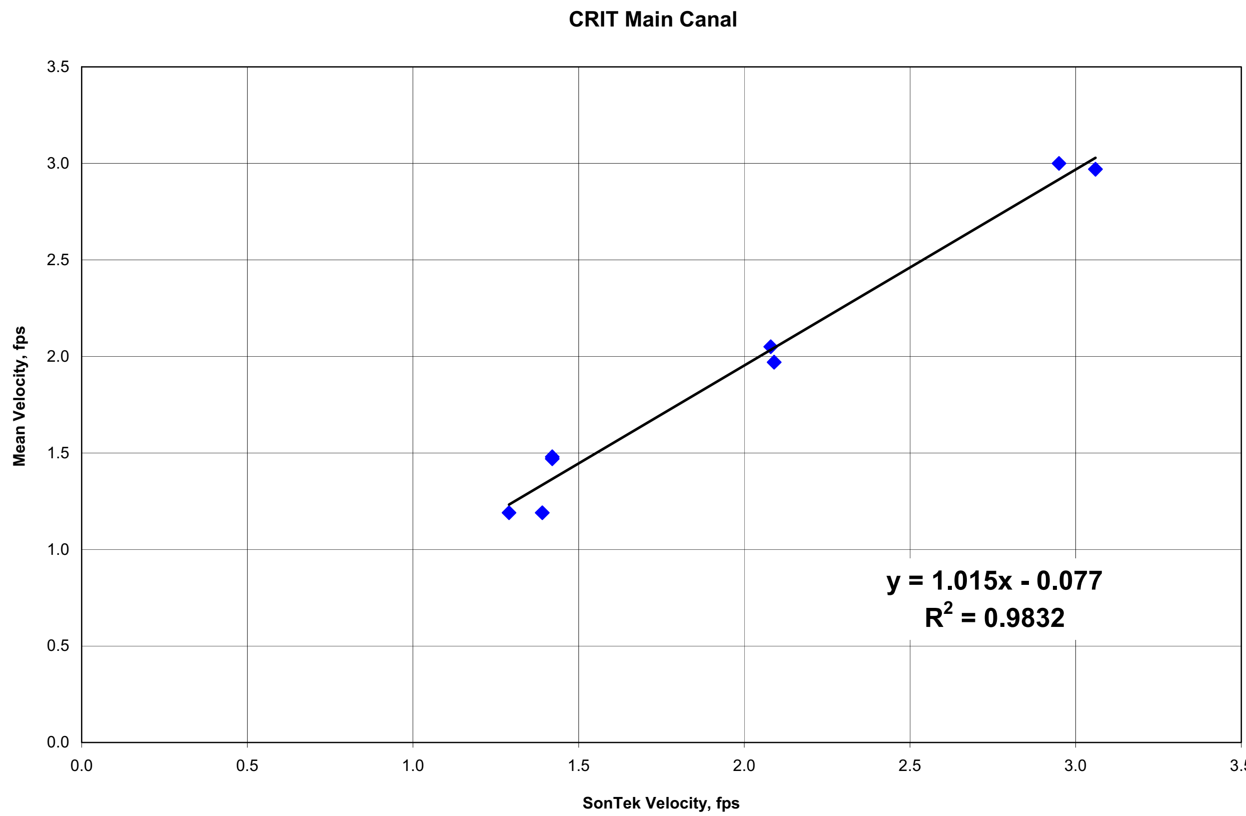

Figure 2. Index velocity rating using simple linear equation

The r^2 value of 0.98 indicates that 98 percent of the variation in the mean velocity can be explained by the variation in the SonTek velocity.

The above analysis assumes that the SonTek velocity is the only parameter to consider when determining the index velocity rating. However depending on the site conditions, stage may be a significant factor in the prediction of mean channel velocity using the SonTek instrument.

An equation that relates both the SonTek velocity and stage to mean velocity is:

$$V_m = V_{SL}(x + yH) + C$$

where,

V_m = computed mean velocity
V_{SL} = average velocity measured by the SonTek during one measurement period
x = velocity coefficient
y = stage coefficient
H = stage
C = constant

Using multiple regression analysis, the equation and r^2 value determined for the CRIT Main Canal dataset in **Table 1** assuming that stage is a factor is:

$$V_m = V_{SL}(1.995 - 0.080H) - 0.192$$
$$r^2 = 0.99$$

Figure 3 shows the relation between the mean velocity and the computed index velocity using multiple regression.

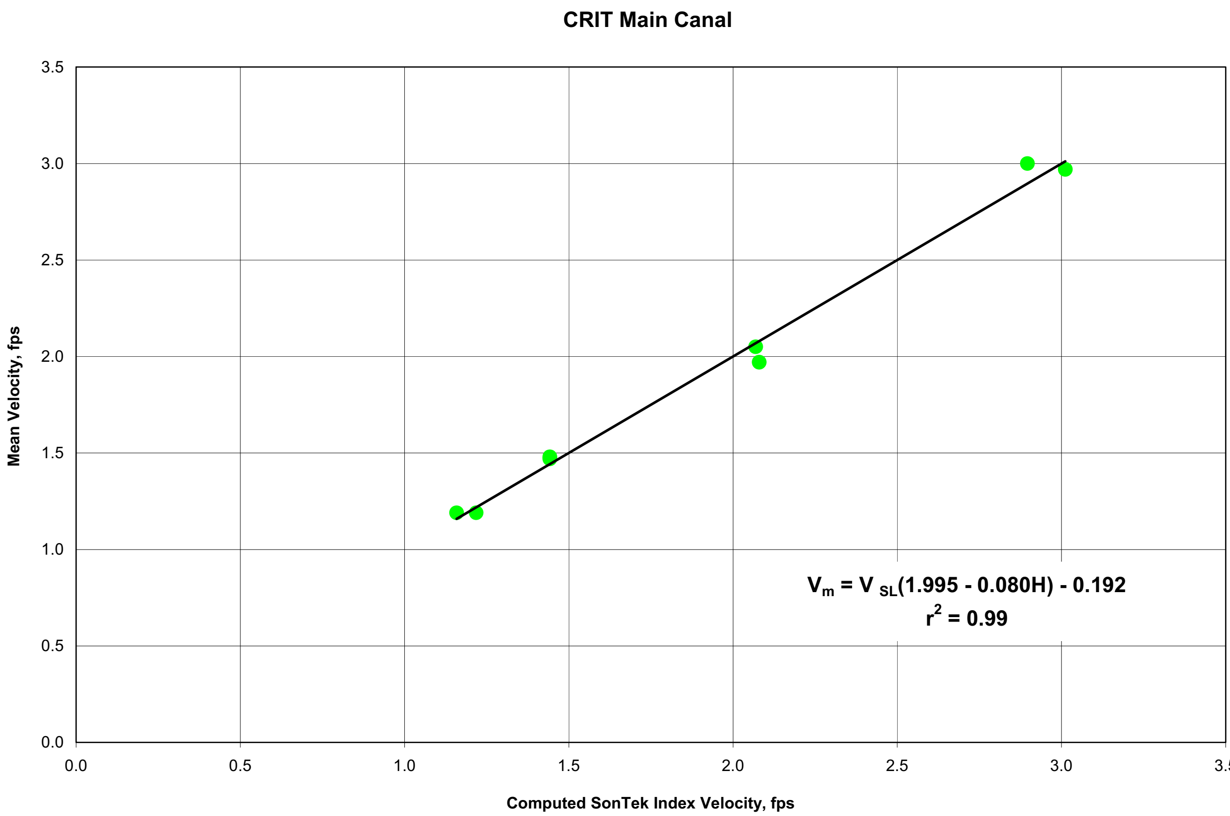

Figure 3. Index velocity rating using multiple regression equation

Table 2 summarizes the computed discharge using both index velocity equations and the percent error relative to the current meter measurements. The flow rate (Q = VA) was computed using the index velocity and channel area based on the measured stage and a bottom width of 25 ft and side slope of 1:1.

Table 2. Discharge (cfs) and percent error using simple linear regression and multiple regression with stage

No.	Current meter discharge, cfs	Simple linear equation no stage		Multiple regression with stage	
		cfs	% error	cfs	% error
1	514	535	4.1%	503	-2.1%
2	540	605	12.1%	553	2.4%
3	841	834	-0.8%	849	0.9%
4	805	839	4.2%	853	6.0%
5	1318	1267	-3.9%	1258	-4.6%
6	1304	1315	0.9%	1308	0.3%
7	562	509	-9.5%	538	-4.3%
8	547	509	-7.0%	538	-1.7%

The index velocity rating determined using the multiple regression analysis is generally closer to the discharge measured with a current meter. The average percent error in index velocity for the simple linear equation and the multiple regression equation is approximately ±5.3% and ±2.8%, respectively. In other words, the inclusion of stage as a factor in determining the index velocity rating improved the accuracy by about ±2.5%.

E-2: Contra Costa Water District Site Visit Report

Irrigation Training and Research Center
BioResource and Agricultural Engineering Department
California Polytechnic State University
San Luis Obispo, California 93407
Tel: (805) 756-2434 Fax: (805) 756-2433

Site Visit Report

Date: September 26, 2003

To: Stuart Styles, ITRC Director

From: Bryan Busch, Student Assistant Engineer

Subject: Contra Costa Water District, Flow Measurement
Site Visit Report: 9/3/03, 9/11/03, 6/14/04, 7/19/04, 8/5/04, 10/7/04, 5/25/05, and 9/1/05

A site visit was conducted to the Contra Costa Water District on multiple dates from September 2003 to September 2005. The purpose of the site visit was to install (temporarily) a SonTek acoustic Doppler current meter upstream of CCWD's Pumping Plant No. 2. The trip was coordinated with Jeff Quimby and Luke (electrical technician) from CCWD. Further site visits were conducted to download data and index the flow meter installed previously. This report includes descriptions and photographs of the installation, a comparison graph of the flow data collected, summary of indexing, and a rating curve of the canal section.

Contact Information

Contra Costa Water District - 1331 Concord Ave., Concord, CA 94524-2099.
Jeff Quimby, Assoc. Water Resources Specialist
Tel: 925.688.8310
Fax: 925.688.8122
email: jquimby@ccwater.com

SonTek at Pumping Plant No. 2

In order to perform an evaluation of the potential for the use of acoustic Doppler flow meters in conditions typical at CCWD, the SonTek unit was installed and operated upstream of CCWD's pumping plant No. 2. The SonTek unit will be recording data for approximately 3-4 months and data will be downloaded on a monthly basis. The data collected from the unit will be used to compare to the districts ultrasonic flow measurement unit for the same period. The ultrasonic unit is located directly downstream of the SonTek unit.

Photographs and descriptions of the installation of the unit are included in this report. Further information about the unit is available from the ITRC and the manufacturer.

SonTek Installation

The first step to install the current meter was to attach the unit to the angle adjusting mounting bracket and connect the sensor cable with the watertight plug. Second step was to mark and drill holes into the side of the canal for installation of anchors for the height adjusting mounting brackets. Then anchor the two height adjusting brackets to the canal with the concrete anchors. Once anchored the 2" galvanized pipe is lowered into the canal to the correct depth and secured with the 3/8" jam bolts. The sensor was manually adjusted with the turnbuckle to level, and the cross section and instrument elevation was recorded. Finally, the sensor cable was tied to the pipe and run to the battery/solar panel enclosure location.

The next procedure for this installation was the mounting of the battery/solar panel enclosure. A 2 ½-in galvanized pipe base was pounded into the ground, to anchor the 2" galvanized standpipe. The standpipe is inserted into the base and locked with a 5/8" pin and Master lock. The solar panel was attached to the standpipe using a sliding bracket with jam bolts for easy adjustment. A Nema 4, 20" x 24" locking box was secured to the standpipe and used to house the battery, solar panel regulator, and the sensor cable end. Power was given to the sensor, and the wires were tied to the standpipe to complete the setup.

Installation Photographs

These photographs were taken at CCWD, upstream of Pumping Plant No. 2.

Figure 1. Anchoring height adjusting brackets

Figure 2. Installation of the standpipe

Figure 3. Sensor mounting completed

Figure 4. Standpipe completed

Programming and Index-Rating

The last step of installation was to program the SonTek using the manufacture's software. The SonTek software is easy to use, and can be set up in less than 15 minutes. To program the unit to complete internal flow calculations a cross-section and index rating was completed. Further information about programming the SonTek is available from the ITRC and the manufacture.

A cross-section of the canal was obtained from CCWD, if this was a permanent installation the cross-section would have to be manually surveyed to insure accuracy. To develop a rating curve the channel must be current metered at ten different flow rates to develop a representative curve.

To develop a rating curve for the channel ITRC has acquired a SonTek RiverCAT that measures both cross-section and flow rate accurately. More information on the RiverCAT can be found at http://www.SonTek.com/product/rivercat/rivercat.htm. Figure 5 shows the SonTek RiverCAT.

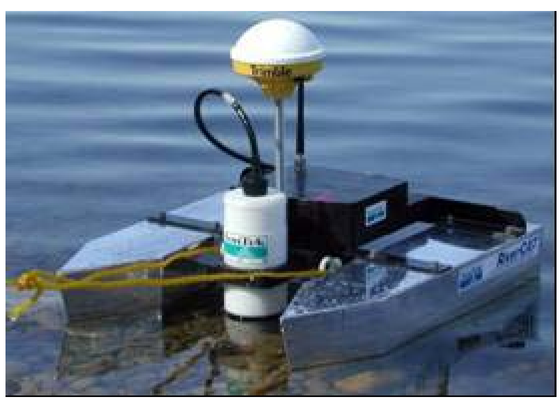

Figure 5. The SonTek RiverCAT can measure both cross-section and flow.

Data

Data was collected from the site and the unit was reset to continue taking data for the next month. After initial startup thee SonTek and CCWD flow meter were providing reasonable flow rate values. However, the discrepancies were attributed to not having an index-rating curve. Each of the flow measuring devices shows the same pattern of flow yet are off by a constant percent difference. Figure 6 shows a comparison of the three different flow-measuring devices in the canal.

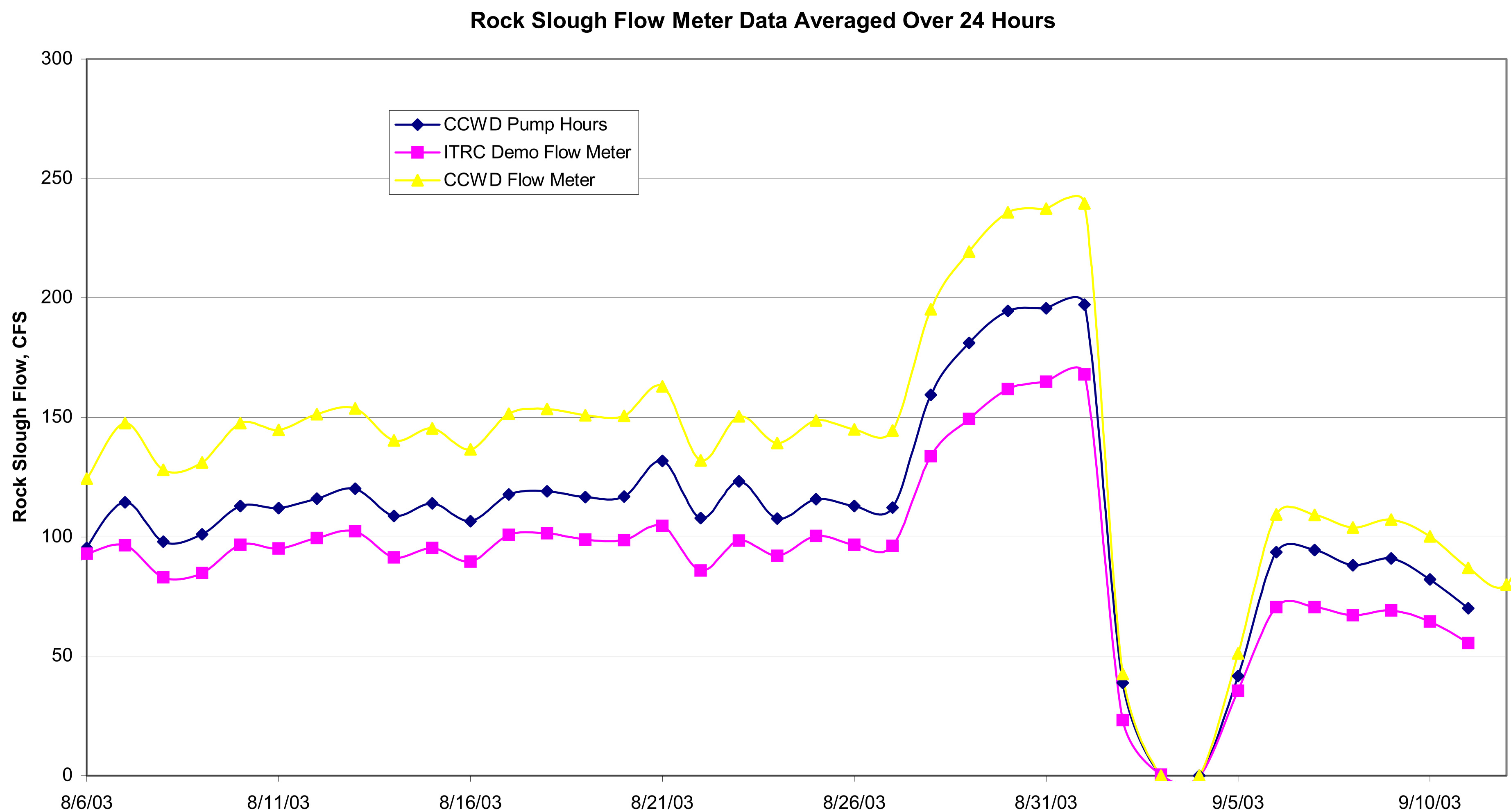

Figure 6. Flow rate comparison of demo ITRC SonTek SL unit with CCWD two methods of measuring flow.

Indexing

On July 19, 2004 to September 1, 2005 flow measurement were taken from acoustic Doppler boats. The flow measurements are used to make the SonTek SL meter more accurate for the whole range of flows. The ITRC's Calibration and indexing procedure was used to determine the single and multiple regression coefficients. Table 1 shows a summary of data from the indexing procedure and the single and multiple regression coefficients and their correlation.

Table 1. Summary of Indexing Procedure with % Error, and correlation calculations.

					Simple Regression			Multiple Regression		
	Date	Velocity * Stage	Velocity (ft/sec)	Calculated Ave Velocity (ft/sec)	Adjusted Velocity (ft/sec)	Adjusted Flow (cfs)	% Error in Flow Rate	Adjusted Velocity (ft/sec)	Adjusted Flow (cfs)	% Error in Flow Rate
1	7/19/2004	17.2044	2.360	1.880	1.914	224	1.77%	1.906	223	1.35%
2	8/5/2004	8.3172	1.160	0.921	0.960	109	4.21%	0.901	103	-2.17%
3	10/7/2004	0	0.007	0.007	0.043	6	517.40%*	0.007	1	3.33%
4	5/25/2005	9.1256	1.220	1.107	1.008	123	-8.95%	1.069	130	-3.43%
5	9/1/2005	2.373	0.300	0.286	0.276	37	-3.29%	0.318	42	11.33%

*Issues with the very low flow measurement caused the error to be very large. Because this is at the lowest flow rate it will not have a significant impact on the normal operation of the SonTek. This value was not included in the average error calculation.

	Single Regression				Multiple Regression		
	Vslope	Vint	Scoef		Vslope	Scoef	Vint
	0.7948	0.0379	0		-1.5501	0.3223	0.0182
	0.036830659	0.048003362			0.970120508	0.133322	0.030781
r^2 =	0.993598889	0.067903615		r^2 =	0.998368185	0.04199	

The average percent error for the raw SonTek data compared with the measured flow from the acoustic Doppler boat was +/-13.3%. After the indexing procedure was completed the average percent error dropped to +/-4.6% and +/-4.3% for the linear and multiple regression adjustments, respectively.

E-3: Lower Colorado River Authority (LCRA) Lake Plant Site – QIP

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TECHNICAL MEMORANDUM

Date: June 24, 2004

To: Matt Ables
Lower Colorado River Authority
3505 Montopolis Drive
Austin, TX 78744

From: Dr. Stuart Styles, ITRC Director; David Leinfelder, Student Engineer

Subject: Summary Results of the LCRA Lake Plant Site – Flow Rate Indexing Procedure

This memo summarizes the results of the flow rate indexing procedure (QIP) for the LCRA at the Lake Plant site. LCRA personnel collected the following information between April 3, 2002 and May 21, 2003, which was used for the index calculation:

Current meter measurement: mean velocity (fps) and water surface elevation (ft)
Average stage (ft) and computed area (ft^2)
Velocity (fps) and stage (ft) data from SonTek/YSI files

The newly developed QIP procedure (Styles et al. 2003) was used to relate the mean channel velocity to the velocity measured by the SonTek/YSI unit to develop the ultimate flow rate index for the site.

Summary

A simple linear canal index velocity rating and a multiple regression index velocity rating were developed for the LCRA Lake Plant site. The raw data produced a +/-9.9% error when comparing the flow rate measured by the SonTek to the standard current meter measured flow rate. The ITRC index ratings of the same data produced a +/-3.7% error in rated flow rate compared to the standard current meter measured flow rate with both the linear and multiple regression techniques.

Introduction

The objective of this document was to generate indexed velocities for the Lake Plant site of LCRA. The principle of the QIP procedure is to develop a regression equation or rating curve relating an index velocity and a sensor-measured velocity. This canal-based QIP was developed by Styles et al (2003). A series of flow measurements were collected at the LCRA Lake Plant site between April 3, 2002 and May 21, 2003. The stage, mean velocity, and sensor-measured velocity selected for the index velocity rating are presented in Table 1.

Table 1. LCRA Lake Plant site stage, and metered mean and SonTek velocity measurements

Date	Depth (ft)	Mean Velocity (fps)	Sensor Measured Velocity (fps)
4/3/2002	6.77	0.26	0.28
4/3/2002	6.91	0.41	0.41
4/4/2002	7.39	0.55	0.56
4/5/2002	7.26	0.56	0.58
4/23/2002	7.48	0.79	0.89
4/24/2002	8.02	0.87	0.97
4/26/2002	8.77	1.06	1.25
8/26/2002	7.65	0.45	0.52
8/27/2002	7.83	0.62	0.69
8/29/2002	7.61	0.74	0.85
5/21/2003	9.18	1.01	1.13

Results

The following index velocity ratings were generated from the calculated metered velocity and the SonTek measured velocity (Figure 1):
Simple linear regression relationship

$$V_m = 0.8297\ V_S + 0.0530 \qquad R^2 = 0.992$$

Multiple linear regression relationship

$$V_m = (0.8480 - 0.00193H)\ V_S + 0.0507 \qquad R^2 = 0.992$$

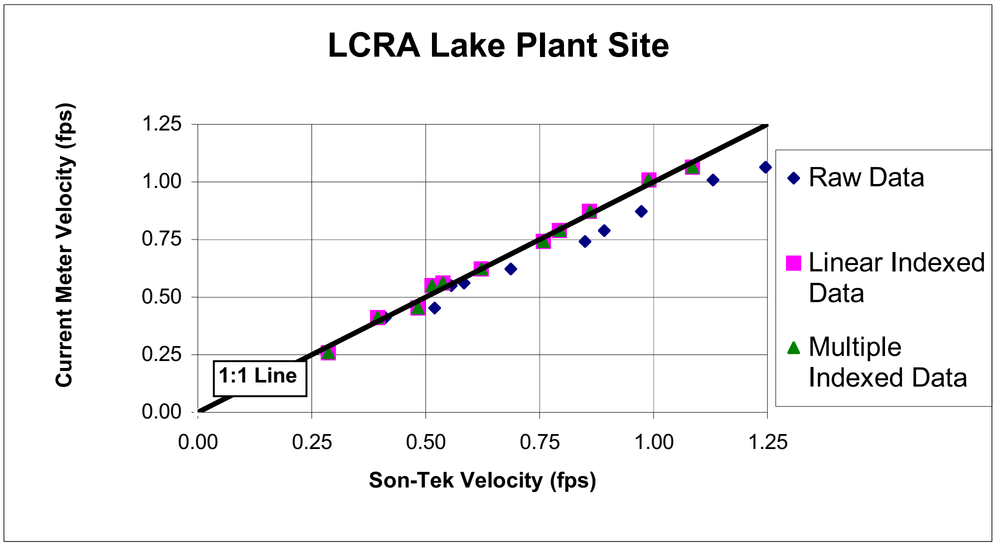

Figure 1. ITRC single and multiple linear regression analysis of the SonTek measured velocity and the metered mean velocity.

The addition of stage to the rating calculation did not increase the correlation coefficient (R^2) or the average error (+/-3.7%) between the standard current meter measured flow rate and SonTek measured flow rate.

Table 2 summarizes the computed error between the un-indexed sensor-measured discharges and the metered discharges. The percent error was calculated using the following relationship:

Percent Error = 100*[(Sensor Measured Discharge)-(Metered Discharge)]/[Metered Discharge]

Table 2. Calculated percent error of the Sensor-measured data without QIP correction.

Current Meter Discharge	W/O Correction Discharge, cfs	W/O Correction Error (%)
64	70	8.7%
105	105	0.3%
157	158	0.9%
155	162	4.4%
229	259	13.1%
283	316	11.6%
397	465	17.1%
136	156	14.9%
194	214	10.5%
221	254	14.8%
404	453	12.1%
Average		**9.9%**

Table 3 summarizes the computed discharge using both index velocity rating equations and the percent error relative to the metered discharge. The flow rate (Q=VA) was computed using the index velocity and the calculated area. The error in discharge was reduced from an average value of +/-9.9% to +/-3.7 % by using the index velocity rating. No significant improvement was observed using the multiple linear regression compared with the linear regression model.

Table 3. Discharge (cfs) and percent error using simple and multiple linear regression.

No.	Current Meter Measured Discharge (cfs)	Simple Linear Regression - No Stage		Multiple Linear Regression with Stage	
		Discharge (cfs)	Error (%)	Discharge (cfs)	Error (%)
1	64.2	71	10.54	70.8	10.27
2	105	101	-3.87	101	-3.91
3	157	146	-6.71	146	-6.70
4	155	149	-3.96	149	-3.91
5	229	230	0.58	231	0.74
6	283	279	-1.38	279	-1.31
7	397	405	2.11	405	2.06
8	136	146	7.06	145	6.98
9	194	194	0.17	194	0.17
10	221	226	2.40	227	2.53
11	404	397	-1.78	396	-1.93

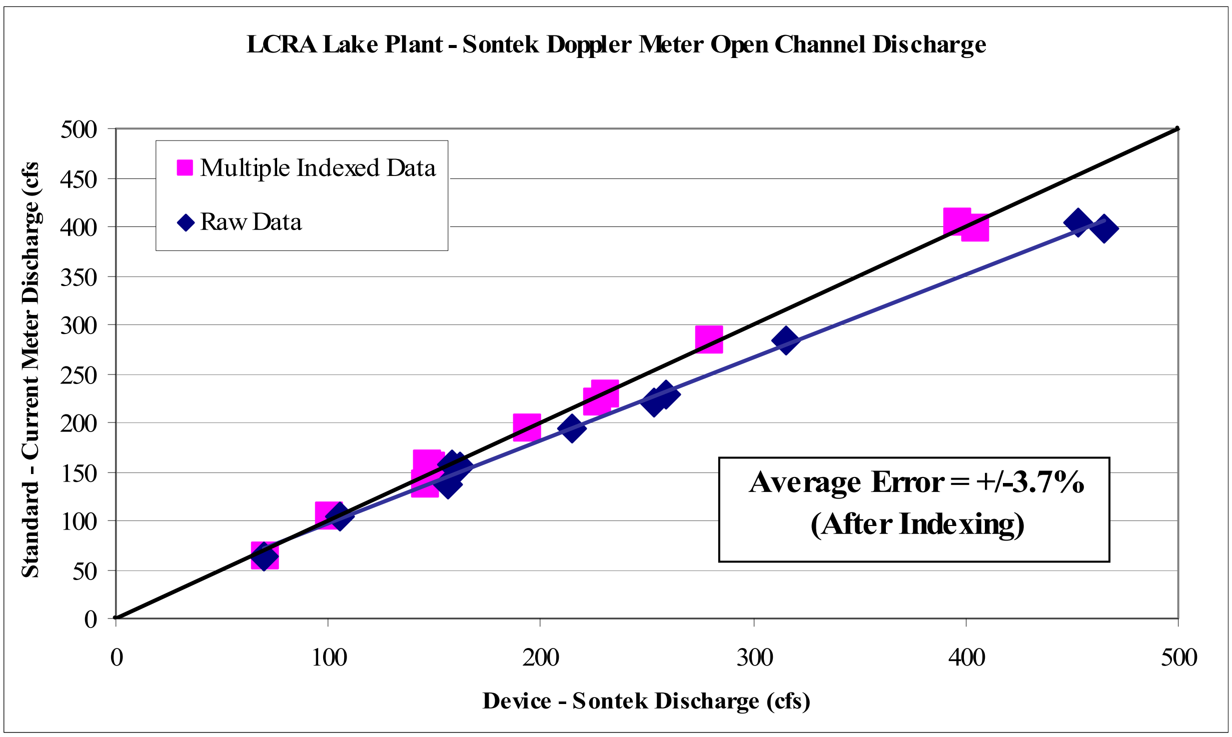

Figure 2. SonTek Indexed Discharge Error compared to Raw Data Error

Reference:

Styles, S., M. Niblack, and B. Freeman. 2003. Canal Velocity Indexing at Colorado River Indian Tribes (CRIT) Irrigation Project in Parker, Arizona using the SonTek Argonaut SL. ITRC Paper No. P 03-001. http://www.itrc.org/papers/crit/canalvelocity.pdf

Appendix 1
Measurements, Computed Areas, and Indexing Calculations

ITRC Index Velocity Rating - Lake Plant Site

CURRENT METER MEASUREMENTS

Date	A Computed Area	D Depth	Vm Mean Vel	Q Current Meter Q (cfs)	Q Sontek Measured Q (cfs)	Error % Q Linear In. to Current Meter	Vsl Son Tek Vel	Vsl*D Vel * Depth	Linear Vel Index	Multiple Vel Index
4/3/2002	247.29	6.77	0.26	64.2	69.8	8.7	0.28	1.91	0.29	0.29
4/3/2002	255.65	6.91	0.41	105	105.4	0.3	0.41	2.85	0.39	0.39
4/4/2002	284.87	7.39	0.55	157	158.4	0.9	0.56	4.11	0.51	0.51
4/5/2002	276.88	7.26	0.56	155	161.8	4.4	0.58	4.24	0.54	0.54
4/23/2002	290.44	7.48	0.79	229	259.1	13.1	0.89	6.67	0.79	0.79
4/24/2002	324.44	8.02	0.87	283	315.7	11.6	0.97	7.80	0.86	0.86
4/26/2002	373.24	8.77	1.06	397	464.8	17.1	1.25	10.92	1.09	1.09
8/26/2002	301.04	7.65	0.45	136	156.3	14.9	0.52	3.97	0.48	0.48
8/27/2002	312.36	7.83	0.62	194	214.3	10.5	0.69	5.37	0.62	0.62
8/29/2002	298.53	7.61	0.74	221	253.8	14.8	0.85	6.47	0.76	0.76
5/21/2003	400.65	9.18	1.01	404	452.7	12.1	1.13	10.37	0.99	0.99
					Avg Error %	**9.9**				

Linear Regression with Vsl as only independent variable:

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.995947624
R Square	0.99191167
Adjusted R Square	0.991012967
Standard Error	0.024003569
Observations	11

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.635928504	0.635928504	1103.714252	9.99048E-11
Residual	9	0.005185542	0.000576171		
Total	10	0.641114046			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Jpper 95.0%*
Intercept	0.052864307	0.019826912	2.666290504	0.025778677	0.008012682	0.097715931	0.008012682	0.097716
X Variable 1	0.8296684	0.024973317	33.22219517	9.99048E-11	0.77317479	0.88616201	0.77317479	0.886162

Linear Regression with Vsl and Vsl*Depth as independent variables:

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.995952307
R Square	0.991920998
Adjusted R Square	0.989901247
Standard Error	0.025444945
Observations	11

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	0.635934485	0.317967242	491.1106463	4.26021E-09
Residual	8	0.005179562	0.000647445		
Total	10	0.641114046			

E-4: Paradise Valley Irrigation District (PVID) - QIP

IRRIGATION TRAINING AND RESEARCH CENTER
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TECHNICAL MEMORANDUM

Date: June 28, 2004

To: Dr. Stuart Styles, ITRC Director

From: David Leinfelder, Student Engineer

Subject: Summary Results of the Montana USBR Paradise Valley ID HydroMet SonTek Calibration – Flow Rate Indexing Procedure

This memo summarizes the results of the flow rate indexing procedure (QIP) for the Paradise Valley ID HydroMet SonTek Calibration. Montana USBR personnel collected the following information between July 30, 2002 and August 20, 2003, which was used for the index calculation:

Current meter measurement: mean velocity (fps) and water surface elevation (ft)
Average stage (ft) and computed area (ft^2)
Velocity (fps) and stage (ft) data from SonTek/YSI files

The newly developed QIP procedure (Styles et al. 2003) was used to relate the mean channel velocity to the velocity measured by the SonTek/YSI unit to develop the ultimate flow rate index for the site.

Summary

A simple linear canal index velocity rating and a multiple regression index velocity rating were developed for the Montana USBR Paradise Valley Irrigation District site. The raw data produced +/-12.7% average error when comparing the flow rate measured by the SonTek to the standard current meter measured flow rate. The ITRC index ratings of the data recorded from this site produced a +/-6.62% and a +/-6.92% average error in rated flow rate compared to the standard current meter measured flow rate with the simple linear and multiple regression procedures, respectively. However, these results are an approximation because only eight flow rates were evaluated instead of ten as recommended by the QIP procedure.

Introduction

The objective of this document was to generate indexed velocities for the flow data at the Paradise Valley ID site recorded by the Montana USBR. The principle of the QIP procedure is to develop a regression equation or rating curve relating an index velocity and a sensor-measured velocity. This canal-based QIP was developed by Styles et al (2003). A series of flow measurements were collected at the Paradise Valley site between July 30, 2002 and August 20, 2003. The stage, mean velocity, and sensor-measured velocity selected for the index velocity rating are presented in Table 1.

Table 1. Paradise Valley HydroMet SonTek Calibration site stage, and metered mean and SonTek velocity measurements

Date	Depth (ft)	Mean Velocity (fps)	Sensor Measured Velocity (fps)
7/30/2002	3.75	1.23	1.14
5/30/2003	3.70	1.25	1.05
6/17/2003	2.65	0.87	0.75
6/24/2003	1.50	0.47	0.45
7/16/2003	4.00	1.02	0.88
7/22/2003	4.30	1.43	1.09
7/24/2003	4.14	1.27	1.08
8/20/2003	2.94	0.68	0.72

Results

The following index velocity ratings were generated from the calculated metered velocity and the SonTek measured velocity:

Simple linear regression relationship

$$V_m = 1.3404(V_S) - 0.1702 \qquad R^2 = 0.929 \text{ (ITRC)}$$

Multiple linear regression relationship

$$V_m = (0.4874 + 0.1457H)\, V_S + 0.1263 \qquad R^2 = 0.947 \text{ (ITRC)}$$

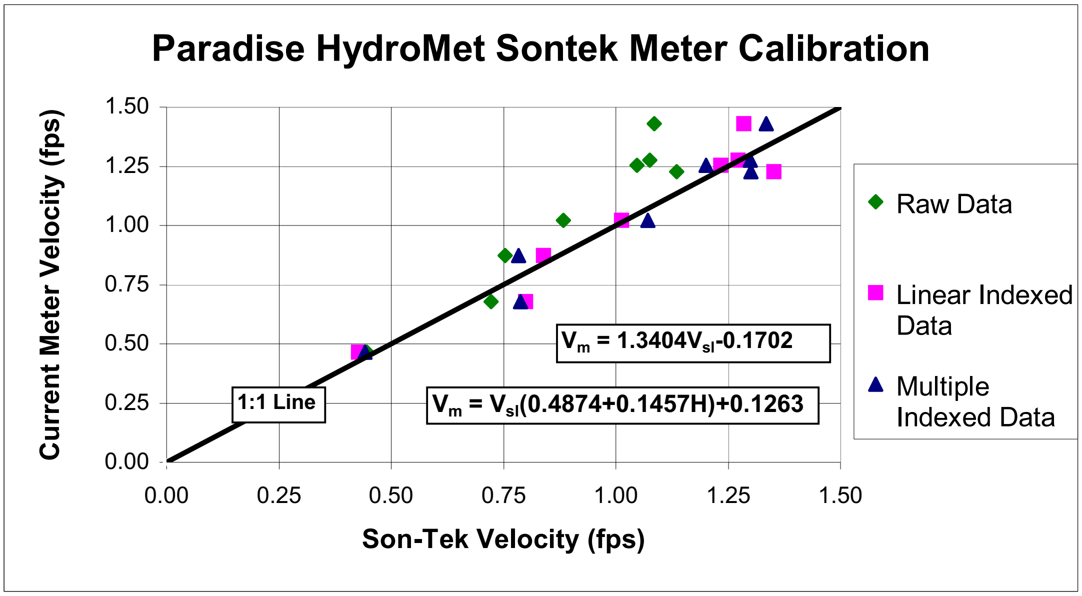

Figure 1. ITRC single and multiple linear regression analysis of the SonTek measured velocity and the metered mean velocity.

The addition of stage to the rating calculation increased the correlation coefficient (R^2) from 0.929 to 0.947. It also slightly increased the average error between the standard current meter measured flow rate and SonTek measured flow rate from +/-6.62% +/-6.92%. Both of these are obviously a huge improvement from +/-12.7% average error before indexing.

Table 2 summarizes the computed error between the un-indexed sensor-measured discharges and the metered discharges. The percent error was calculated using the following relationship:

Percent Error = 100*[(Sensor Measured Discharge)-(Metered Discharge)]/[Metered Discharge]

Table 2. Calculated percent error of the Sensor-measured data without QIP correction.

Current Meter Q (cfs)	SonTek Measured Q without correction (cfs)	SonTek to Current Meter Error (%)
162.15	150.14	-7.4
170.73	142.57	-16.5
95.67	82.61	-13.6
37.84	36.25	-4.2
148.15	128.01	-13.6
227.34	172.60	-24.1
189.44	159.90	-15.6
78.17	83.45	6.8
	Avg Error %	**+/-12.7%**

Table 3 summarizes the computed discharge using both index velocity rating equations and the percent error relative to the metered discharge. The flow rate (Q=VA) was computed using the index velocity and the calculated area. The error in discharge was reduced from an average value of –11.0% to 0.39% by using the multiple linear index velocity rating. No significant difference in error was observed using the simple linear regression.

Table 3. Discharge (cfs) and percent error using simple and multiple linear regression.

No.	Current Meter Measured Discharge (cfs)	Simple Linear Regression - No Stage		Multiple Linear Regression with Stage	
		Discharge (cfs)	Error (%)	Discharge (cfs)	Error (%)
1	162.2	179	10.24	171.9	6.01
2	171	168	-1.64	164	-4.21
3	96	92	-3.77	86	-10.09
4	38	35	-8.17	36	-5.22
5	148	147	-0.83	155	4.84
6	227	204	-10.14	212	-6.60
7	189	189	-0.21	193	1.96
8	78	92	17.98	91	16.42

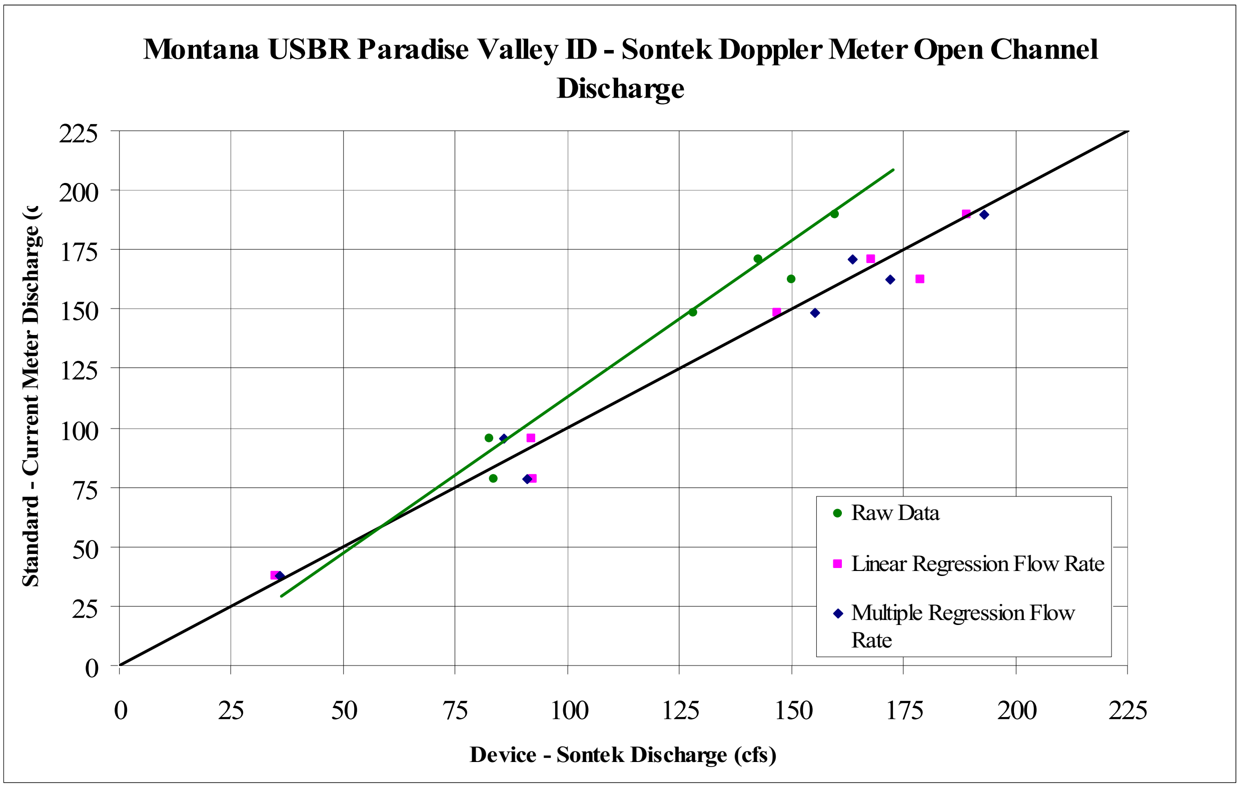

Figure 2. SonTek Indexed Discharge Error compared to Raw Data Error

Reference:

Styles, S., M. Niblack, and B. Freeman. 2003. Canal Velocity Indexing at Colorado River Indian Tribes (CRIT) Irrigation Project in Parker, Arizona using the SonTek Argonaut SL. ITRC Paper No. P 03-001. http://www.itrc.org/papers/crit/canalvelocity.pdf

Appendix 1

Measurements, Computed Areas, and Indexing Calculation

Montana USBR Flow Rate Indexing - Paradise HydroMet Sontek Calibration

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.95306
R Square	0.90831
Adjusted R Squa	0.87164
Standard Error	22.57221
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	25237.9641	12618.9820	24.7672	0.0025
Residual	5	2547.5233	509.5047		
Total	7	27785.4873			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-83.8177	32.9065	-2.5472	0.0514	-168.4063	0.7708	-168.4063	0.7708
Staff Gage (ft)	35.4172	23.1046	1.5329	0.1859	-23.9751	94.8094	-23.9751	94.8094
Sontek Meter Ve	115.3438	91.5617	1.2597	0.2634	-120.0226	350.7102	-120.0226	350.7102

Date	Discharge Measurement	Discharge Measurement Average Velocity (cfs)	Staff Gage (ft)	Sontek Meter Velocity (Vx)	Computed Discharge	Match	% Error
7/30/02	162.15	1.23	3.75	1.14	179.99	111%	11.0%
5/30/03	170.73	1.25	3.70	1.05	168.01	98%	-1.6%
6/17/03	95.66	0.87	2.65	0.75	96.88	101%	1.3%
6/24/03	37.84	0.47	1.50	0.45	20.72	55%	-45.2%
7/16/03	148.15	1.02	4.00	0.88	159.68	108%	7.8%
7/22/03	227.33	1.43	4.30	1.09	193.62	85%	-14.8%
7/24/03	189.44	1.27	4.14	1.08	186.89	99%	-1.4%
8/20/03	78.17	0.68	2.94	0.72	103.69	133%	32.6%

E-5: Tulare Irrigation District Site Visit Report

IRRIGATION TRAINING AND RESEARCH CENTER
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Site Visit Report

Date: September 28, 2005

To: Charles Burt, ITRC Chairman
Stuart Styles, ITRC Director

From: Bryan Busch, Irrigation Support Engineer, ITRC

Subject: Tulare Irrigation District at Rocky Ford
Flow Measurement Report

This report summarizes the flow measurement activities conducted at Tulare Irrigation District (TID), Rocky Ford. The following activities were performed at both the upstream and downstream sites:

1) Flow measurement using the SonTek and RDI boats
2) Flow measurement using the SonTek SL unit
3) Installation of a Telog PR-31 for water level measurement in stilling well
4) Installation of new firmware on SonTek SL unit
5) Calibration of the flow meters with new indexing constants

The primary purpose was to evaluate two SonTek Argonaut SL flow meters previously installed at the Rocky Ford site. Field data collection and site evaluations were done for calibration and developing index velocity ratings for the previously installed Acoustic Doppler flow meters. This report includes installation notes, photographs, calibration and indexing techniques, and SonTek flow data.

The SonTek SL flow meters were found to be working correctly. The flow meters were found to record a flow rate that is within ± 4.5% (multiple regression model) of the actual after the calibration procedure.

Contact Information

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Background

Tulare has installed two acoustic Doppler flow meters (SonTek SLs) at the Rocky Ford site. The meters needed to be calibrated and set up properly to record and transmit accurate flow data. The district is using a 4-20 mA converter to send a signal from the flow meter to a newly installed SCADA system to control Langemann gates on the Kaweah River. The signal travels ¼ mile through small 22-gauge wire. Power was also supplied from the SCADA site, through the same type of wire.

The SonTek units were not working when ITRC arrived to calibrate and set up the meters. The first problem found was that the unit was not getting power. The power supply is a 24 VDC battery, which was wired to the AC power input side. The polarity is not marked on the AC power side so the wires must have been switched. The AC power input side uses more power to regulate the voltage, so the unit was wired to the battery power input side.

Once the unit had power, it needed to be set up with a new deployment. The deployment software was run, and the meter started taking data on its internal recorder. **Appendix E** gives the SonTek SL setup program for future reference.

The next task was to set up the 4-20 mA converters. The converters are internally set to a channel that corresponds to the output of the SonTek and the wiring of the converters. The converters are not labeled on the outside of the unit, so the channel had to be checked with the computer program for each converter. Also, the converters had different settings that were set up at the factory and needed to be checked. Once the channel was determined and the settings were checked, the units could be wired according the SonTeks wiring diagram.

After wiring the converters, the SonTek had to be further programmed for current output using the SonUtils program. The SonTek SW Users Manual provides the codes for setting up a current output. During setup, a flow rate and water level output were selected for the two channels. The minimum and maximum values were set in the program.

After setting up the second site, the DC-to-DC converter the district was using as a power supply failed. The converter was removed, providing the SonTeks and converters with only 12 VDC. Once the converters were set up, the outputs were checked to verify the correct output signal.

When the converters were finally set up properly, the output signal was checked and the current was found to be jumping from 4 to 20 mA. This would not work for the SCADA system, so the problem was evaluated. The power was found to be dropping to 8 volts. Once a 12V battery was used as a power supply, the converter stopped jumping and stayed at the correct value. To prevent this from happening again, solar panels and batteries were installed at the two sites.

After installation of the solar panel at the U/S site it was found that the channel 1 converter was not working properly and would only output 4 mA. Since only one converter was working, the flow rate was the only value being given to the SCADA system at this time.

Both sites were programmed with a minimum flow of 0 cfs and maximum flow of 1122 cfs. The SonTek SLs output the depth as referenced above the meter so the minimum was set to 0 ft and the maximum to 9.6 ft:

- offset for the D/S meter is 1.234 ft
- offset for the U/S meter is 1.685 ft

The 4-20mA converter was replaced in the upstream site and a calibration was completed for each of the sites. **Appendix A** is a summary of the current conditions of the SonTek flow meters.

Site Calibration and Indexing

To determine an index velocity rating at a SonTek flow measurement site, concurrent mean channel velocity and SonTek SL measured stage and velocities are required. Each discharge measurement yields a computed mean channel velocity (actual velocity), measured stage, and measured Argonaut SL velocity. The procedure requires at least 10 measurement values over the entire range of flows. The result is a dataset comprised of:

1) Mean channel velocity
2) Measured SonTek SL velocity
3) Measured SonTek SL stage

Calibration started when the meters were first recording flow rate on the internal recorder. The values given by the SonTek SL are compared to the values of the ADCP boats (SonTek River Surveyor and the RDI Stream Pro). These are additional Acoustic Doppler devices mounted on a boat that measure velocity, depth, and distance traveled while being moved across the channel to calculate a accurate (within 5%) flow rate.

Appendix B contains the SonTek SL measured velocity and stage compared to the measured flow rate using the ADCP boats. The flow rate measured from the ADCP boat is converted to a mean channel velocity by dividing the flow rate by the SonTek SL computed cross sectional area. The procedure assumes the SonTek SL measured stage and resultant calculated area to be correct.

With data points covering most of the entire range of flows, an indexing equation is developed using multiple regression. The final indexing equation uses both the measured depth and velocity to determine the mean channel velocity of the canal. An equation that relates both the Argonaut SL velocity and stage to mean velocity is:

$$V_m = V_{SL}(x + yH) + C$$

where,

V_m = computed mean velocity
V_{SL} = average measured Argonaut SL velocity during one measurement period
x = velocity coefficient
y = stage coefficient
H = stage
C = constant

The values of the coefficients and constant in the index velocity equation can be determined from the multiple linear regression analysis where mean velocity is the dependent variable and the independent variables are the Argonaut SL measured velocity and the product of measured velocity and stage.

Appendix B also contains a summary table of the measured velocity and stage along with the product of measured velocity and stage and the actual mean channel velocity. Microsoft Excel is able to complete both single and multiple linear regressions to determine the best-fit coefficients in the index velocity equation. **Table 1** shows the coefficients found in Excel using single and multiple regression.

Table 1. Coefficients found in Excel

	Velocity Coefficient	Constant	Stage Coefficient
Rocky Ford Upstream Single Regression	0.840	0.525	---
Rocky Ford Upstream Multiple Regression	0.013	0.997	0.147
Rocky Ford Downstream Single Regression	1.040	0.033	---
Rocky Ford Downstream Multiple Regression	0.089	1.374	0.080

The summary table also includes a calculated average velocity for each point using both the single and multiple regression equations.

<u>Data Recorded</u>

The flow meters are working within there stated specifications. Data collected from June 30, 2005 to September 15, 2005 is shown in **Appendix C**. The data has been corrected to use the indexing coefficients used in the velocity indexing procedure. **Figures 1 & 2** show the relationship between the corrected SonTek measured flow rate and the actual flow rate.

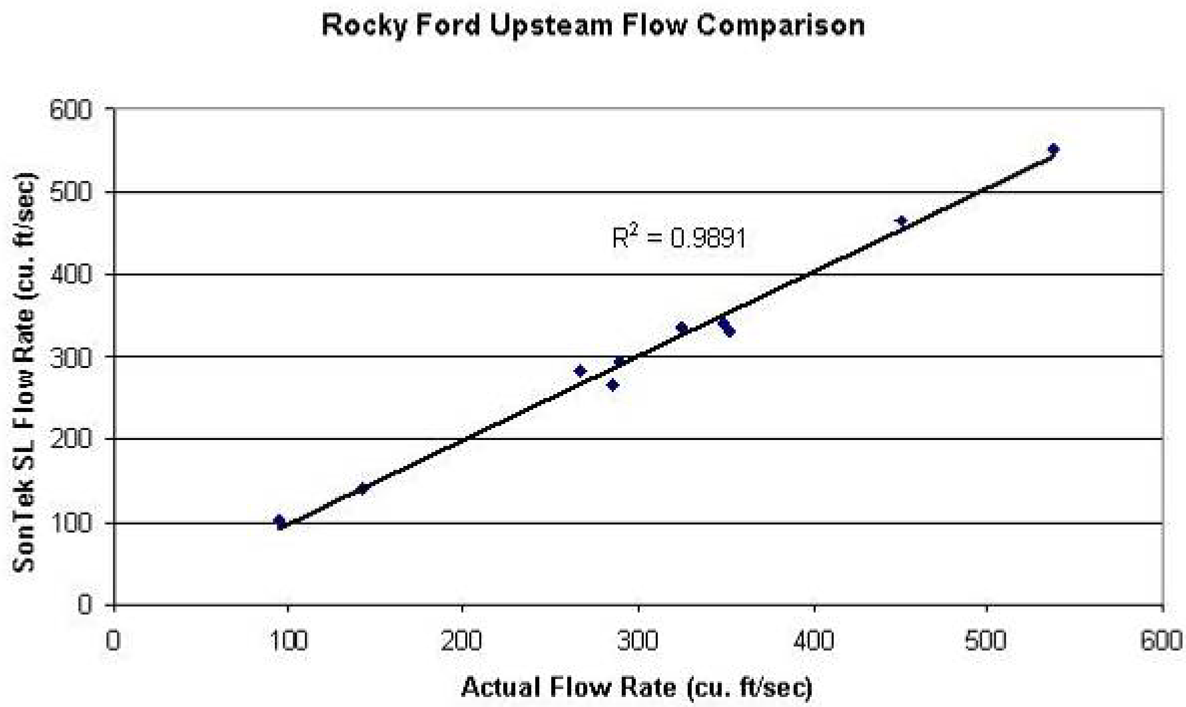


Figure 1. SonTek SL measured flow rate versus the actual flow rate at the upstream site

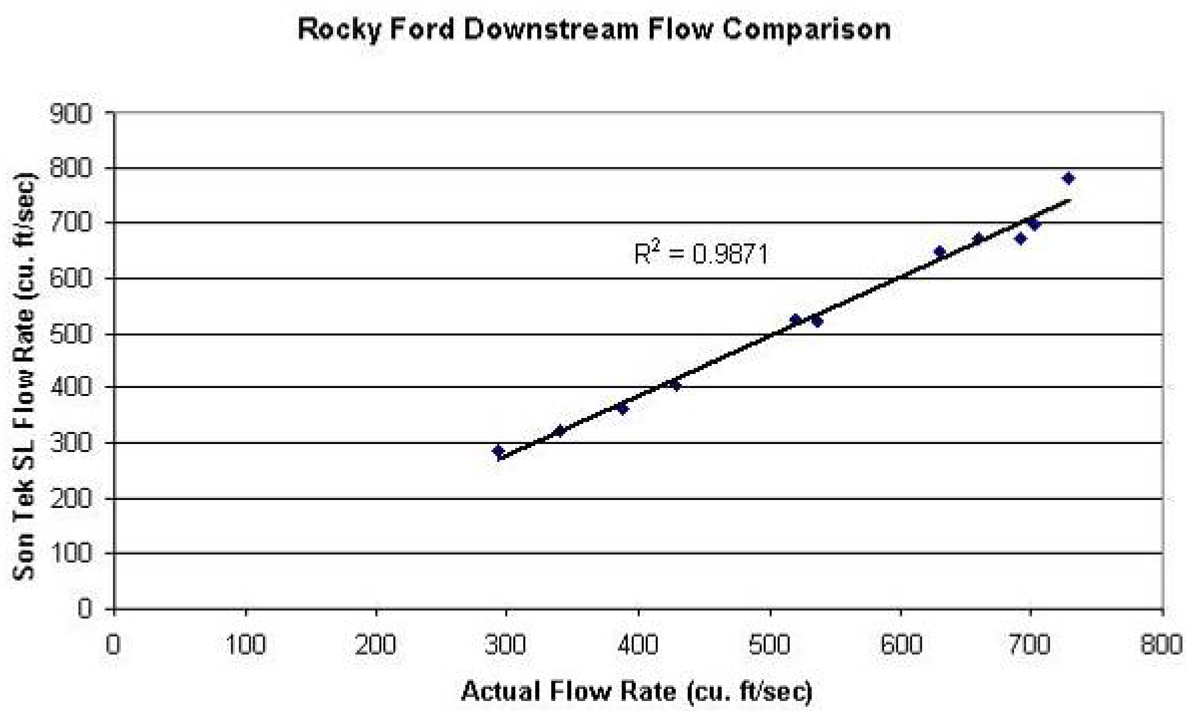


Figure 2. SonTek SL measured flow rate versus the actual flow rate at the downstream site

Rating Curves and Tables

The use of hydro-acoustic flow meters dramatically reduces the time required to generate a rating curve for a site by the ability to record many more data points for stage and discharge measurements in an autonomous installation. The data collected by the SonTek SL flow measurement units is graphed versus stage in Microsoft Excel. Data is evaluated using the trendline function to evaluate the equation. The equation is in the form of a power curve. The exponent should be between 0.3 and 0.7. The equation should be of the form:

$$H = KQ^x$$

where "x" is a value between 0.3 and 0.7

The regression coefficient (r^2) must be better than **0.96** to assure confidence in the results. This has been determined to provide the required +/-5% flow measurement accuracy of a rated site. If the data is less than 0.96, additional data points must be obtained. **Figures 3 & 4** show the rating curves for the two sites.

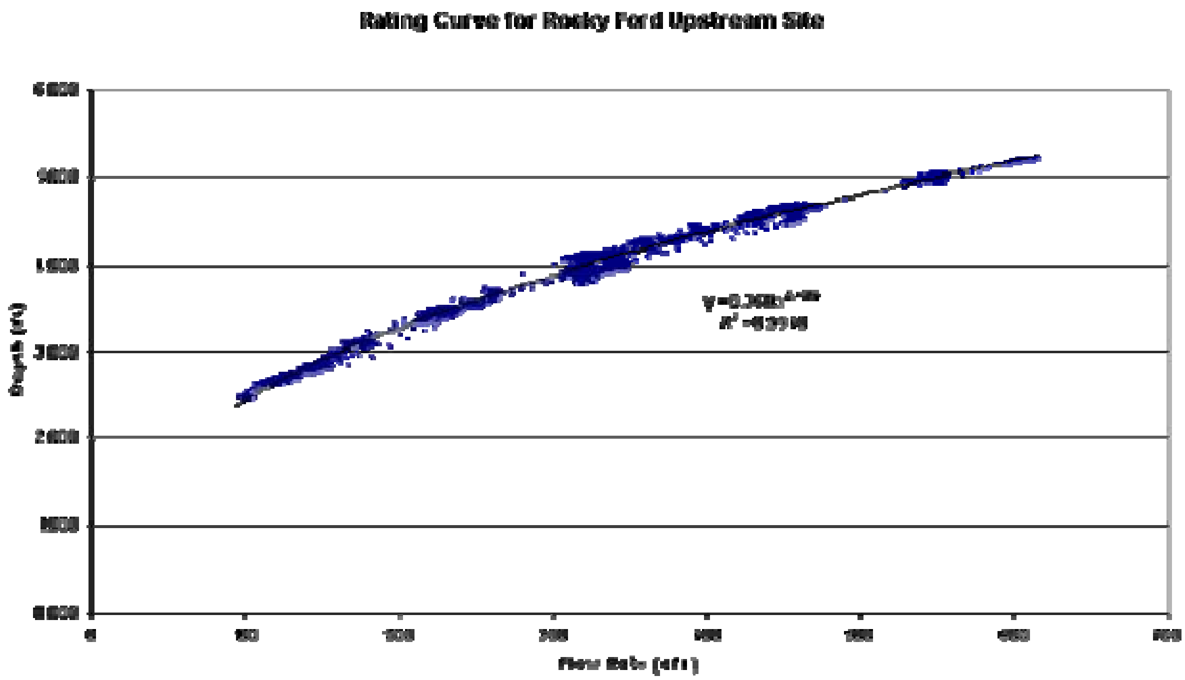


Figure 3. Rating curve for the Rocky Ford upstream site

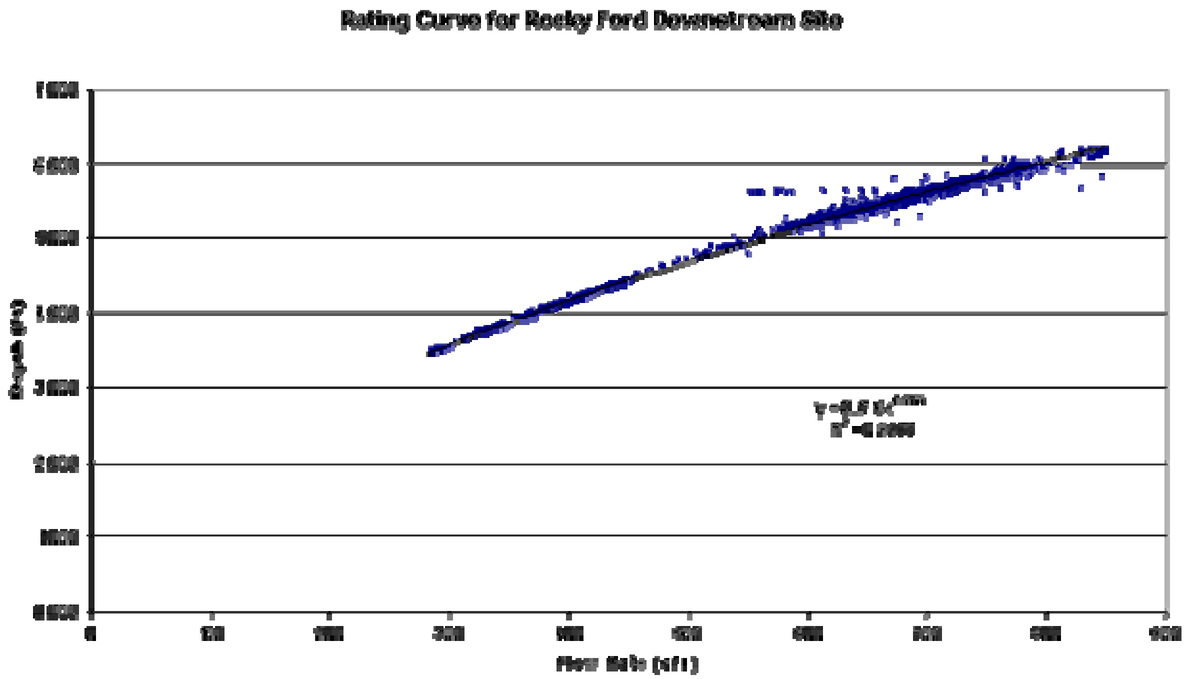


Figure 4. Rating curve for the Rocky Ford downstream site

Both sites have a regression coefficient of 0.99 which shows a very strong relationship between stage and flow rate. **Appendix D** gives rating tables and curves for each of the Rocky Ford sites. The equations found in Excel are:

Rocky Ford Upstream site: $y = 0.1716x^{0.5325}$ $r^2 = 0.9978$

Rocky Ford Downstream site: $y = 0.3514x^{0.4206}$ $r^2 = 0.9940$

Photographs

These photographs were taken on April 24, 2005, an example of a typical site visit.

Figure 5. Data is downloaded from the SonTek SL using a laptop computer

Figure 6. The SonTek SL needs to be cleaned regularly to avoid debris buildup

Figure 7. Using an RDI stream Pro to measure the flow rate at TID

Figure 8. Using the SonTek RiverCat to measure the flow rate at TID

SonTek for Flow Control

TID has not used the SonTek SL data for flow control for two reasons:

1. The SonTek data is accurate to within ± 5%, but the data will fluctuate within that accuracy over short periods of time. Since the SonTek data does not stay constant over short time periods, it causes the gate control to be unstable and constantly in motion. The control will attempt to adjust for the 5% change in flow rate by moving the gate and causing a wave that compounds the stability problem. The only way to avoid this problem is to set the dead band to ± 5% of the measured flow.

2. When a large change in flow rate is made, a slug/wave of water is sent down the channel, causing the SonTek SL to exaggerate the flow change until the channel reaches a steady state. This can take hours due to the length of the channel. The exaggerated flow changes will cause the gate to make big movements, compounding the instability. **Figure 9** shows a flow change and corresponding wave from the downstream site. The only way to avoid this problem is to lengthen the time step between gate movements.

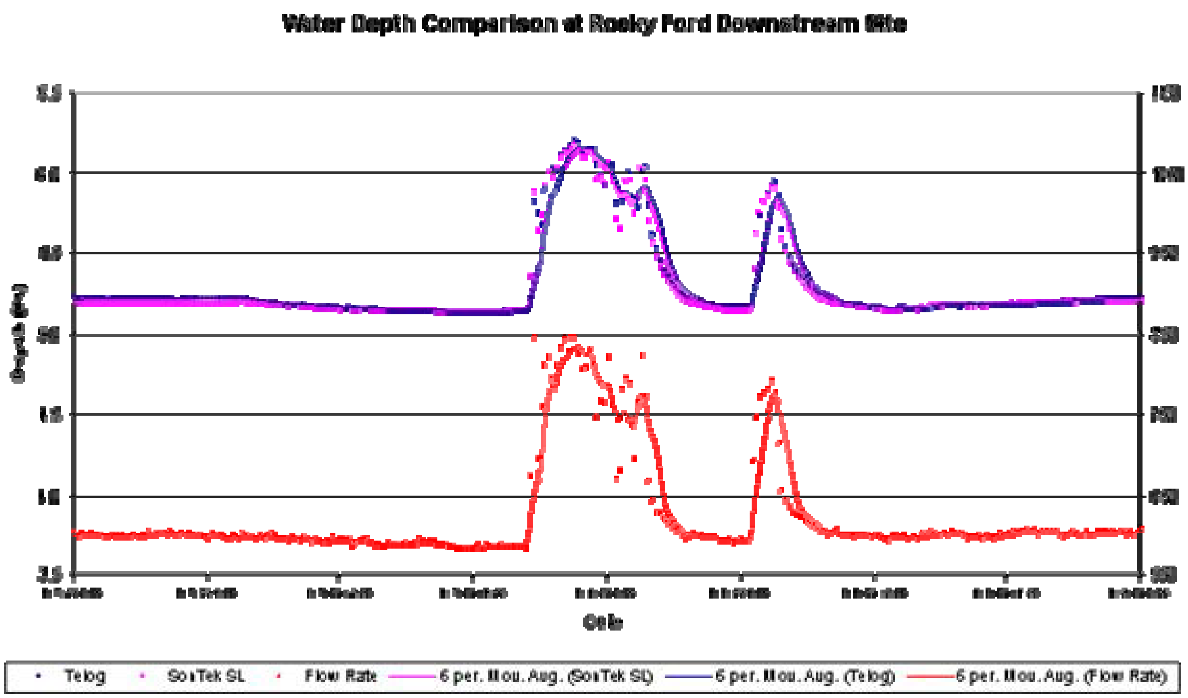


Figure 9. Gate movement causes exaggerated flow measurements

<u>Conclusion</u>

The index velocity rating determined using the multiple linear regression analysis is generally closer to the discharge measured using only single regression. The percent errors of the index velocity for the single regression equation and the multiple linear regression equation are approximately ±6.3% and ±4.5%, respectively for the upstream site. The inclusion of velocity and stage as a factor in determining the index velocity rating for this particular dataset improved the accuracy by about ±1.8%. It is recommended to always include stage in the development of an Index Velocity Rating Procedure. The final indexed coefficients can be readily programmed into the instrument for use with the internal flow computations option.

The SonTek SL flow data fluctuates within the stated ±4.5% accuracy over short periods of time causing problems for control. The SonTek SL may not work for flow control at these locations. A good rating curve was developed for each of the sites. The stage measurement is buffered using a stilling well and gives a stable flow rate for control.

Recommendations

Calibration – More calibrations should be done regularly to include the entire range of flows. The equation would be better if the maximum flow rate is included in the indexing procedure; the measured flow rates only went to a maximum of 730 cfs and the canal can go as high as 1,000 cfs. Also, further calibrations will determine if conditions at the site have changed over time.

SCADA – Use flow rate data from the depth and rating curves for the control at the sites; this will provide a stable number for flow rate. Use the flow rate data from the SonTek SL to double check the values.

Appendix A
Status of TID SonTek Meters

Status of SonTek Argonaut SL Meters at Rocky Ford

Kaweah River Power Authority –Peak Power Generation Project

Status – Upstream at Rocky Ford site (SonTek Argonaut SL)

SonTek is installed correctly, getting good values
SonTek is recording internally
SonTek is outputting correctly
Solar power is connected and working properly
Flow rate is being output through converter properly
Water level is being output through converter
ITRC installed an additional pressure transducer and Telog datalogger to check the recorded data from the SonTek

Settings

Minimum flow @ 4mA = 0 cfs wire labeled #3
Maximum flow @ 20mA = 1122 cfs

Minimum Level @ 4mA = 0 ft wire labeled #4
Maximum Level @ 20mA = 9.62 ft
Water Level Offset (add to level for depth) = 1.685 ft

Status - D/S at Rocky Ford site (SonTek Argonaut SL)

SonTek is installed correctly, getting good values
SonTek is recording internally
SonTek is outputting correctly
Solar power is connected and working properly
Flow rate is being output through converter properly
Water level is being output through converter properly
ITRC installed an additional pressure transducer and Telog datalogger to check the recorded data from the SonTek

Settings

Minimum flow @ 4mA = 0 cfs wire labeled #1
Maximum flow @ 20mA = 1122 cfs

Minimum Level @ 4mA = 0 ft wire labeled #2
Maximum Level @ 20mA = 9.62 ft
Water Level Offset (add to level for depth) = 1.234 ft

Appendix B
Calibration and Index Data

Rocky Ford Upstream Calibration

	A	B	C	D	E	F	G	H	I	J	K
1	TulareID Rocky Ford Upstream										
2			SonTek SL					Flow Meaurement Device			
3	Date	Time	Discharge (cfs)	Velocity (ft/sec)	Area (sq. ft)	Depth (ft)		Instrument	Transect	Discharge (cfs)	Calculated Velocity (ft/sec)
4	7/8//2004	17:43	355	1.483	240	5.881		RDI Boat	1	540	2.255
5		17:49	349	1.46	239	5.878		RDI Boat	2	570	2.380
6		17:55	372	1.552	240	5.885		RDI Boat	3	536	2.238
7		18:01	360	1.506	239	5.878		RDI Boat	4	532	2.222
8		18:07	349	1.457	239	5.878		RDI Boat	5	507	2.117
9		Average	**357**	**1.492**	**239**	**5.880**			Average	**537**	**2.242**
10											
11	7/9/2004	13:07	271	1.978	137	3.785		RDI Boat	1	268	1.994
12		13:10	269	1.978	136	3.765		RDI Boat	2	267	1.987
13		13:13	264	1.972	134	3.719		RDI Boat	3	265	1.972
14		13:16	262	1.975	133	3.69		RDI Boat	4	268	1.994
15		13:20	264	1.991	132	3.683		RDI Boat	5	269	2.002
16		Average	**266**	**1.979**	**134**	**3.728**			Average	**267**	**1.990**
17											
18	7/9/2004	13:44	262	1.975	132	3.686		SonTek Boat	1	312	2.343
19		13:47	263	1.978	133	3.693		SonTek Boat	2	287	2.155
20		13:49	263	1.975	133	3.696		SonTek Boat	3	257	1.930
21		13:52	264	1.978	133	3.703		SonTek Boat	4	265	1.990
22		13:54	265	1.988	133	3.706		SonTek Boat	5	258	1.938
23		13:56	264	1.975	134	3.709		SonTek Boat	6	278	2.088
24		13:58	264	1.978	133	3.706		SonTek Boat	7	306	2.298
25		14:01	269	2.011	134	3.709		SonTek Boat	8	282	2.118
26		Average	**264**	**1.982**	**133**	**3.701**			Average	**281**	**2.108**
27											
28	7/14/2004	10:28	277	2.031	136	3.772		RDI Boat	1	294	2.152
29		10:31						RDI Boat	2	293	2.144
30		10:34	278	2.031	137	3.785		RDI Boat	3	281	2.056
31		10:37						RDI Boat	4	292	2.137
32		Average	**278**	**2.031**	**137**	**3.779**			Average	**290**	**2.122**
33											
34	7/14/2004	11:01	280	2.037	137	3.795		SonTek Boat	1	281	2.044
35		11:03						SonTek Boat	2	272	1.979
36		11:05						SonTek Boat	3	281	2.044
37		11:07	284	2.064	138	3.798		SonTek Boat	4	292	2.124
38		11:09						SonTek Boat	5	285	2.073
39		Average	**282**	**2.051**	**137**	**3.797**			Average	**282**	**2.053**
40											
41	8/2/2004	16:41	301	1.975	152	4.116		RDI Boat	1	352	2.311
42		16:44	302	1.985	152	4.119		RDI Boat	2	349	2.291
43		16:46	309	2.031	152	4.119		RDI Boat	3	354	2.324
44		16:48	309	2.028	152	4.119		RDI Boat	4	339	2.225
45		16:51	304	1.998	152	4.119		RDI Boat	5	346	2.271
46		16:54	304	1.998	152	4.119		RDI Boat	6	352	2.311
47		16:57	307	2.018	152	4.119		RDI Boat	7	350	2.298
48		17:00	298	1.955	152	4.119		RDI Boat	8	352	2.311
49		Average	**304**	**1.999**	**152**	**4.119**			Average	**349**	**2.293**

Rocky Ford Upstream Calibration continued

	A	B	C	D	E	F	G	H	I	J	K
51	TulareID Rocky Ford Upstream										
52			SonTek SL					Flow Meaurement Device			
53	Date	Time	Discharge (cfs)	Velocity (ft/sec)	Area (sq. ft)	Depth (ft)		Instrument	Transect	Discharge (cfs)	Calculated Velocity (ft/sec)
54	8/2/2004	17:48	310	2.031	153	4.126		SonTek Boat	1	309	2.024
55		17:52	299	1.959	153	4.129		SonTek Boat	2	342	2.241
56		17:55	294	1.923	153	4.129		SonTek Boat	3	426	2.791
57		17:59	306	2.008	153	4.123		SonTek Boat	4	334	2.188
58		18:03	304	1.995	153	4.123		SonTek Boat	5	347	2.273
59		18:06	294	1.926	153	4.126		SonTek Boat	6	320	2.096
60		18:09	296	1.939	153	4.129		SonTek Boat	7	367	2.404
61		18:12	289	1.9	152	4.119		SonTek Boat	8	401	2.627
62		Average	**299**	**1.960**	**153**	**4.126**			Average	**356**	**2.331**
63											
64	8/3/2004	11:54	419	2.392	175	4.605		RDI Boat	1	461	2.629
65		11:57	423	2.411	175	4.605		RDI Boat	2	433	2.469
66		11:59	423	2.411	175	4.605		RDI Boat	3	456	2.600
67		12:02	418	2.385	175	4.605		RDI Boat	4	451	2.572
68		Average	**421**	**2.400**	**175**	**4.605**			Average	**450**	**2.568**
69											
70	5/24/2005	15:23	244	1.834	133	3.699		SonTekBoat	1	299.9	2.254
71		15:26	241	1.814	133	3.699		SonTekBoat	2	278.7	2.095
72		15:28	245	1.844	133	3.699		SonTekBoat	3	279.8	2.103
73		15:32	243	1.827	133	3.696		SonTekBoat	4	286.9	2.157
74		Average	**243**	**1.830**	**133**	**3.698**			Average	**286**	**2.152**
75											
76	5/24/2005	15:54	243	1.827	133	3.699		RDI Boat	1	289.8	2.178
77		15:57	240	1.801	133	3.699		RDI Boat	2	286.4	2.153
78		16:00	240	1.804	133	3.699		RDI Boat	3	280.1	2.105
79		16:03	236	1.778	133	3.696		RDI Boat	4	283.5	2.131
80		Average	**240**	**1.803**	**133**	**3.698**			Average	**285**	**2.142**
81											
82	6/30/2005	18:01	313	2.096	149	4.054		RDI Boat	1		
83		18:06	306	2.051	149	4.051		RDI Boat	2		
84		18:11	303	2.034	149	4.051		RDI Boat	3	329.8	2.210
85		18:16	309	2.073	149	4.054		RDI Boat	4	320.7	2.149
86		Average	**308**	**2.064**	**149**	**4.053**			Average	**325**	**2.180**
87											
88	7/29/2005	14:02	292	1.932	151	4.093		RDI Boat	1	349.8	2.316
89		14:05	289	1.913	151	4.09		RDI Boat	2	357.1	2.364
90		14:08	290	1.923	151	4.09		RDI Boat	3	342.8	2.269
91		14:11	295	1.952	151	4.093		RDI Boat	4	359	2.377
92		Average	**292**	**1.930**	**151**	**4.092**			Average	**352**	**2.332**
93											
94	8/30/2005	13:54	106	1.129	94	2.814		RDI Boat	1	147.6	1.566
95		14:04	107	1.138	94	2.814		RDI Boat	2	140.1	1.486
96		14:14	111	1.175	94	2.81		RDI Boat	3	137.5	1.459
97		14:24	112	1.184	94	2.81		RDI Boat	4	145.6	1.545
98		Average	**109**	**1.157**	**94**	**2.812**			Average	**143**	**1.514**

Rocky Ford Upstream Calibration continued

	A	B	C	D	E	F	G	H	I	J	K
100	TulareID Rocky Ford Upstream										
101			SonTek SL					Flow Meaurement Device			
102	Date	Time	Discharge (cfs)	Velocity (ft/sec)	Area (sq. ft)	Depth (ft)		Instrument	Transect	Discharge (cfs)	Calculated Velocity (ft/sec)
103	9/15/2005	12:17	65	0.853	77	2.387		RDI Boat	1	96.5	1.259
104		12:27	72	0.938	77	2.387		RDI Boat	2	92	1.200
105		12:37	68	0.889	77	2.39		RDI Boat	3	95.2	1.242
106		12:47	68	0.889	77	2.387		RDI Boat	4	97.5	1.272
107		12:57	67	0.873	77	2.39		RDI Boat	5	93.7	1.222
108		Average	**68**	**0.888**	**76.658**	**2.388**			Average	**95**	**1.234**

Rocky Ford Upstream Indexing

TulareID Rocky Ford Upstream												
		SonTek SL			Boat		Single Regression			Multiple Regression		
Date	Actual Flow (cfs)	Depth (ft)	Velocity ft/sec)	V*D (sq ft/sec)	Actual Velocity (ft/sec)	% difference	Calculated Velocity (ft/sec)	% difference		Calculated Velocity (ft/sec)	% difference	
7/8/2004*	537	5.880	1.492	8.771	2.242	-40.22%	1.782	-22.87%		2.412	7.31%	
7/9/2004	267	3.728	1.979	7.378	1.990	-0.55%	2.183	9.25%		2.105	5.61%	
7/9/2004	281	3.701	1.982	7.336	2.108	-6.13%	2.186	3.63%		2.097	-0.50%	
7/14/2004	290	3.779	2.031	7.674	2.122	-4.40%	2.226	4.75%		2.149	1.23%	
7/14/2004	282	3.797	2.051	7.785	2.053	-0.12%	2.242	8.79%		2.165	5.32%	
8/2/2004	349	4.119	1.999	8.231	2.293	-13.71%	2.199	-4.18%		2.249	-1.91%	
8/2/2004	356	4.126	1.960	8.086	2.331	-17.27%	2.167	-7.26%		2.230	-4.43%	
8/3/2004	450	4.605	2.400	11.051	2.568	-6.76%	2.529	-1.53%		2.681	4.33%	
5/25/2005	286	3.698	1.830	6.767	2.152	-16.20%	2.060	-4.37%		2.020	-6.36%	
5/25/2005	285	3.698	1.803	6.666	2.142	-17.21%	2.038	-4.98%		2.006	-6.55%	
6/30/2005	325	4.053	2.064	8.362	2.180	-5.48%	2.252	3.27%		2.263	3.75%	
7/29/2005	352	4.092	1.930	7.897	2.332	-18.84%	2.143	-8.44%		2.201	-5.76%	
8/30/2005	143	2.812	1.157	3.252	1.514	-26.76%	1.507	-0.46%		1.505	-0.59%	
9/15/2005	95	2.388	0.888	2.122	1.234	-32.57%	1.286	4.16%		1.347	8.72%	
				Average	2.090	+/-14.73%	2.057	+/-6.28%		2.102	+/-4.46%	
				Standard Dev	0.340	9.96%	0.324	0.059		0.335	0.051	

Vslope	Vint		Scoef	Vslope	Vint
0.822	0.556		0.173	-0.138	1.102
0.095164596	0.179936092		0.075432333	0.426660037	0.283155586
0.871493173	0.131302147		0.91572749	0.111518787	

Rocky Ford Downstream Calibration

	A	B	C	D	E	F	G	H	I	J	K
1	TulareID Rocky Ford Downstream										
2			SonTek SL					Flow Meaurement Device			
3	Date	Time	Discharge (cfs)	Velocity (ft/sec)	Area (sq. ft)	Depth (ft)		Instrument	Transect	Discharge (cfs)	Calculated Velocity (ft/sec)
4	7/8/2004	16:02	569	2.723	209	5.128		RDI Boat	1	534	2.556
5			558	2.671	209	5.128		RDI Boat	2	542	2.595
6			568	2.72	209	5.132		RDI Boat	3	556	2.662
7		16:11	569	2.723	209	5.132		RDI Boat	4	515	2.465
8		Average	**566**	**2.709**	**209**	**5.130**			Average	**537**	**2.569**
9											
10	7/8/2004	14:13	569	2.723	209	5.128		SonTek Boat	1	544	2.602
11			558	2.671	209	5.128		SonTek Boat	2	532	2.544
12			568	2.72	209	5.132		SonTek Boat	3	563	2.692
13			569	2.723	209	5.132		SonTek Boat	4	533	2.549
14			570	2.723	209	5.135		SonTek Boat	5	466	2.229
15			563	2.694	209	5.135		SonTek Boat	6	526	2.515
16			562	2.684	209	5.138		SonTek Boat	7	473	2.262
17			570	2.723	209	5.138		SonTek Boat	8	579	2.769
18			572	2.733	209	5.138		SonTek Boat	9	524	2.506
19		15:13	569	2.717	209	5.138		SonTek Boat	10	513	2.453
20		Average	**567**	**2.711**	**209**	**5.134**			Average	**525**	**2.512**
21											
22	7/9/2004	12:21	360	2.323	155	3.993		RDI Boat	1	357	2.311
23			355	2.297	155	3.987		RDI Boat	2	337	2.182
24			363	2.352	154	3.983		RDI Boat	3	331	2.143
25			355	2.3	154	3.98		RDI Boat	4	341	2.208
26		12:35	360	2.333	154	3.977		RDI Boat	5	334	2.162
27		Average	**358**	**2.321**	**154**	**3.984**			Average	**340**	**2.201**
28											
29	7/9/2004	18:07	446	2.536	176	4.446		RDI Boat	1	427	2.427
30			442	2.513	176	4.449		RDI Boat	2	421	2.393
31			437	2.48	176	4.449		RDI Boat	3	427	2.427
32		18:23	436	2.48	176	4.443		RDI Boat	4	438	2.490
33		Average	**440**	**2.502**	**176**	**4.447**			Average	**428**	**2.435**
34											
35	7/9/2004	18:36	413	2.343	176	4.452		SonTek Boat	1	402	2.282
36			430	2.438	176	4.456		SonTek Boat	2	404	2.293
37			423	2.405	176	4.449		SonTek Boat	3	354	2.009
38			454	2.579	176	4.452		SonTek Boat	4	419	2.378
39			444	2.52	176	4.449		SonTek Boat	5	431	2.446
40		18:57	452	2.562	176	4.456		SonTek Boat	6	413	2.344
41		Average	**436**	**2.475**	**176**	**4.452**			Average	**404**	**2.292**
42											
43	7/14/2004	8:28	483	2.493	194	4.82		RDI Boat	1	516	2.665
44			481	2.484	194	4.817		RDI Boat	2	525	2.711
45			486	2.51	194	4.817		RDI Boat	3	509	2.628
46		8:39	479	2.47	194	4.82		RDI Boat	4	528	2.727
47		Average	**482**	**2.489**	**194**	**4.819**			Average	**520**	**2.683**

Rocky Ford Downstream Calibration continued

	A	B	C	D	E	F	G	H	I	J	K
49	TulareID Rocky Ford Downstream										
50			SonTek SL					Flow Meaurement Device			
51	Date	Time	Discharge (cfs)	Velocity (ft/sec)	Area (sq. ft)	Depth (ft)		Instrument	Transect	Discharge (cfs)	Calculated Velocity (ft/sec)
52	7/14/2004	9:09						SonTek Boat	1	542	2.761
53			480	2.474	194	4.823		SonTek Boat	2	492	2.507
54			481	2.48	194	4.826		SonTek Boat	3	560	2.853
55			531	2.703	196	4.876		SonTek Boat	4	460	2.344
56			556	2.769	201	4.964		SonTek Boat	5	461	2.349
57								SonTek Boat	6	561	2.858
58								SonTek Boat	7	557	2.838
59								SonTek Boat	8	508	2.588
60		9:23						SonTek Boat	9	515	2.624
61		Average	**512**	**2.607**	**196**	**4.872**			Average	**517**	**2.636**
62											
63	8/2/2004	13:40	598	2.697	222	5.391		RDI Boat	1	655	2.948
64			585	2.635	222	5.397		RDI Boat	2	614	2.764
65			576	2.595	222	5.394		RDI Boat	3	618	2.782
66			581	2.615	222	5.394		RDI Boat	4	631	2.840
67			585	2.631	222	5.397		RDI Boat	5	633	2.849
68			590	2.654	222	5.397		RDI Boat	6	619	2.786
69			580	2.608	222	5.401		RDI Boat	7	629	2.831
70		14:00	587	2.641	222	5.397		RDI Boat	8	642	2.890
71		Average	**585**	**2.635**	**222**	**5.396**			Average	**630**	**2.836**
72											
73	8/2/2004	14:52						SonTek Boat	1	635	2.836
74								SonTek Boat	2	664	2.965
75			590	2.641	224	5.424		SonTek Boat	3	676	3.019
76			592	2.644	224	5.43		SonTek Boat	4	586	2.617
77			589	2.628	224	5.433		SonTek Boat	5	693	3.095
78			597	2.661	224	5.437		SonTek Boat	6	520	2.322
79								SonTek Boat	7	539	2.407
80		15:25						SonTek Boat	8	637	2.845
81		Average	**592**	**2.644**	**224**	**5.431**			Average	**619**	**2.763**
82											
83	8/3/2004	11:02	670	2.671	251	5.955		RDI Boat	1	737	2.947
84			671	2.68	251	5.948		RDI Boat	2	733	2.931
85			652	2.612	250	5.932		RDI Boat	3	710	2.839
86		11:18	655	2.625	249	5.929		RDI Boat	4	734	2.935
87		Average	**662**	**2.647**	**250**	**5.941**			Average	**729**	**2.913**
88											
89	5/24/2005	9:10	594	2.707	219	5.342		RDI Boat	1	668	3.055
90			584	2.667	219	5.332		RDI Boat	2	665	3.041
91			567	2.595	219	5.325		RDI Boat	3	642	2.936
92			584	2.677	218	5.315		RDI Boat	4	714	3.265
93			579	2.651	218	5.322		RDI Boat	5	625.0	2.858
94		9:38	570	2.608	219	5.325		RDI Boat	6	646.0	2.954
95		Average	**580**	**2.651**	**219**	**5.327**			Average	**660**	**3.018**

Rocky Ford Downstream Calibration continued

	A	B	C	D	E	F	G	H	I	J	K
97	TulareID Rocky Ford Downstream										
98			SonTek SL					Flow Meaurement Device			
99	Date	Time	Discharge (cfs)	Velocity (ft/sec)	Area (sq. ft)	Depth (ft)		Instrument	Transect	Discharge (cfs)	Calculated Velocity (ft/sec)
100	5/24/2005	9:53	606	2.772	218	5.322		SonTek Boat	1	670	3.069
101			591	2.707	218	5.322		SonTek Boat	2	683	3.129
102			575	2.638	218	5.312		SonTek Boat	3	636	2.914
103			587	2.687	218	5.319		SonTek Boat	4	687	3.147
104		10:10	585	2.68	218	5.319		SonTek Boat	5	677	3.101
105		Average	**589**	**2.697**	**218**	**5.319**			Average	**671**	**3.072**
106											
107	6/30/2005	12:28	680	3.022	225	5.45		RDI Boat	1	715	3.181
108			681	3.031	225	5.447		RDI Boat	2	705	3.137
109			680	3.028	225	5.447		RDI Boat	3	705	3.137
110			681	3.031	225	5.447		RDI Boat	4	664	2.954
111		12:59						RDI Boat	5	672	2.990
112		Average	**681**	**3.028**	**225**	**5.448**			Average	**692**	**3.080**
113											
114	7/29/2005	15:05	680	2.936	232	5.584		RDI Boat	1	704	3.037
115			684	2.953	232	5.584		RDI Boat	2	682	2.942
116			691	2.979	232	5.588		RDI Boat	3	720	3.106
117		15:17	683	2.946	232	5.588		RDI Boat	4	705	3.041
118		Average	**685**	**2.954**	**232**	**5.586**			Average	**703**	**3.030**
119											
120	8/30/2005	9:13	397	2.536	156	4.026		RDI Boat	1	387	2.470
121			398	2.543	157	4.029		RDI Boat	2	396	2.527
122			397	2.53	157	4.042		RDI Boat	3	388	2.476
123		9:23						RDI Boat	4	382	2.438
124		Average	**397**	**2.536**	**157**	**4.032**			Average	**388**	**2.481**
125											
126	8/30/2005	9:35	397	2.526	157	4.042		SonTek Boat	1	345	2.192
127			403	2.559	157	4.049		SonTek Boat	2	357	2.268
128			397	2.52	158	4.052		SonTek Boat	3	345	2.192
129		9:45						SonTek Boat	4	353	2.243
130		Average	**399**	**2.535**	**157**	**4.048**			Average	**350**	**2.234**
131											
132	9/15/2005	13:38						RDI Boat	1	292	2.172
133			291	2.169	134	3.534		RDI Boat	2	295	2.194
134			295	2.195	134	3.534		RDI Boat	3	297	2.209
135			291	2.159	135	3.54		RDI Boat	4	291	2.164
136		13:51	290	2.152	135	3.54		RDI Boat	5	291	2.164
137		Average	**292**	**2.169**	**134**	**3.537**			Average	**293**	**2.183**

Rocky Ford Downstream Indexing

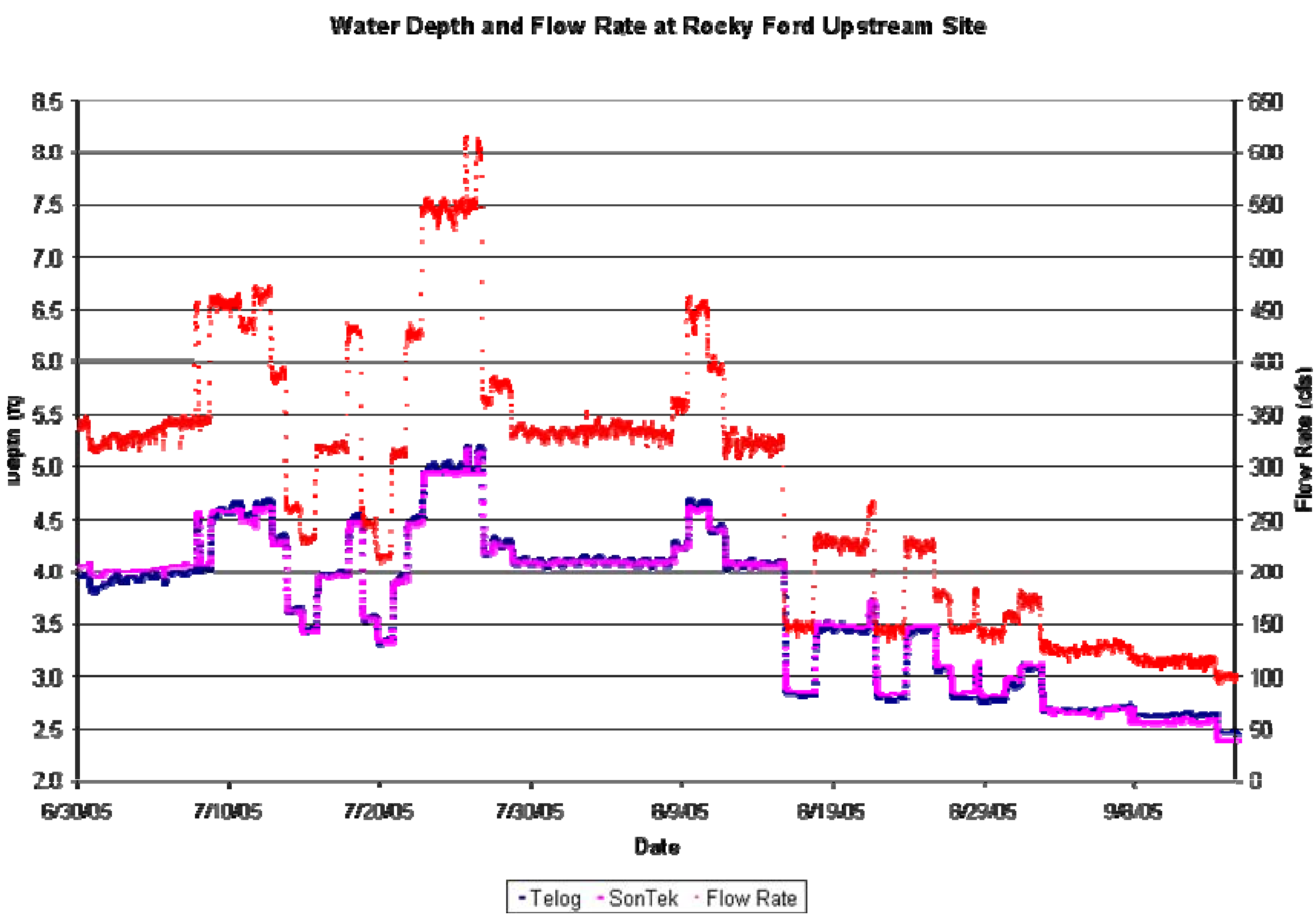
TulareID Rocky Ford Downstream										
		SonTek SL			Boat		Single Regression		Multiple Regression	
Date	Actual Flow (cfs)	Depth (ft)	Velocity ft/sec)	V*D (sq ft/sec)	Actual Velocity (ft/sec)	% difference (raw data)	Calculated Velocity (ft/sec)	% difference	Calculated Velocity (ft/sec)	% difference
7/8/2004	537	5.130	2.709	13.90	2.569	5.30%	2.769	7.48%	2.756	7.00%
7/8/2004	525	5.134	2.711	13.92	2.512	7.62%	2.771	9.81%	2.758	9.33%
7/9/2004	340	3.984	2.321	9.25	2.201	5.30%	2.295	4.16%	2.260	2.65%
7/9/2004	428	4.447	2.502	11.13	2.435	2.74%	2.516	3.30%	2.454	0.81%
7/9/2004	404	4.452	2.475	11.02	2.292	7.65%	2.482	7.96%	2.447	6.55%
7/14/2004	520	4.819	2.489	11.99	2.683	-7.48%	2.500	-7.04%	2.569	-4.34%
7/14/2004	517	4.872	2.607	12.70	2.636	-1.11%	2.644	0.30%	2.629	-0.26%
8/2/2004	630	5.396	2.635	14.22	2.836	-7.37%	2.678	-5.75%	2.816	-0.72%
8/2/2004	619	5.431	2.644	14.36	2.763	-4.42%	2.689	-2.73%	2.831	2.44%
8/3/2004	729	5.941	2.647	15.73	2.913	-9.55%	2.693	-7.83%	3.006	3.15%
5/24/2005	660	5.327	2.651	14.12	3.018	-12.95%	2.698	-11.20%	2.799	-7.52%
5/24/2005	671	5.319	2.697	14.34	3.072	-13.01%	2.754	-10.93%	2.816	-8.70%
6/30/2005	692	5.448	3.028	16.50	3.080	-1.69%	3.159	2.53%	3.006	-2.41%
7/29/2005	703	5.586	2.954	16.50	3.030	-2.56%	3.068	1.23%	3.026	-0.14%
8/30/2005	388	4.032	2.536	10.23	2.481	2.22%	2.558	3.07%	2.330	-6.24%
8/30/2005	350	4.048	2.535	10.26	2.234	12.60%	2.556	13.43%	2.335	4.40%
9/15/2005	293	3.537	2.169	7.67	2.183	-0.65%	2.109	-3.46%	2.098	-3.98%

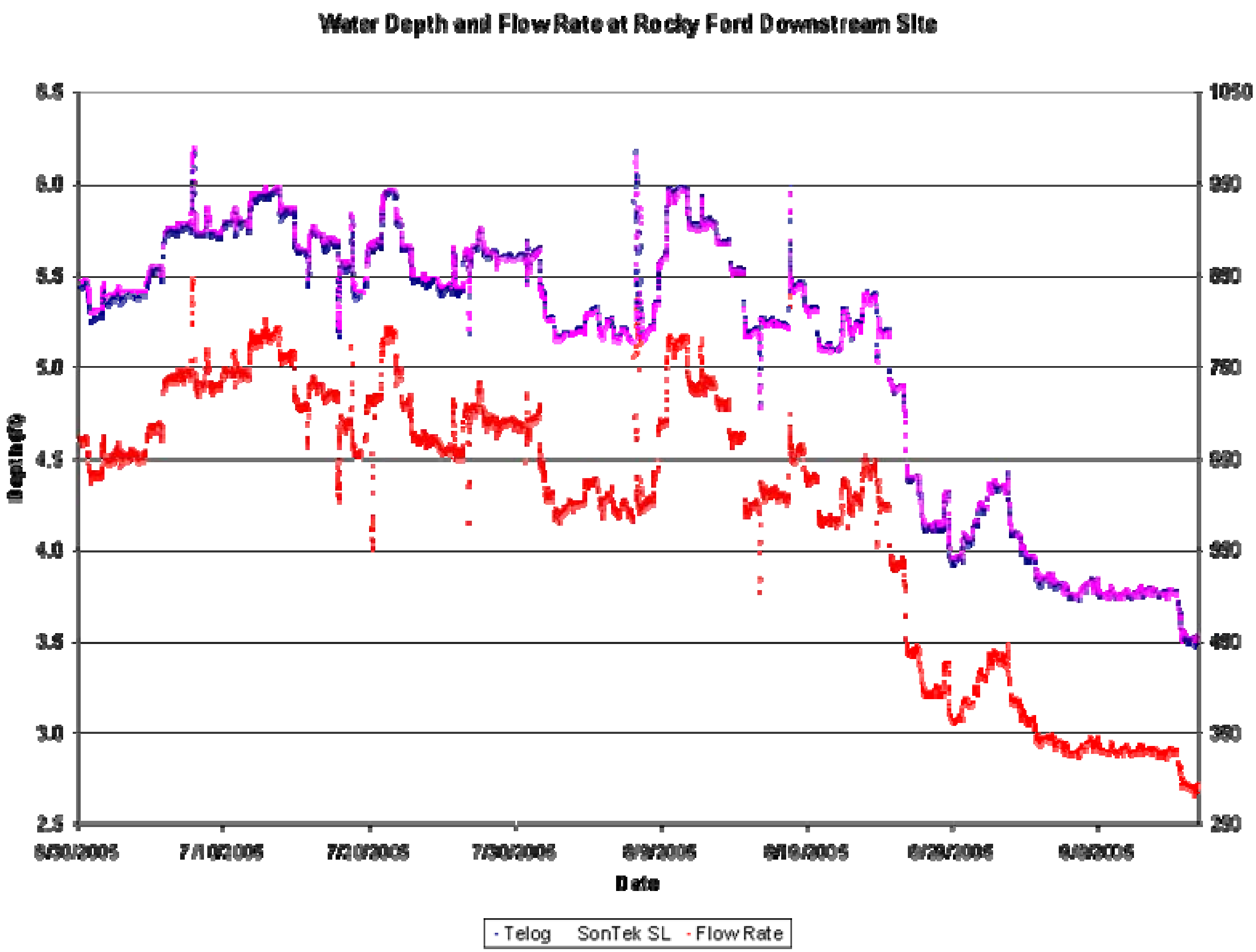
Average	2.643	6.13%	2.643	6.01%	2.643	4.16%
Standard dev	0.314	7.48%	0.248	7.28%	0.282	5.21%

Vslope	Vint	Vslope	Scoef	Vint
	-0.541	0.128	-0.257	1.673
0.245852821	0.642605039	0.035389512	0.447969321	0.77693330
0.622165725	0.199533907	0.804675372	0.148499894	

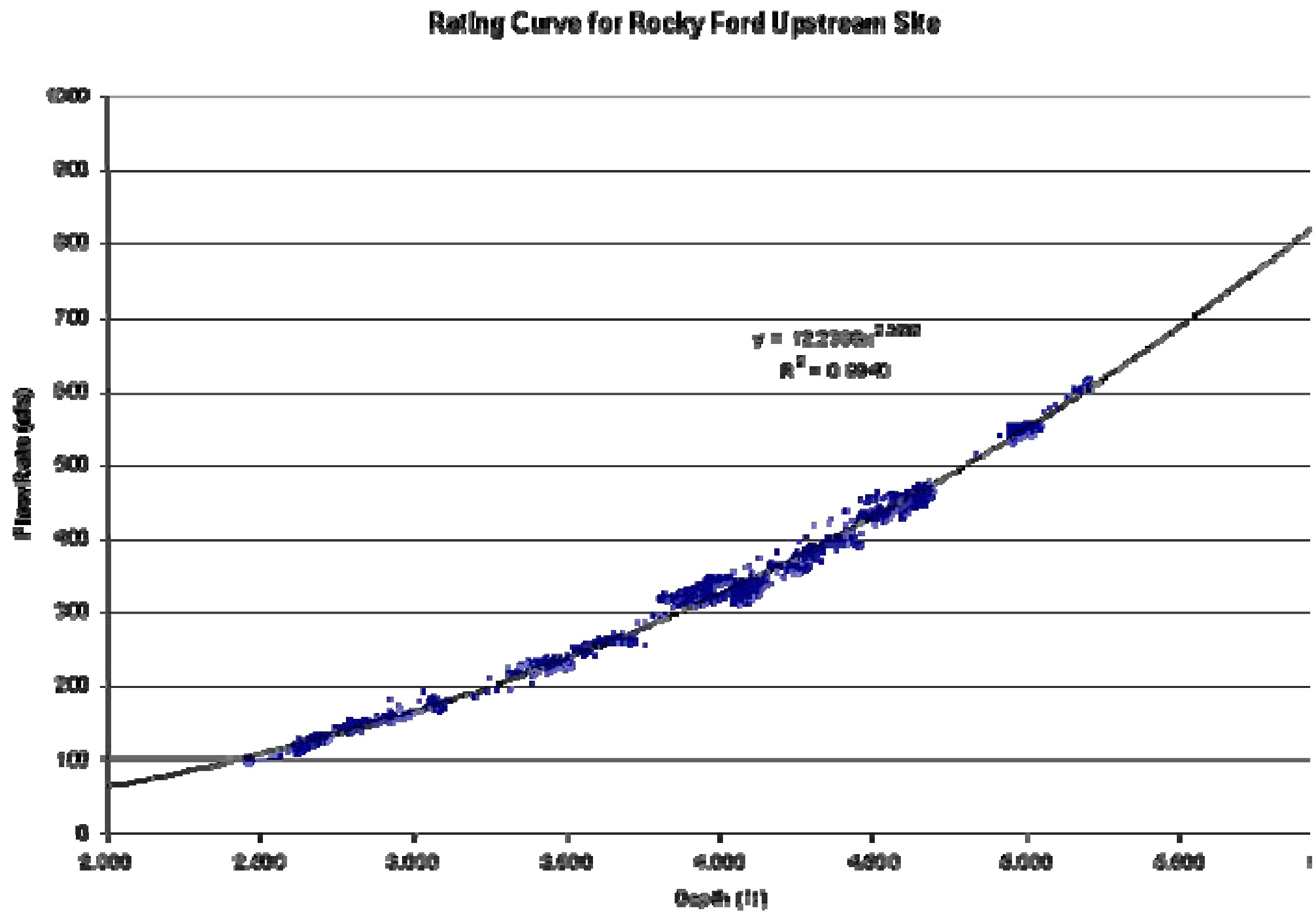
1.222

Appendix C
Corrected Data Graphs


Water Depth and Flow Rate at Rocky Ford Upstream Site
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
Depth (ft)
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Flow Rate (cfs)
6/30/05
7/10/05
7/20/05
7/30/05
8/9/05
8/19/05
8/29/05
9/8/05
Date
Telog
SonTek
Flow Rate

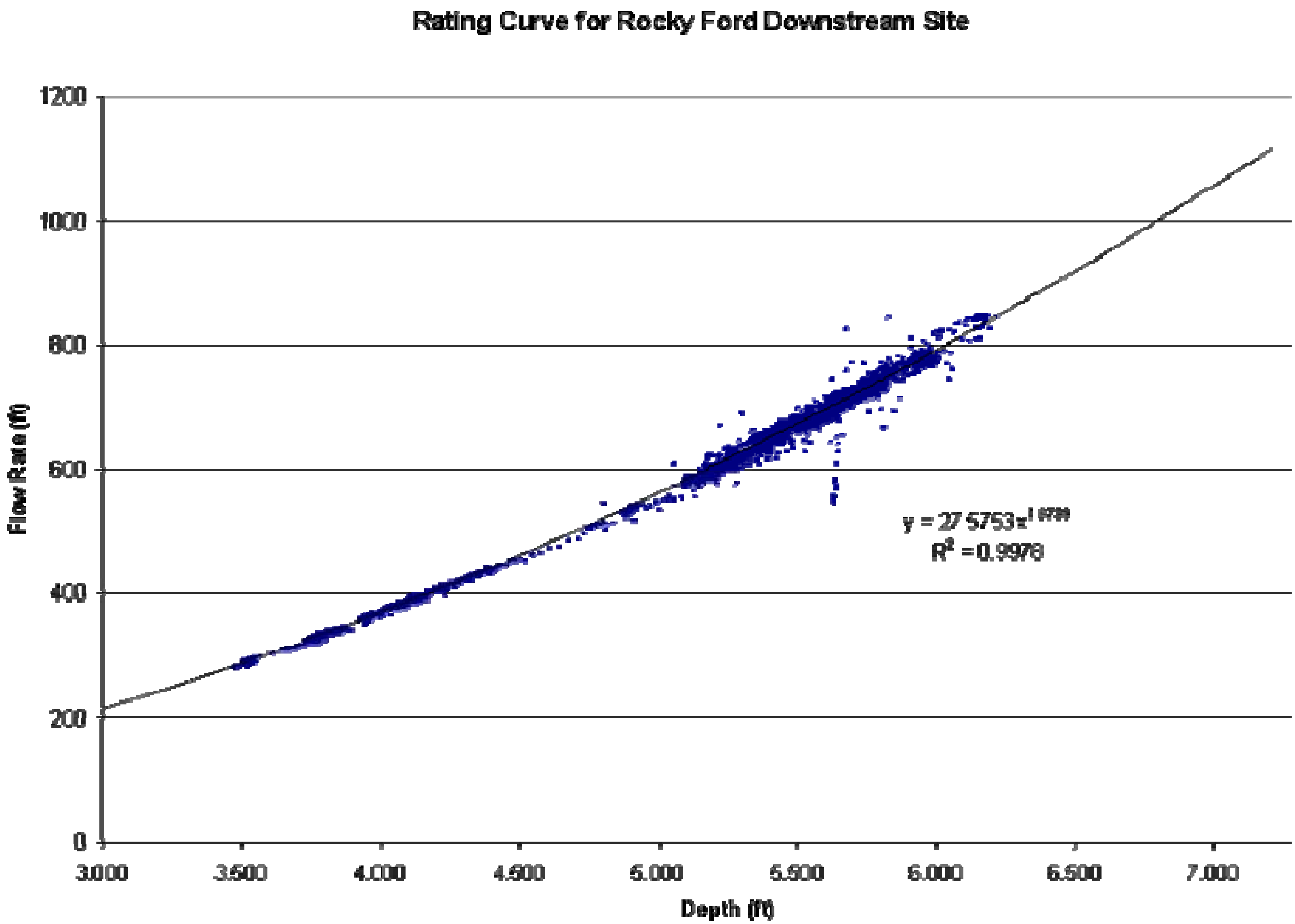

Water Depth and Flow Rate at Rocky Ford Downstream Site
Depth (ft)
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
1050
950
850
750
650
550
450
350
250
6/30/2005
7/10/2005
7/20/2005
7/30/2005
8/9/2005
8/19/2005
8/29/2005
9/8/2005
Date
Telog
SonTek SL
Flow Rate

Appendix D
Rating Curves & Tables


Rating Curve for Rocky Ford Upstream Site
Flow Rate (cfs)
Depth (ft)
0
100
200
300
400
500
600
700
800
900
1000

TulareID Rocky Ford Upstream									
Depth (ft)	Flow (cfs)	Depth (ft)	Flow (cfs)	Depth (ft)	Flow (cfs)	Depth (ft)	Flow (cfs)	Depth (ft)	Flow (cfs)
2.00	64	2.55	113	3.10	180	3.65	264	4.20	368
2.01	64	2.56	114	3.11	181	3.66	266	4.21	370
2.02	65	2.57	115	3.12	182	3.67	268	4.22	372
2.03	66	2.58	116	3.13	184	3.68	269	4.23	374
2.04	67	2.59	117	3.14	185	3.69	271	4.24	376
2.05	68	2.60	118	3.15	186	3.70	273	4.25	378
2.06	68	2.61	120	3.16	188	3.71	275	4.26	381
2.07	69	2.62	121	3.17	189	3.72	276	4.27	383
2.08	70	2.63	122	3.18	191	3.73	278	4.28	385
2.09	71	2.64	123	3.19	192	3.74	280	4.29	387
2.10	72	2.65	124	3.20	194	3.75	282	4.30	389
2.11	72	2.66	125	3.21	195	3.76	283	4.31	391
2.12	73	2.67	126	3.22	196	3.77	285	4.32	393
2.13	74	2.68	127	3.23	198	3.78	287	4.33	396
2.14	75	2.69	128	3.24	199	3.79	289	4.34	398
2.15	76	2.70	130	3.25	201	3.80	290	4.35	400
2.16	76	2.71	131	3.26	202	3.81	292	4.36	402
2.17	77	2.72	132	3.27	204	3.82	294	4.37	404
2.18	78	2.73	133	3.28	205	3.83	296	4.38	406
2.19	79	2.74	134	3.29	207	3.84	298	4.39	409
2.20	80	2.75	135	3.30	208	3.85	300	4.40	411
2.21	81	2.76	136	3.31	210	3.86	301	4.41	413
2.22	82	2.77	138	3.32	211	3.87	303	4.42	415
2.23	82	2.78	139	3.33	213	3.88	305	4.43	417
2.24	83	2.79	140	3.34	214	3.89	307	4.44	420
2.25	84	2.80	141	3.35	216	3.90	309	4.45	422
2.26	85	2.81	142	3.36	217	3.91	311	4.46	424
2.27	86	2.82	144	3.37	219	3.92	313	4.47	426
2.28	87	2.83	145	3.38	220	3.93	315	4.48	429
2.29	88	2.84	146	3.39	222	3.94	316	4.49	431
2.30	89	2.85	147	3.40	223	3.95	318	4.50	433
2.31	90	2.86	148	3.41	225	3.96	320	4.51	435
2.32	91	2.87	150	3.42	226	3.97	322	4.52	438
2.33	91	2.88	151	3.43	228	3.98	324	4.53	440
2.34	92	2.89	152	3.44	230	3.99	326	4.54	442
2.35	93	2.90	153	3.45	231	4.00	328	4.55	445
2.36	94	2.91	155	3.46	233	4.01	330	4.56	447
2.37	95	2.92	156	3.47	234	4.02	332	4.57	449
2.38	96	2.93	157	3.48	236	4.03	334	4.58	452
2.39	97	2.94	158	3.49	238	4.04	336	4.59	454
2.40	98	2.95	160	3.50	239	4.05	338	4.60	456
2.41	99	2.96	161	3.51	241	4.06	340	4.61	459
2.42	100	2.97	162	3.52	242	4.07	342	4.62	461
2.43	101	2.98	164	3.53	244	4.08	344	4.63	463
2.44	102	2.99	165	3.54	246	4.09	346	4.64	466
2.45	103	3.00	166	3.55	247	4.10	348	4.65	468
2.46	104	3.01	167	3.56	249	4.11	350	4.66	470
2.47	105	3.02	169	3.57	251	4.12	352	4.67	473
2.48	106	3.03	170	3.58	252	4.13	354	4.68	475
2.49	107	3.04	171	3.59	254	4.14	356	4.69	478
2.50	108	3.05	173	3.60	256	4.15	358	4.70	480
2.51	109	3.06	174	3.61	257	4.16	360	4.71	482
2.52	110	3.07	175	3.62	259	4.17	362	4.72	485
2.53	111	3.08	177	3.63	261	4.18	364	4.73	487
2.54	112	3.09	178	3.64	262	4.19	366	4.74	490

TulareID Rocky Ford Upstream									
Depth (ft)	Flow (cfs)	Depth (ft)	Flow (cfs)	Depth (ft)	Flow (cfs)	Depth (ft)	Flow (cfs)	Depth (ft)	Flow (cfs)
4.75	492	5.30	638						
4.76	495	5.31	641						
4.77	497	5.32	643						
4.78	500	5.33	646						
4.79	502	5.34	649						
4.80	505	5.35	652						
4.81	507	5.36	655						
4.82	510	5.37	658						
4.83	512	5.38	661						
4.84	515	5.39	664						
4.85	517	5.40	666						
4.86	520	5.41	669						
4.87	522	5.42	672						
4.88	525	5.43	675						
4.89	527	5.44	678						
4.90	530	5.45	681						
4.91	532	5.46	684						
4.92	535	5.47	687						
4.93	537	5.48	690						
4.94	540	5.49	693						
4.95	543	5.50	696						
4.96	545	5.51	699						
4.97	548	5.52	702						
4.98	550	5.53	705						
4.99	553	5.54	708						
5.00	556	5.55	711						
5.01	558	5.56	714						
5.02	561	5.57	717						
5.03	564	5.58	720						
5.04	566	5.59	723						
5.05	569	5.60	726						
5.06	572	5.61	729						
5.07	574	5.62	732						
5.08	577	5.63	736						
5.09	580	5.64	739						
5.10	582	5.65	742						
5.11	585	5.66	745						
5.12	588	5.67	748						
5.13	590	5.68	751						
5.14	593	5.69	754						
5.15	596	5.70	757						
5.16	599	5.71	760						
5.17	601	5.72	764						
5.18	604	5.73	767						
5.19	607	5.74	770						
5.20	610	5.75	773						
5.21	612	5.76	776						
5.22	615	5.77	779						
5.23	618	5.78	783						
5.24	621	5.79	786						
5.25	624	5.80	789						
5.26	626	5.81	792						
5.27	629	5.82	796						
5.28	632	5.83	799						
5.29	635	5.84	802						


Rating Curve for Rocky Ford Downstream Site
Flow Rate (ft)
0
200
400
600
800
1000
1200
3.000
3.500
4.000
4.500
5.000
5.500
6.000
6.500
7.000
Depth (ft)
y = 27 5753x
R2 =0.9978

TulareID Rocky Ford Downstream									
Depth (ft)	**Flow (cfs)**	**Depth (ft)**	**Flow (cfs)**	**Depth (ft)**	**Flow (cfs)**	**Depth (ft)**	**Flow (cfs)**	**Depth (ft)**	**Flow (cfs)**
2.00	101	2.55	159	3.10	230	3.65	312	4.20	406
2.01	102	2.56	161	3.11	231	3.66	314	4.21	408
2.02	103	2.57	162	3.12	233	3.67	315	4.22	410
2.03	104	2.58	163	3.13	234	3.68	317	4.23	411
2.04	105	2.59	164	3.14	235	3.69	318	4.24	413
2.05	106	2.60	165	3.15	237	3.70	320	4.25	415
2.06	107	2.61	166	3.16	238	3.71	322	4.26	417
2.07	108	2.62	168	3.17	240	3.72	323	4.27	419
2.08	109	2.63	169	3.18	241	3.73	325	4.28	421
2.09	110	2.64	170	3.19	242	3.74	327	4.29	422
2.10	111	2.65	171	3.20	244	3.75	328	4.30	424
2.11	112	2.66	172	3.21	245	3.76	330	4.31	426
2.12	113	2.67	174	3.22	247	3.77	332	4.32	428
2.13	114	2.68	175	3.23	248	3.78	333	4.33	430
2.14	115	2.69	176	3.24	250	3.79	335	4.34	432
2.15	116	2.70	177	3.25	251	3.80	336	4.35	433
2.16	117	2.71	179	3.26	252	3.81	338	4.36	435
2.17	118	2.72	180	3.27	254	3.82	340	4.37	437
2.18	119	2.73	181	3.28	255	3.83	341	4.38	439
2.19	120	2.74	182	3.29	257	3.84	343	4.39	441
2.20	121	2.75	184	3.30	258	3.85	345	4.40	443
2.21	122	2.76	185	3.31	260	3.86	347	4.41	445
2.22	123	2.77	186	3.32	261	3.87	348	4.42	447
2.23	124	2.78	187	3.33	263	3.88	350	4.43	449
2.24	125	2.79	189	3.34	264	3.89	352	4.44	450
2.25	126	2.80	190	3.35	266	3.90	353	4.45	452
2.26	127	2.81	191	3.36	267	3.91	355	4.46	454
2.27	128	2.82	192	3.37	269	3.92	357	4.47	456
2.28	129	2.83	194	3.38	270	3.93	358	4.48	458
2.29	130	2.84	195	3.39	272	3.94	360	4.49	460
2.30	131	2.85	196	3.40	273	3.95	362	4.50	462
2.31	132	2.86	198	3.41	275	3.96	364	4.51	464
2.32	133	2.87	199	3.42	276	3.97	365	4.52	466
2.33	135	2.88	200	3.43	278	3.98	367	4.53	468
2.34	136	2.89	201	3.44	279	3.99	369	4.54	470
2.35	137	2.90	203	3.45	281	4.00	370	4.55	472
2.36	138	2.91	204	3.46	282	4.01	372	4.56	474
2.37	139	2.92	205	3.47	284	4.02	374	4.57	475
2.38	140	2.93	207	3.48	285	4.03	376	4.58	477
2.39	141	2.94	208	3.49	287	4.04	377	4.59	479
2.40	142	2.95	209	3.50	288	4.05	379	4.60	481
2.41	143	2.96	211	3.51	290	4.06	381	4.61	483
2.42	144	2.97	212	3.52	292	4.07	383	4.62	485
2.43	146	2.98	213	3.53	293	4.08	384	4.63	487
2.44	147	2.99	215	3.54	295	4.09	386	4.64	489
2.45	148	3.00	216	3.55	296	4.10	388	4.65	491
2.46	149	3.01	217	3.56	298	4.11	390	4.66	493
2.47	150	3.02	219	3.57	299	4.12	392	4.67	495
2.48	151	3.03	220	3.58	301	4.13	393	4.68	497
2.49	152	3.04	222	3.59	302	4.14	395	4.69	499
2.50	154	3.05	223	3.60	304	4.15	397	4.70	501
2.51	155	3.06	224	3.61	306	4.16	399	4.71	503
2.52	156	3.07	226	3.62	307	4.17	400	4.72	505
2.53	157	3.08	227	3.63	309	4.18	402	4.73	507
2.54	158	3.09	228	3.64	310	4.19	404	4.74	509

TulareID Rocky Ford Downstream									
Depth (ft)	Flow (cfs)	Depth (ft)	Flow (cfs)	Depth (ft)	Flow (cfs)	Depth (ft)	Flow (cfs)	Depth (ft)	Flow (cfs)
4.75	511	5.30	628	5.85	755	6.40	894		
4.76	513	5.31	630	5.86	758	6.41	896		
4.77	515	5.32	632	5.87	760	6.42	899		
4.78	517	5.33	634	5.88	763	6.43	902		
4.79	519	5.34	637	5.89	765	6.44	904		
4.80	521	5.35	639	5.90	767	6.45	907		
4.81	523	5.36	641	5.91	770	6.46	910		
4.82	525	5.37	643	5.92	772	6.47	912		
4.83	527	5.38	646	5.93	775	6.48	915		
4.84	529	5.39	648	5.94	777	6.49	917		
4.85	532	5.40	650	5.95	780	6.50	920		
4.86	534	5.41	652	5.96	782	6.51	923		
4.87	536	5.42	655	5.97	785	6.52	925		
4.88	538	5.43	657	5.98	787	6.53	928		
4.89	540	5.44	659	5.99	789	6.54	931		
4.90	542	5.45	661	6.00	792	6.55	933		
4.91	544	5.46	664	6.01	794	6.56	936		
4.92	546	5.47	666	6.02	797	6.57	939		
4.93	548	5.48	668	6.03	799	6.58	941		
4.94	550	5.49	671	6.04	802	6.59	944		
4.95	552	5.50	673	6.05	804	6.60	947		
4.96	554	5.51	675	6.06	807	6.61	950		
4.97	556	5.52	677	6.07	809	6.62	952		
4.98	559	5.53	680	6.08	812	6.63	955		
4.99	561	5.54	682	6.09	814	6.64	958		
5.00	563	5.55	684	6.10	817	6.65	960		
5.01	565	5.56	687	6.11	819	6.66	963		
5.02	567	5.57	689	6.12	822	6.67	966		
5.03	569	5.58	691	6.13	824	6.68	968		
5.04	571	5.59	694	6.14	827	6.69	971		
5.05	573	5.60	696	6.15	829	6.70	974		
5.06	575	5.61	698	6.16	832	6.71	977		
5.07	578	5.62	701	6.17	835	6.72	979		
5.08	580	5.63	703	6.18	837	6.73	982		
5.09	582	5.64	705	6.19	840	6.74	985		
5.10	584	5.65	708	6.20	842	6.75	988		
5.11	586	5.66	710	6.21	845	6.76	990		
5.12	588	5.67	712	6.22	847	6.77	993		
5.13	590	5.68	715	6.23	850	6.78	996		
5.14	593	5.69	717	6.24	852	6.79	999		
5.15	595	5.70	719	6.25	855	6.80	1001		
5.16	597	5.71	722	6.26	857	6.81	1004		
5.17	599	5.72	724	6.27	860	6.82	1007		
5.18	601	5.73	726	6.28	863	6.83	1010		
5.19	603	5.74	729	6.29	865	6.84	1012		
5.20	606	5.75	731	6.30	868	6.85	1015		
5.21	608	5.76	734	6.31	870	6.86	1018		
5.22	610	5.77	736	6.32	873	6.87	1021		
5.23	612	5.78	738	6.33	876	6.88	1023		
5.24	614	5.79	741	6.34	878	6.89	1026		
5.25	617	5.80	743	6.35	881	6.90	1029		
5.26	619	5.81	746	6.36	883	6.91	1032		
5.27	621	5.82	748	6.37	886	6.92	1035		
5.28	623	5.83	750	6.38	889	6.93	1037		
5.29	625	5.84	753	6.39	891	6.94	1040		

Appendix E
SonTek Program

Rocky Ford Upstream Site
Connected to COM1: at 9600
<BREAK>

Argonaut-SL
SonTek/YSI, Inc.
Copyright 1996-2004

Wake up initialization. Please wait...
>show fdatum
Flow equation type is: INDEX
Q = Vmean x Area
Vmean = Vintercept + Vmeas x (Vslope + (StageCoef x Stage))

Index coefficients:
Vintercept: 0.988 (ft/s)
Vslope: 0.057
StageCoef: 0.154 (1/ft)
Arg Elevation is: 1.685 (ft).
Flow channel type: IRREGULAR

Point	Horiz Dist(ft)	Elev (ft)
1	0.0	6.70
2	10.8	0.70
3	28.5	0.00
4	46.1	0.70
5	55.1	6.70
6	BLANK	BLANK
7	BLANK	BLANK
8	BLANK	BLANK
9	BLANK	BLANK
10	BLANK	BLANK
11	BLANK	BLANK
12	BLANK	BLANK
13	BLANK	BLANK
14	BLANK	BLANK
15	BLANK	BLANK
16	BLANK	BLANK
17	BLANK	BLANK
18	BLANK	BLANK
19	BLANK	BLANK
20	BLANK	BLANK

TotalVolume output: 0 (DISABLED)
TotalVolume settings:
0 (DISABLED)
1 (CFS+ACRE-FT)

```
 2  (GPM+GAL)
 3  (MGD+GAL)
 4  (M3/S+M3)
 5  (L/S+L)
 6  (MLD+M3)
>sao

AO SETTINGS
-----------
Chan Parameter     MinVal       MaxVal
 1       FLOW        0.00      1000.00  cfs
 2      LEVEL        0.00        10.00  ft

>sao 1 flow 0 1100
OK
>sao

AO SETTINGS
-----------
Chan Parameter     MinVal       MaxVal
 1       FLOW        0.00      1100.00  cfs
 2      LEVEL        0.00        10.00  ft

>savesetup
OK
>saveflowdatum
OK
>Show conf

Hardware Configuration
----------------------
System Type ----------------- SL
Sensor serial # ------------- E610
Sensor frequency - (kHz) ---- 1500
Number of beams ------------- 2
Beam Geometry --------------- 2_BEAMS
Vertical Beam --------------- YES
Slant angle - (deg) --------- 25.0
System Orientation ---------- SIDE
Compass installed  ---------- NO
Recorder installed ---------- YES
Temperature sensor ---------- YES
Pressure    sensor ---------- YES
PressOffset  - (dbar) ------- -1.263800
PressScale  -- (dbar/count) - 0.000208
PressScale_2 - (pdbar/cnt^2)- 50
```

```
Ctd      sensor ---------- NO
Ext. Press. sensor ---------- NONE
YSI      sensor ---------- NO
Waves Option ---------------- NO
Internal SDI-12 Option ------ YES
Internal Flow Computations -- YES
Analog Output Option -------- YES
Multi-cell Profiling Option - NO
>Show System

System Parameters
-------------------
CPU Ver ----------- ARG 11.0
BoardRev ---------- REV F
Date -------------- 2005/09/15
Time -------------- 15:59:21
AutoSleep --------- YES
VoltageProtection - YES
OutMode ----------- AUTO
OutFormat --------- ENGLISH
Recorder ---------- ON
ModemMode --------- NO

>Show setup

Setup Parameters
----------------
Temp ----------- 20.00 deg C
Sal ------------ 0.00 ppt
TempMode ------- MEASURED
Sound Speed ---- 1481.6 m/s
AvgInterval ---- 600 s
SampleInterval - 600 s
CellBegin ------ 0.50 m
CellEnd -------- 10.00 m
CoordSystem ---- XYZ
RevXVelocity --- NO
PowerPing ------ YES
>start
Checking Setup Parameters...

4063232 free bytes left in recorder.
Free space is sufficient for 421.15 days of operation.
Data will be recorded to file TIDUS003.
OK
```

Rocky Ford Downstream Site
Connected to COM1: at 9600
<BREAK>

Argonaut-SL
SonTek/YSI, Inc.
Copyright 1996-2004

Wake up initialization. Please wait...

```
>show fdatum
Flow equation type is: INDEX
 Q     = Vmean x Area
 Vmean = Vintercept + Vmeas x (Vslope + (StageCoef x Stage))

 Index coefficients:
   Vintercept:   0.679 (ft/s)
   Vslope:       0.435
   StageCoef:    0.064 (1/ft)
Arg Elevation is:   1.234  (ft).
Flow channel type: IRREGULAR
 Point  Horiz Dist(ft)  Elev (ft)
   1        0.0         32.80
   2       52.5          0.00
   3       85.3          0.00
   4      137.8         32.80
   5       BLANK        BLANK
   6       BLANK        BLANK
   7       BLANK        BLANK
   8       BLANK        BLANK
   9       BLANK        BLANK
  10       BLANK        BLANK
  11       BLANK        BLANK
  12       BLANK        BLANK
  13       BLANK        BLANK
  14       BLANK        BLANK
  15       BLANK        BLANK
  16       BLANK        BLANK
  17       BLANK        BLANK
  18       BLANK        BLANK
  19       BLANK        BLANK
  20       BLANK        BLANK

TotalVolume output: 0  (DISABLED)
TotalVolume settings:
 0  (DISABLED)
```

```
 1  (CFS+ACRE-FT)
 2  (GPM+GAL)
 3  (MGD+GAL)
 4  (M3/S+M3)
 5  (L/S+L)
 6  (MLD+M3)
>sao

AO SETTINGS
-----------
Chan Parameter    MinVal      MaxVal
 1      FLOW       0.00     1000.00  cfs
 2     LEVEL       0.00       10.00  ft

>sao 1 flow 0 1100
OK
>sao

AO SETTINGS
-----------
Chan Parameter    MinVal      MaxVal
 1      FLOW       0.00     1100.00  cfs
 2     LEVEL       0.00       10.00  ft

>savesetup
OK
>saveflowdatum
OK
>Show conf

Hardware Configuration
----------------------
System Type ----------------- SL
Sensor serial # ------------- E1009
Sensor frequency - (kHz) ---- 1500
Number of beams ------------- 2
Beam Geometry --------------- 2_BEAMS
Vertical Beam --------------- YES
Slant angle - (deg) --------- 25.0
System Orientation ---------- SIDE
Compass installed  ---------- NO
Recorder installed ---------- YES
Temperature sensor ---------- YES
Pressure    sensor ---------- YES
PressOffset  - (dbar) ------- -1.305860
PressScale  -- (dbar/count) - 0.000209
```

PressScale_2 - (pdbar/cnt^2)- 41
Ctd sensor ---------- NO
Ext. Press. sensor ---------- NONE
YSI sensor ---------- NO
Waves Option ---------------- NO
Internal SDI-12 Option ------ YES
Internal Flow Computations -- YES
Analog Output Option -------- YES
Multi-cell Profiling Option - NO
>Show System
System Parameters

CPU Ver ----------- ARG 11.0
BoardRev ---------- REV F
Date -------------- 2005/09/15
Time -------------- 15:53:06
AutoSleep --------- YES
VoltageProtection - YES
OutMode ----------- AUTO
OutFormat --------- ENGLISH
Recorder ---------- ON
ModemMode --------- NO

>Show setup
Setup Parameters

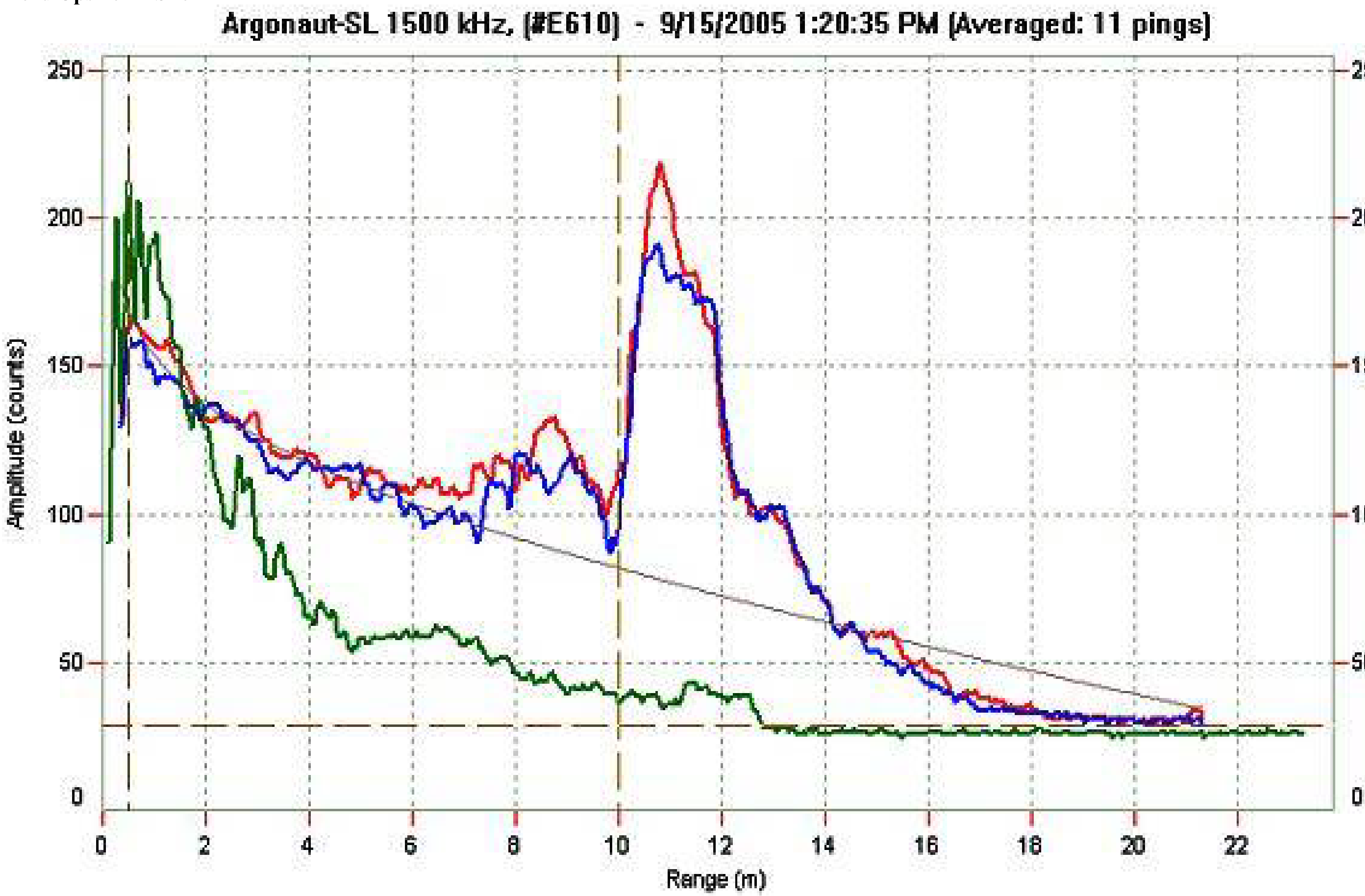
Temp ----------- 20.00 deg C
Sal ------------ 0.00 ppt
TempMode ------- MEASURED
Sound Speed ---- 1520.9 m/s
AvgInterval ---- 600 s
SampleInterval - 600 s
CellBegin ------ 1.00 m
CellEnd -------- 9.00 m
CoordSystem ---- XYZ
RevXVelocity --- NO
PowerPing ------ YES
>start
Checking Setup Parameters...

4128768 free bytes left in recorder.
Free space is sufficient for 427.94 days of operation.

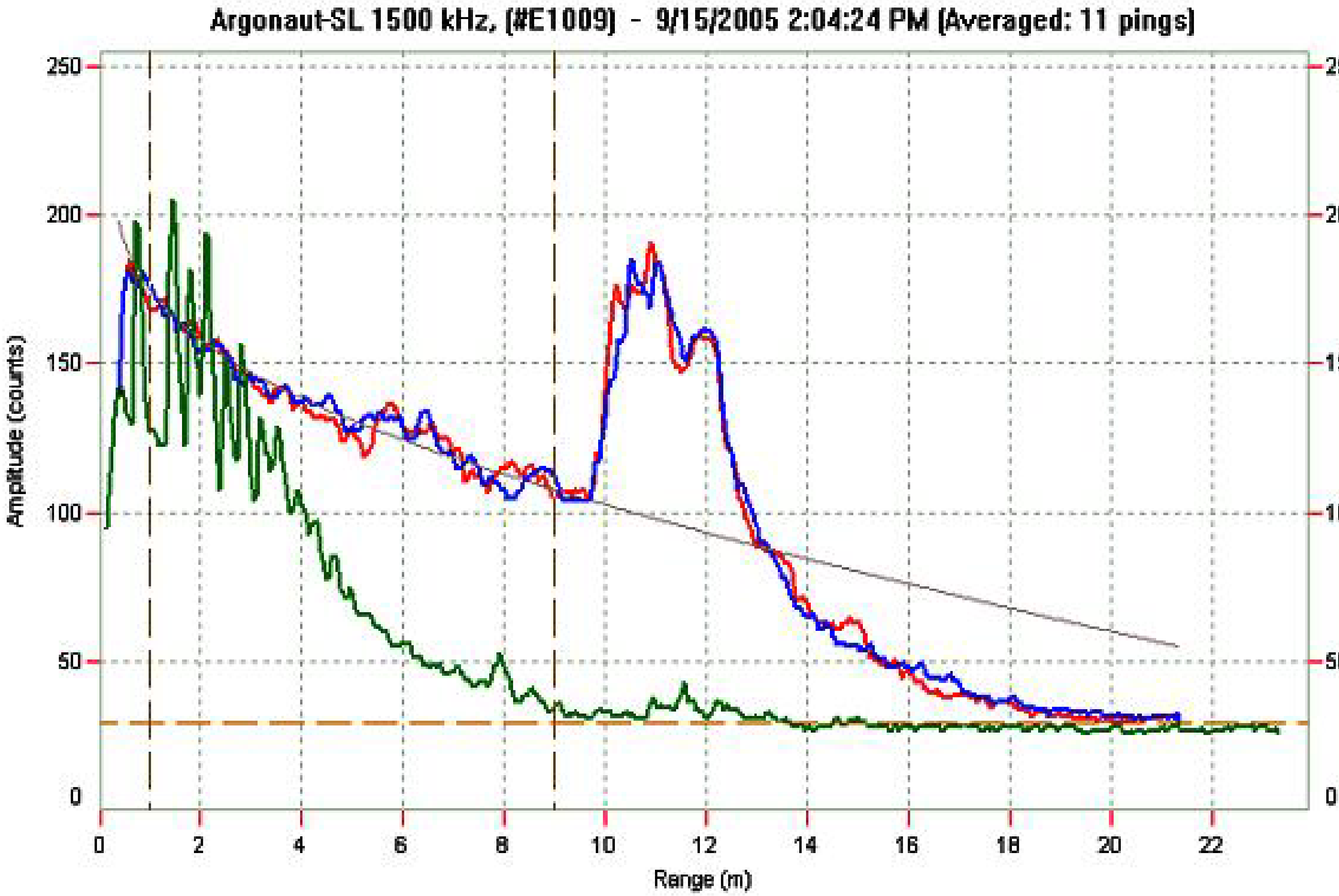
Data will be recorded to file TIDDS002.
OK

Appendix F
SonTek Beam Signal

Rocky Ford Upstream Site



Rocky Ford Downstream Site



E-6: Yuma Co. Water Users Assoc. West Main Canal – QIP

IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, California 93407
Tel: (805) 756-2434 Fax: (805) 756-2433 www.itrc.org

TECHNICAL MEMORANDUM

Date: June 23, 2004 (rev. Aug. 10, 2004)

To: Dr. Stuart Styles, ITRC Director

From: Ben Burgoa, ITRC Engineer; David Leinfelder, Student Engineer

Subject: Summary Results of the YCWUA West Main Canal – Flow Rate Indexing Procedure

This memo summarizes the results of the flow rate indexing procedure (QIP) for the Yuma County Water User Association (YCWUA) West Main Canal. YCWUA personnel collected the following information between November 11, 2003 and May 7, 2004, which was used for the indexing calculations:

Current meter measurement: mean velocity (fps) and water surface elevation (ft)
Average stage (ft) and computed area (ft^2)
Velocity (fps) and stage (ft) data from SonTek/YSI files

The newly developed QIP (Styles *et. al.* 2003) was used to relate the mean channel velocity to the velocity measured by the SonTek/YSI unit to develop the indexing coefficients.

Summary

The canal index velocity rating derived from a multiple regression analysis provides the best result at the YCWUA West Main Canal. The in SonTek discharge data accuracy was improved from +/-32.0% to +/-11.0% and +/-9.2% using the QIP single and multiple regression models, respectively.

Introduction

This report summarizes the development of an index velocity rating for the YCWUA West Main Canal. The principle of the QIP is to develop a regression equation or rating curve relating an index velocity to the mean channel velocity. The canal-based QIP was developed by Styles *et. al.* (2003).

A series of flow data were collected at the YCWUA West Main Canal between November 11, 2003 and May 7, 2004. During the tests the discharge was measured using a current meter (metered discharge and velocity), the average water surface was recorded, and the flow area was calculated (refer to Appendix 1).

A SonTek/YSI Argonaut Side-Looking (SL) ultrasonic Doppler flow meter was installed in the West Main Canal. The sensor collected stage and water velocity data every 10 minutes. Only the data points within the metered discharge time were used for the calculation of the average sensor-measured flow rate and stage. The stage, measured velocity, and mean channel velocity selected for the index velocity rating are presented in Table 1.

Table 1. YCWUA West Main Canal stage, and metered and Argonaut SL velocity measurements

No.	Stage, ft	Mean Velocity, fps	Sensor Measured Velocity, fps
1	5.97	0.95	0.74
2	5.83	0.6	0.52
3	5.8	0.55	0.41
4	5.99	1.13	0.85
5	5.93	1.18	0.78
6	6.03	1.44	0.98
7	6.06	1.48	1.11
8	5.96	0.92	0.57
9	5.45	0.27	0.06
10	5.96	1.7	1.26

Results

The following index velocity ratings were generated from the mean channel velocity and the SonTek measured velocity (Figures 1a and 1b):

Simple linear regression relationship

$$V_m = 1.2575\ V_S + 0.1079 \qquad R^2 = 0.961$$

Multiple linear regression relationship

$$V_m = (-3.730 + 0.822H)\ V_S + 0.170 \quad R^2 = 0.966$$

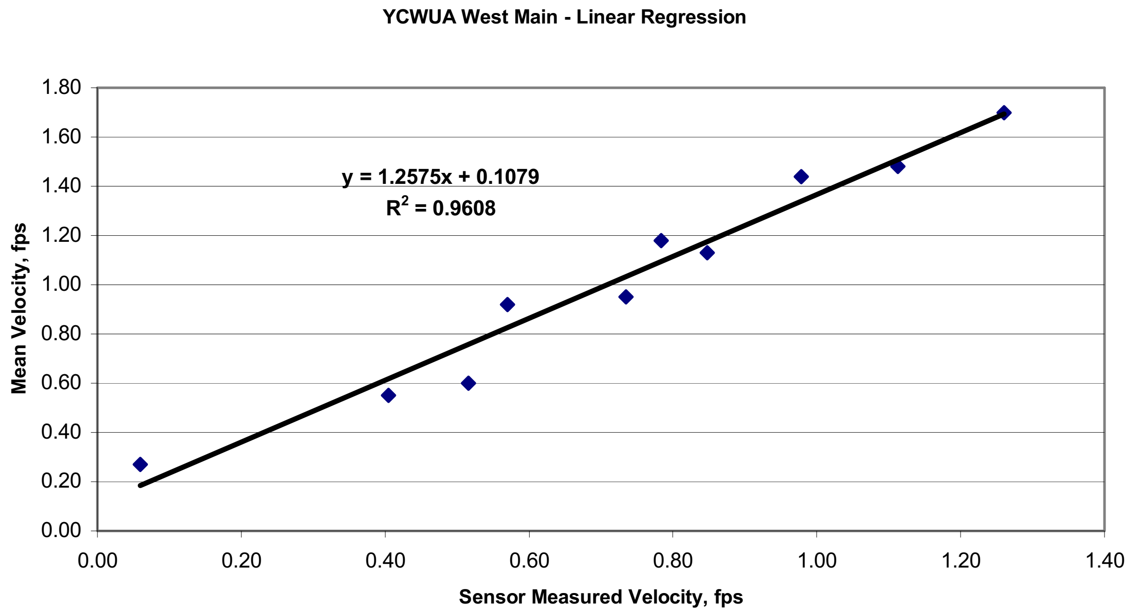


Figure 1a. Single linear regression analysis of the mean velocity and the SonTek measured velocity

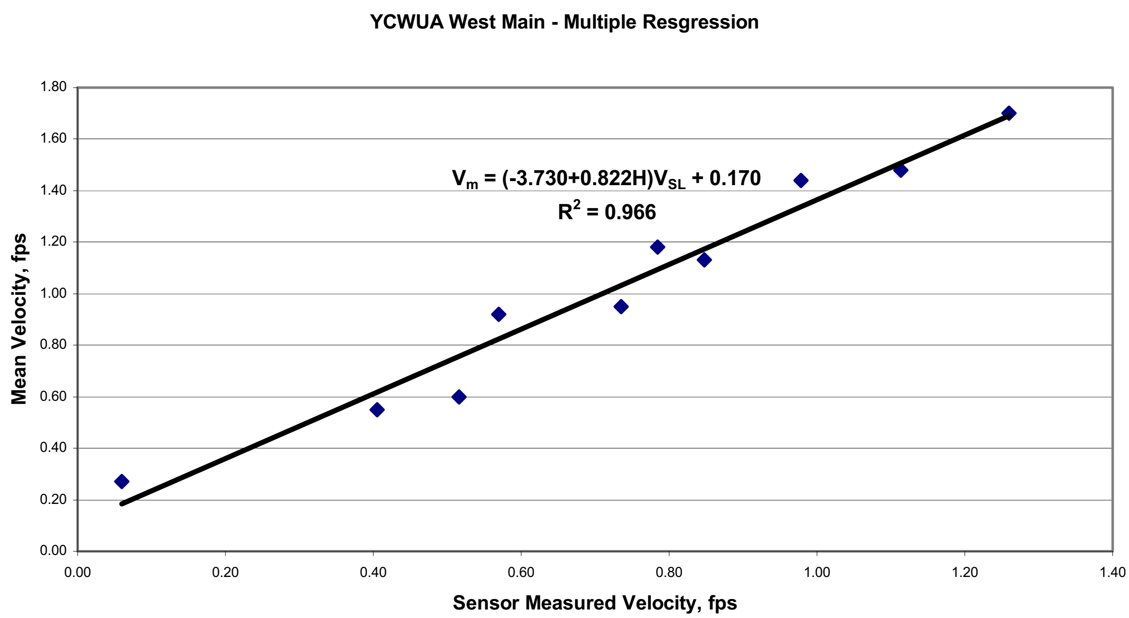


Figure 1b. Multiple linear regression analysis of the mean velocity and the SonTek measured velocity

The addition of stage to the rating calculation slightly increased the correlation coefficient (R^2). Further analysis shows that increasing discharge by 300 cfs had a very small influence (less than 0.3 ft) on the stage values.

Table 2 summarizes the computed error between the actual sensor-measured discharges and the metered discharge. The percent error was calculated using the following relationship:

Percent Error = 100*[(Sensor Measured Discharge)-(Metered Discharge)]/[Metered Discharge]

Table 2. Calculated percent error of the sensor-measured data without index velocity rating correction

Current Meter Discharge, cfs	W/O Correction	
	Discharge, cfs	Error (%)
267	207	-22.6%
165	142	-14.0%
150	111	-26.4%
319	239	-25.0%
330	219	-33.6%
409	278	-32.1%
422	318	-24.8%
258	160	-38.0%
69	15	-77.8%
477	354	-25.9%

Table 3 summarizes the computed discharge using both index velocity rating equation and the percent error relative to the metered discharge. The flow rate (Q=VA) was computed using the index velocity and the calculated area. The discharge variation was reduced from +/-32% to +/-11.0% by using the simple linear index velocity rating. An improvement to +/-9.2% variation was observed using the multiple regression.

Table 3. Discharge (cfs) and percent error using simple and multiple linear regression

No.	Current Meter Discharge, cfs	Linear Regression - No Stage		Multiple Linear Regression with Stage	
		Discharge, cfs	Error (%)	Discharge, cfs	Error (%)
1	267	290	8.6%	291	9.0%
2	165	208	26.1%	197	19.7%
3	150	169	12.2%	161	7.3%
4	319	331	3.9%	334	4.6%
5	330	305	-7.3%	298	-9.6%
6	409	380	-7.1%	389	-4.9%
7	422	430	1.9%	446	5.6%
8	258	231	-10.4%	235	-9.1%
9	69	47	-32.1%	55	-20.4%
10	477	475	-0.4%	461	-3.3%

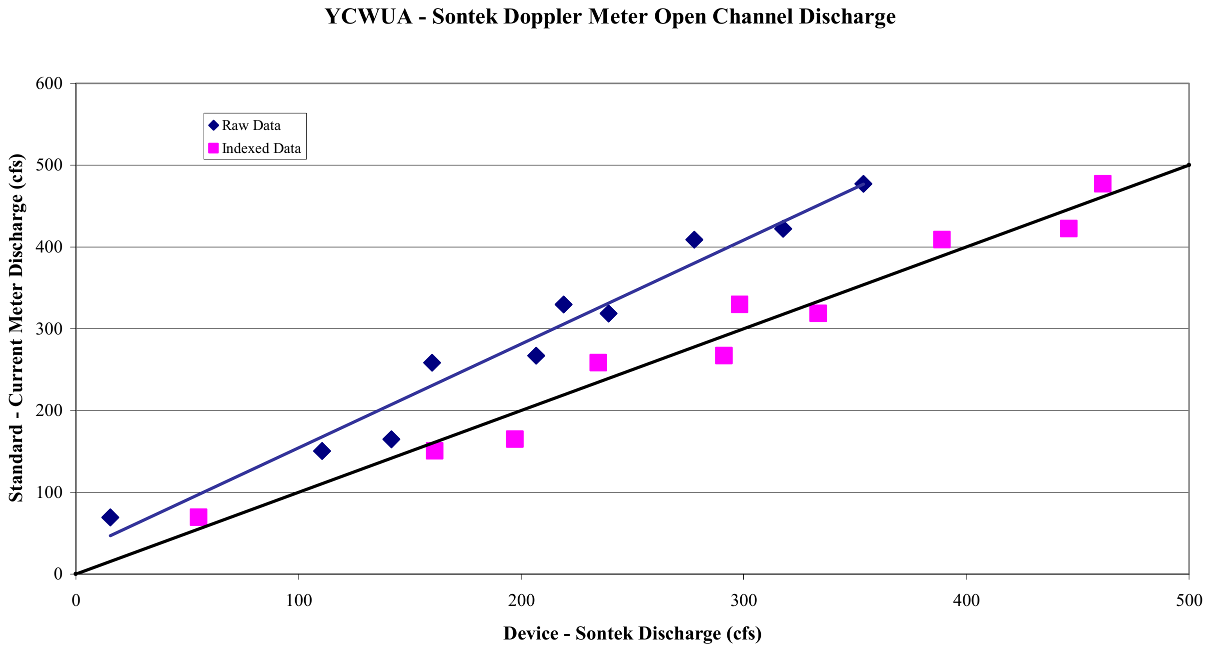


Figure 2. Indexed SonTek Discharge data compared to SonTek data before indexing (raw data)

Reference

Styles, S., M. Niblack, and B. Freeman. 2003. Canal Velocity Indexing at Colorado River Indian Tribes (CRIT) Irrigation Project in Parker, Arizona using the SonTek Argonaut SL. ITRC Paper No. P 03-001. http://www.itrc.org/papers/crit/canalvelocity.pdf

Appendix 1

Measurements, Computed Areas, and Indexing Calculations

Current Meter Measurements and Computed Areas

Date	Time Begin	Time End	El Avg WS Elev	A Computed Area	Q Metered Q CFS	Vm Metered Vel
11/21/2003	10:45	12:20	130.57	281.19	267.7	0.95
12/5/2003	7:15	8:03	130.43	274.59	164.2	0.60
12/5/2003	8:04	8:42	130.4	273.18	151.2	0.55
12/5/2003	9:20	10:13	130.59	282.13	318.2	1.13
12/5/2003	10:15	11:01	130.53	279.30	330.6	1.18
12/5/2003	11:05	11:57	130.63	284.01	408.7	1.44
12/5/2003	11:58	12:40	130.66	285.43	421.7	1.48
12/17/2003	9:40	10:35	130.56	280.72	258.4	0.92
1/13/2004	9:10	10:30	130.05	256.70	68.8	0.27
5/7/2004	9:55	11:00	130.56	280.72	476.5	1.70

Canal Velocity Indexing

Reference: Styles, Niblack, and Freeman. 2003.

Location: YCWUA West Main

Date: 11/21/03 to 12/5/03

No.	Stage, ft	Mean Velocity, fps	Sensor Measured Velocity, fps	
1	5.97	0.95	0.74	5.97
2	5.83	0.6	0.52	5.83
3	5.8	0.55	0.41	5.80
4	5.99	1.13	0.85	5.99
5	5.93	1.18	0.78	5.93
6	6.03	1.44	0.98	6.03
7	6.06	1.48	1.11	6.06
8	5.96	0.92	0.57	5.96
9	5.45	0.27	0.06	5.45
10	5.96	1.7	1.26	5.96

Linear Regression Coefficient

Vm = xVs + C

Coefficients: $R^2 =$ 0.9571

x = 1.2575

C = 0.1079

Multiple Regression Coefficient

Vm = (x + yH)Vs + C

Coefficients: $R^2 =$ 0.9572

x = -3.73

y = 0.822

C = 0.17

No.	Current Meter Discharge, cfs	Linear Regression - No Stage		Multiple Linear Regression with	
		Discharge, cfs	Error (%)	Discharge, cfs	Error (%)
1	267	290	8.6%	291	9.0%
2	165	208	26.1%	197	19.7%
3	150	169	12.2%	161	7.3%
4	319	331	3.9%	334	4.6%
5	330	305	-7.3%	298	-9.6%
6	409	380	-7.1%	389	-4.9%
7	422	430	1.9%	446	5.6%
8	258	231	-10.4%	235	-9.1%
9	69	47	-32.1%	55	-20.4%
10	477	475	-0.4%	461	-3.3%

ATTACHMENT F

PARTIAL INDEX RATING SITE VISIT REPORTS

F-1: AgTAC Center Site Visit Report

Irrigation Training and Research Center
BioResource and Agricultural Engineering Department
California Polytechnic State University
San Luis Obispo, California 93407
Tel: (805) 756-2434 Fax: (805) 756-2433

Date: December 6, 2005

To: Stuart Styles, ITRC Director

From: Bryan Busch, Irrigation Support Engineer

Subject: AgTAC Center
Site Visit Report: Feb 9, 2005 and Dec 6, 2005

A site visit was conducted to the AgTAC Center on Feb 9, 2005 and Dec 6, 2005. The purpose of the site visit was to install an acoustic Doppler flow meter in the AgTAC demonstration canal. The trip was coordinated with Traeger Cotton from AgTAC. This report includes the collected flow rate data, a rating curve for the canal, and pictures.

Contact Information

Traeger Cotton, Controls Specialist, Southern California Edison
Tel: 800-772-4822

Itinerary

Feb 9, 2005 Installed an acoustic Doppler flow measurement unit, SonTek SW. Downloaded the data sets form the unit.

Dec 6, 2005 Used SonTek SW in a Flow measurement class that included introduction to electronic flow devices, and calibration of the electronic flow devices. Downloaded data, upgraded firmware, reprogrammed visual display and calibrated SonTek SW with the Replogle flume.

Acoustic Doppler Flow Meter

The SonTek SW meter was placed in the demonstration canal at the center for comparison to other traditional flow meters and to expose water users to new technology. The data collected from the unit was used to compare to the AgTAC center's Replogle flume located downstream.

Programming and Index-Rating

The last step of installation is to program the SonTek using the manufacture's software. The SonTek software is easy to use, and can be set up in less than 15 minutes. To program the unit to complete flow calculations a cross-section and index rating must be complete. Further information about programming the SonTek is available from the ITRC and the manufacture.

A cross-section of the canal was obtained by surveying the canal. Also the unit was calibrated by creating a velocity index rating curve that uses accurate data from the Replogle flume downstream of the SonTek SW at multiple flow rates.

Data

On Dec 6, 2005 data was collected from the site and the unit was reset to continue taking data for the next month. A year worth of data can be stored on the flow meter if the time interval is set to 15 minutes. Figure 1 shows data collected on July 28, 2005. The data collected will be used for the rating curve needed to calibrate the site. Figure 2 shows the rating curve for the demonstration canal.

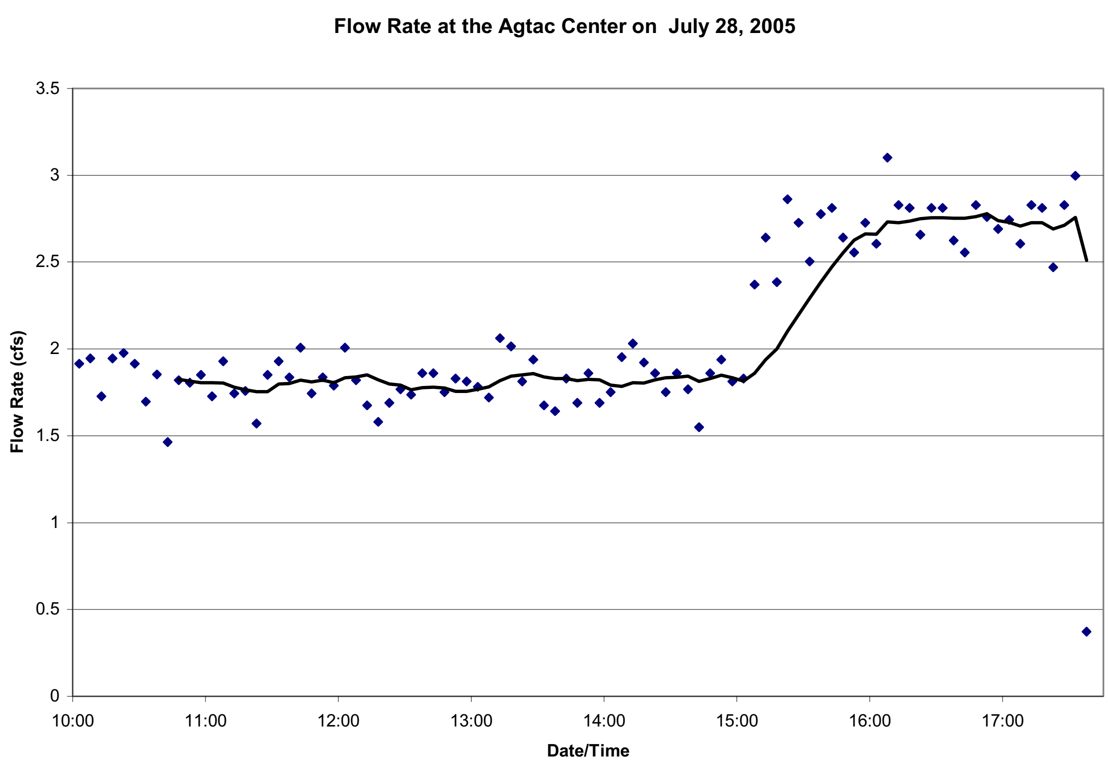


Figure 1. SonTek SW flow rate data from Southern Edison AgTAC Center in Tulare, CA

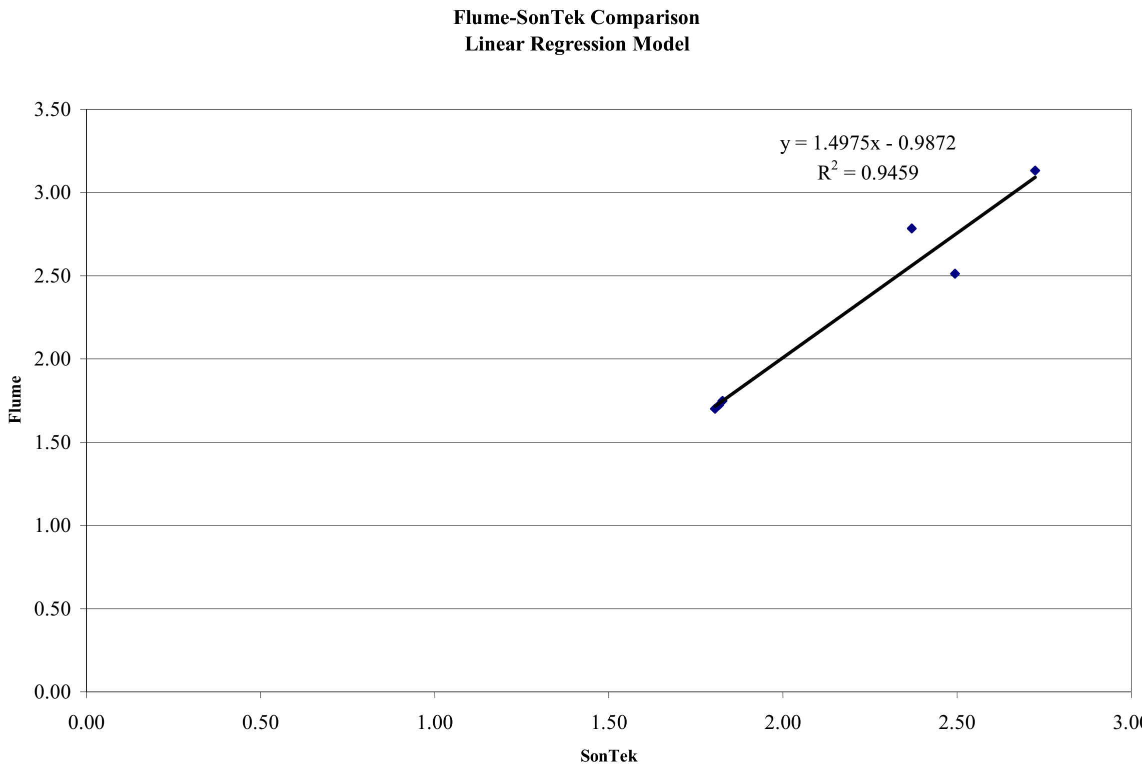


Figure 2. Linear regression equation using the flume to index the SonTek SW

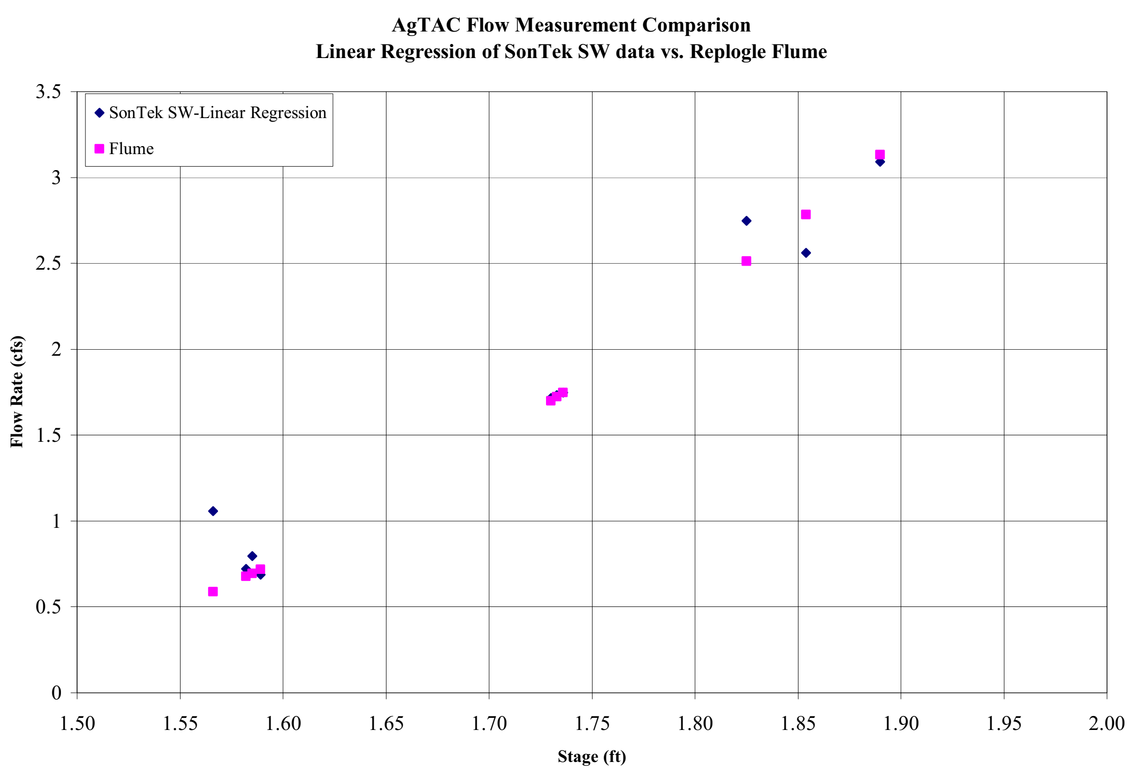


Figure 3. Adjusted SonTek values using the QIP linear regression

Photographs

These photographs were taken at the AgTAC center.

Figure 4. Southern Edison AgTAC Center building, Tulare, CA.

Figure 5. Demonstration canals at the AgTAC center.

F-2: Alta Irrigation District Site Visit Report

Irrigation Training and Research Center
BioResource and Agricultural Engineering Department
California Polytechnic State University
San Luis Obispo, California 93407
Tel: (805) 756-2434 Fax: (805) 756-2433

SITE VISIT REPORT

Date: Nov. 10, 2004

To: Stuart Styles, ITRC Director

From: Bryan Busch, Student Assistant Engineer
David Leinfelder, Student Assistant Engineer

Subject: Alta Irrigation District
Site Visit Report: July 20-21, 2004 & August 3, 2004

A site visit was conducted to the Alta Irrigation District on July 20-21, 2004, and August 3, 2004. The purpose of the site visit was to install (temporarily) an acoustic Doppler flow meter in the district to rate a non-standard structure. The trip was coordinated with Jeff Heringer from AID. This site visit report includes photographs of the installations.

Contact Information

Alta Irrigation District – 8951
Avenue 432, Dinuba, CA 93618.
Tel: 559.591.4203 Yard Office
Tel: 559.591.0800 Main Office

Jeff Heringer, Superintendent
Tel: 559.352.1930
Fax: 209.656.2180
email: jh@altaid.org

Itinerary

July 20, 2004 Installed an acoustic Doppler flow measurement unit, SonTek SW and Telog/Druck water level sensor. Downloaded the data sets for the unit, performed indexing by running boats at current flow rate of 150 cfs.

July 21, 2004 ITRC *Flow Measurement* class that included flume design, and introduction to electronic flow devices, and calibration of the electronic flow devices.

August 3, 2004 Collected flow rate data with Acoustic Doppler Profiling boats. Data could not be downloaded from SonTek SW. It was discovered that the solar panel charging the battery supplying power to the SonTek was stolen. Power loss resulted in lost data. The SonTek SW and Telog/Druck were removed from the site.

Acoustic Doppler Flow Meter

In order to perform an evaluation of the potential for the use of acoustic Doppler flow meters in conditions typical at AID, the SonTek SW unit was installed and operated downstream of one of AID's large turnouts. Since the SonTek is mounted on its side, a pressure transducer, Telog unit, is used in conjunction to record the water level. The SonTek and Telog unit recorded data for approximately 1 month and data was downloaded after that period. The data collected from the unit will be used to evaluate the accuracy and discharge rating of the district's current method of measuring flows at two rated sections downstream.

Programming and Index-Rating

The final installation step is to program the SonTek using the manufacture's software. The SonTek software is easy to use, and can be set up in less than 15 minutes. To program the unit to perform flow calculations, a cross-sectional survey and index rating must be completed. Further information about programming the SonTek is available from the ITRC and the manufacture.

A cross-section of the canal was obtained by using the data from acoustic Doppler boats; if this was a permanent installation the cross-section would have to be accurately surveyed to provide the SonTek flow meter with good data.

The SW unit is calibrated by developing a rating curve using data from the acoustic Doppler profiler (ADP) boat at multiple flow rates. To develop a rating curve the channel must be current metered at ten different flow rates to develop a representative curve. The ITRC has prepared guidelines on doing the index rating for hydroacoustic flow meter installations.

Data

On July 20, July 21 data was collected at the site and the unit was reset to continue taking data for the next month. The unit can record and store 15-minute data for over 12 months. On August 3 it was discovered that the solar panel charging the battery supplying power to the SonTek was stolen. Power loss resulted in lost data. The only data collected was from the initial setup. The instrument was setup with a Vslope = 1.278, StageCoef = 0, and Vint = 0. If all the datasets had been collected they would have been used to develop an accurate index velocity rating curve necessary to calibrate the site.

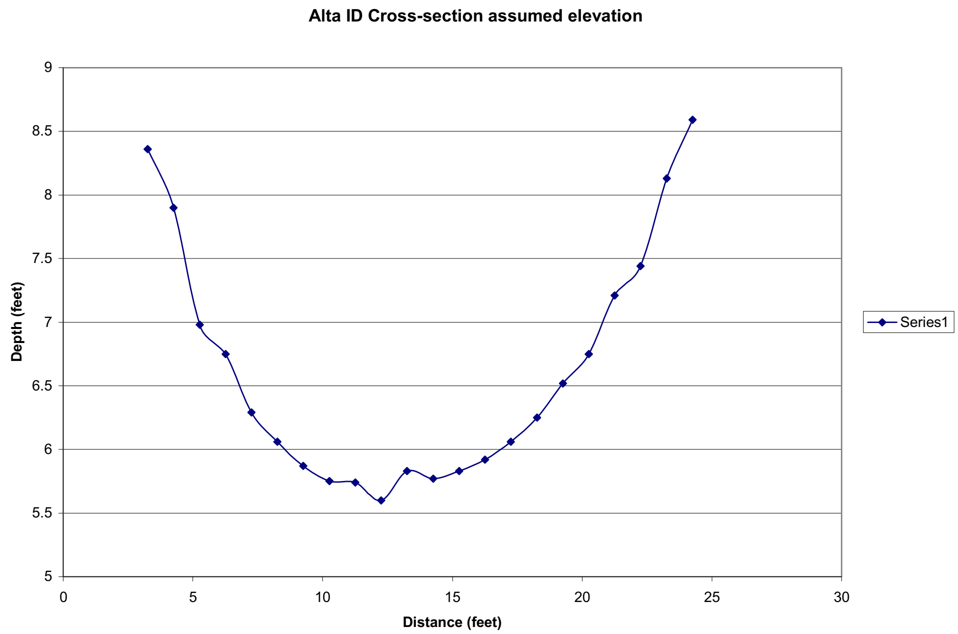


Figure 1. Cross section of canal at Alta Irrigation district.

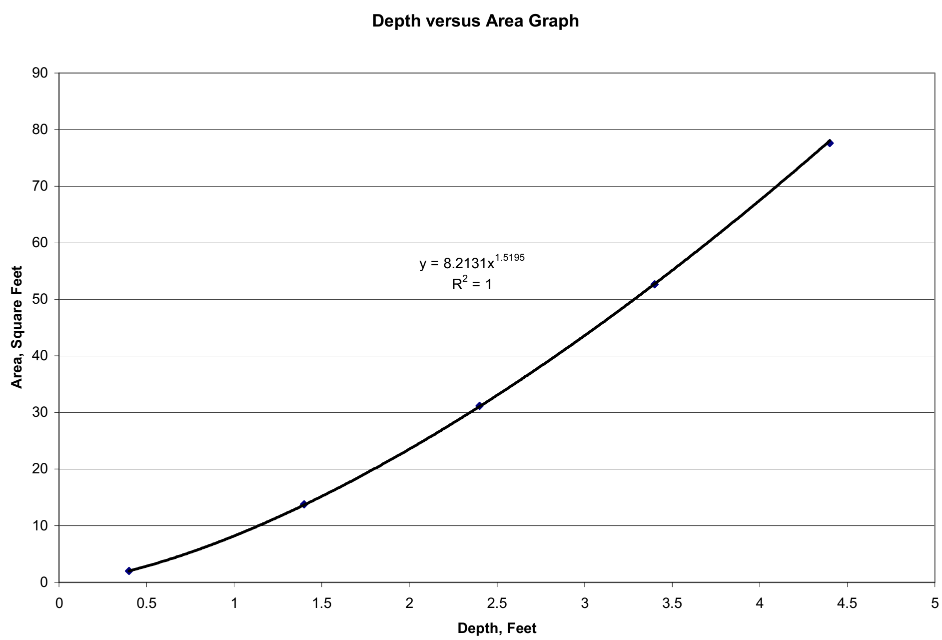


Figure 2. Alta Irrigation Districts canal's relationship between the depth and area.

Photographs

These photographs were taken at AID during the site visit in July 2004.

Figure 3. Acoustic Doppler Profilers collecting indexing data at Alta Irrigation District with installed SonTek SW and non-standard weir structure just downstream.

Figures 4 & 5. Participants in the ITRC Flow Measurement Class

F-3: Anderson Cottonwood Irrigation District Site Visit Report

Irrigation Training and Research Center
BioResource and Agricultural Engineering Department
California Polytechnic State University
San Luis Obispo, California 93407
Tel: (805) 756-2434 Fax: (805) 756-2433

SITE VISIT REPORT

Date: October 11, 2005

To: Stuart Styles, ITRC Director

From: Bryan Busch, Irrigation Support Engineer

Subject: Anderson Cottonwood ID
Site Visit Report: October 11, 2005

A site visit was conducted to the Anderson Cottonwood Irrigation District on October 11, 2005. The purpose of the site visit was to inspect and index an acoustic Doppler flow meter in the district. The trip was coordinated with Kevin Kibby from USBR. This site visit report includes photographs of the installations. This site visit was also completed to train Kevin on installation and calibration procedures developed by the ITRC.

Contact Information

Kevin Kibby, Hydrologist
Tel: (530) 200-4649

Itinerary

Oct 11, 2005 Collected flow rate data with Acoustic Doppler Profiling boats. Data was downloaded by Kevin from the SonTek SL. The flow rate from the Doppler boats were compared. The visit included comparing both of the USBR and ITRC SonTek boats and the ITRC RDI boat.

Acoustic Doppler Flow Meter

The current SonTek SL Doppler flow meter was installed by ITRC in 2003 downstream of the ACID main turnout. Since the SonTek was installed before the use of the ADCP boats it was necessary to start the calibration and indexing procedure. The SonTek SL has been recording for the last two years and been maintained by Kevin Kibby and the USBR. The data from the SonTek units was downloaded and given to Kevin to complete the indexing procedure. The data collected from the unit will be used to evaluate the accuracy and discharge rating of the district's current method of measuring flows at rated sections downstream.

Programming and Index-Rating

The SonTek software is easy to use, and can be set up in less than 15 minutes. To program the unit to perform flow calculations, a cross-sectional survey and index rating must be completed. Further information about programming the SonTek is available from the ITRC and the manufacture.

A cross-section of the canal was obtained by using the surveyed data provided by the district. The SL unit is calibrated by developing a rating curve using data from the acoustic Doppler profiler (ADP) boat at multiple flow rates. To develop a rating curve the channel must be current metered at ten different flow rates to develop a representative curve. The ITRC has prepared guidelines on doing the index rating for hydroacoustic flow meter installations.

Data

During the October 11th site visit data was collected at the site and the unit was reset to continue taking data for the next 3 months. The unit can record and store 15-minute data for over 12 months. The data from the SonTek is being used by the USBR to develop an index rating using the ITRC velocity indexing procedures.

Photographs

These photographs were taken at ACID during the site visit.

Figure 1. SonTek SL mount at ACID before installation.

Figure 2. SonTek SL recording data at ACID.

Figure 3. Kevin Kibby inspecting SCADA equipment at ACID

F-4: Banta Carbona Irrigation District Site Visit Report

IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, California 93407
Tel: (805) 756-2434 Fax: (805) 756-2433 www.itrc.org

SITE VISIT REPORT

Date: 20 September 2004

To: Dr. Stuart Styles, Director ITRC

From: Bryan Busch, Irrigation Support Engineer

Subject: Site Visit Report: October 8, October 27, November 4, 2004 Banta Carbona Irrigation District, Pump rating

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A site visit was conducted to the Banta Carbona Irrigation District on October 8, October 27, and November 4, 2004. The purpose of the trip was to determine the flow rate out of each pump for pump efficiency tests.

Contact Information

Banta Carbona Irrigation District
David Weisenberger
Tel: 209.835.4670
Fax: 209.835.2009

Itinerary

Oct 8, 2004 Tested flow rates out of pump with ADFM RDI boat. Collected data on power usage by pumps and water level upstream and downstream of pumps.

Oct 27, 2004 Collected data on power useage by pumps and water level upstream and downstream of pumps. Tested flow rates out of pump with ADFM RDI boat.

Nov 4, 2004 Tested flow rates out of pump with ADFM RDI boat. Collected data on power usage by pumps and water level upstream and downstream of pumps.

Discharge Measurement

The RDI Acoustic Doppler Current Profiler was used to measure flow rates in the canal for the pump efficiency tests. The RDI StreamPro was used in a lined section of canal downstream of the pumping plant.

Data

Data was collected from the site and used in the efficiency study for the district. The summary of pump efficiency calculations is shown in Table 1.

Table 1. Summary of pump efficiency calculations

	Q (cfs)	TDH (ft)	Avg. Billed KW	IHP	Est. Motor Eff.	WHP	BHP	Bearing Loss (HP)	BHP to Impellers	Pump Bowl Eff. %	**PPE %**
Pump #1	51.4	36.2	248	332	0.96	211	319	3	316	67	**63**
Pump #2	31.9	34.9	139	186	0.96	126	179	2	177	71	**68**
Pump #3	19.5	34.8	84	113	0.96	77	108	1	107	72	**68**
Pump #4	16.0	34.6	67	90	0.96	63	86	1	85	74	**70**
Pump #5	37.1	34.9	156	209	0.96	147	201	2	199	74	**70**
Pump #6	27.6	34.7	131	176	0.96	109	169	2	167	65	**62**

Photographs

These photographs were taken at BCID.

Figure 1. The RDI StreamPro being used to measure flow from the output of pumps at BCID.

Figure 2. BCID pumping plant downstream view.

F-5: Biggs West Gridley Irrigation District Site Visit Report

Irrigation Training and Research Center
BioResource and Agricultural Engineering Department
California Polytechnic State University
San Luis Obispo, California 93407
Tel: (805) 756-2434 Fax: (805) 756-2433

SITE VISIT REPORT

Date: October 12, 2005

To: Stuart Styles, ITRC Director

From: Bryan Busch, Irrigation Support Engineer

Subject: Biggs West Gridley Irrigation District
Site Visit Report: October 12, 2005

A site visit was conducted to the Biggs West Gridley Irrigation District on October 12, 2005. The purpose of the site visit was to inspect and index two acoustic Doppler flow meters in the district. The trip was coordinated with Kevin Kibby from USBR and Donnie Stinnett, Water Master. This site visit report includes photographs of the installations.

Contact Information

Kevin Kibby, Hydrologist
Tel: (530) 200-4649

Donnie Stinnett, Water Master
Tel: (530) 846-3307

Itinerary

Oct 12, 2005 Collected flow rate data with Acoustic Doppler Profiling boats. Data was downloaded by Kevin from the SonTek SW. The flow rate from the Doppler boats was compared. The visit included comparing both of ITRC SonTek boats and the ITRC RDI boat. The flow rate was measured at both locations that have a SonTek SW installed.

Acoustic Doppler Flow Meter

The current SonTek SW Doppler flow meters were installed by Ron Nauman throughout the district. The SonTek SW's have been recording for the last year and been maintained by Kevin Kibby and the USBR. The meters have not been calibrated; therefore the use of ADP boats was necessary to index the site. The data from the SonTek units was downloaded and given to Kevin to complete the indexing procedure. The data collected from the unit will be used to evaluate the accuracy and discharge rating of the district's current method of measuring flows at rated sections downstream.

Programming and Index-Rating

The SonTek software is easy to use, and can be set up in less than 15 minutes. To program the unit to perform flow calculations, a cross-sectional survey and index rating must be completed. Further information about programming the SonTek is available from the ITRC and the manufacture.

A cross-section of the canal was obtained by using the surveyed data provided by the district SonTek SW units. The SL unit is calibrated by developing a rating curve using data from the acoustic Doppler profiler (ADP) boat at multiple flow rates. To develop a rating curve the channel must be current metered at ten different flow rates to develop a representative curve. The ITRC has prepared guidelines on doing the index rating for hydroacoustic flow meter installations.

Data

October, 12 data was collected at the site and the unit was reset to continue taking data for the next 3 months. The unit can record and store 15-minute data for over 12 months. The data from the SonTek is being used by the USBR to develop an index rating using the ITRC procedures.

Photographs

These photographs were taken at BWGID during the site visit.

Figure 1. SonTek SW #1 Location at BWGID.

Figure 2. SonTek SW uses new flow display.

Figure 3. SonTek SW site using plastic lining.

F-6: Klamath Irrigation District Site Visit Report

Irrigation Training and Research Center
BioResource and Agricultural Engineering Department
California Polytechnic State University
San Luis Obispo, California 93407
Tel: (805) 756-2434 Fax: (805) 756-2433

Site Visit Report

Date: May 16, 2005

To: Dr. Stuart Styles, ITRC Director

From: Bryan Busch, Irrigation Support Engineer

Subject: Klamath Irrigation District, A, B, C, and D Canals
Site Visit Report: April 25-29, 2005

ITRC conducted a site visit to Klamath Irrigation District on April 25-29, 2005 as part of the Klamath Project, on behalf of the U.S. Bureau of Reclamation, Klamath Basin Area Office. The purpose of the site visit was to inspect and index the hydroacoustic flow meters in the A, B, C, and D Canals. The trip was coordinated with Darin Kandra and Mark Stuntebeck from KID and Jon House from the USGS. This report includes the collected flow rate data and site photographs.

Contact Information

Klamath Irrigation District (KID) - 6640 KID Lane, Klamath Falls, OR 97603
Darin Kandra, SCADA Manager KID
Tel: 541.882.6661
Fax: 541.882.4004

Mark Stuntebeck, Assistant Manager KID
Tel: 541.882.6661
Fax: 541.882.4004

Jon House, Supervisory Hydrologic Technician
Tel: 541.776.4282
Fax: 541.776.4257
Email: jghouse@usgs.gov

Itinerary

April 26, 2005 Arrived at the KID B Canal and inspected the SonTek Argonaut SL flow meter and the RTU. The data sets from the Argonaut SL were downloaded, containing the cross-section dimensions, recording intervals, date/time, etc. Completed flow measurement with Acoustic Doppler Current Profilers (ADCP's) for indexing. Reviewed and updated the gate control setup procedures in the RTU with Darin.

Completed taking the ADCP flow measurement data at the KID A Canal. The portable ITRC water depth measurement system (Druck pressure transmitter and Telog datalogger) was installed to record water elevations upstream of the canal headgates. Concurrently, Jon House current metered the A Canal approximately 1 mile downstream of the headgates. Data was also collected from the Accusonic flow meter that is the primary device used for the automation of the A Canal.

April 28, 2005 Reviewed and updated the gate control setup procedures in RTU with Darin. Completed flow measurement data collection with the ADCP's for indexing at the C and D Canals. Downloaded data collected from both flow meters.

April 29, 2005 Reviewed and updated the gate control setup procedures in RTU with Darin. Collected data from the Accusonic flow meter at the A Canal. Retrieved the ITRC Druck/Telog unit.

A Canal

The water depth in the A Canal upstream of the headgates at the location of the Accusonic flow meter is measured by a Milltronics Probe ultrasonic water level sensor. The velocity through the A Canal is measured using the Accusonic transit time flow meter. The meter utilizes a multiple parallel path transit time flow measurement technique, which is designed for accurate flow measurement, ±5% of the actual flow rate.

As part of the verification of the flow measurement and automation performance of the A Canal, ITRC and the USGS will be conducting flow measurement tests throughout the 2005 irrigation season. The ITRC will be using a SonTek RiverCat (a boat-mounted ADCP) and the USGS is using a current metering process on a free spanning bridge located 1 mile downstream of the headgates. Table 1 summarizes the flow data collected during the site visit.

Table 1. Flow rates at the headgate of the A Canal

	Average Flow, cfs	Area at headgate (sq ft)	Mean Velocity at Headgate, ft/sec	% error from Accusonic Meter
ADCP ITRC	402	964	0.417	0.7%
Accusonic	405	986	0.411	---
USGS current metering	433			6.9%

The data collected on April 26, 2005 showed the Accusonic flow meter reading 405 cfs, while the ITRC RiverCat measured a flow rate of 402 cfs, and the USGS current metered a flow rate of 433 cfs. As a general rule, all flow rate measurements taken with standard, properly installed and maintained flow meters are assumed to be ±5% accurate. Therefore, these flow rate measurements indicate that the Accusonic flow meter is performing with an acceptable accuracy at this low-mid range flow rate.

Additional data will be collected and analyzed later in the season over the entire range of flow rates to verify acceptable accuracies.

B Canal

Klamath Irrigation District upgraded the flow measurement station in the B Canal by installing a SonTek Argonaut SL flow meter in 2004. Currently the gate at the start of the B Canal is operated using inputs including upstream and downstream water levels and gate position to determine the flow through the gate. The Argonaut SL can be used to control the gate, and sends real-time data back to the district headquarters.

A connection was adjusted in the wiring after KID staff re-installed the meter in preparation for the start of the irrigation season.

Data was downloaded from the flow meter and saved as KIDB001-KIDB008.arg using ViewArgonaut software. The SonTek diagnostics program was checked to verify that the current set-up and deployment parameters were correct (Refer to Appendix 1 for a copy of the deployment settings). A beam check was done to determine if the sensor was measuring the correct area of the channel, and no obstructions or irregularities were found to be interfering. Figure 1 shows the beam check graph from the test.

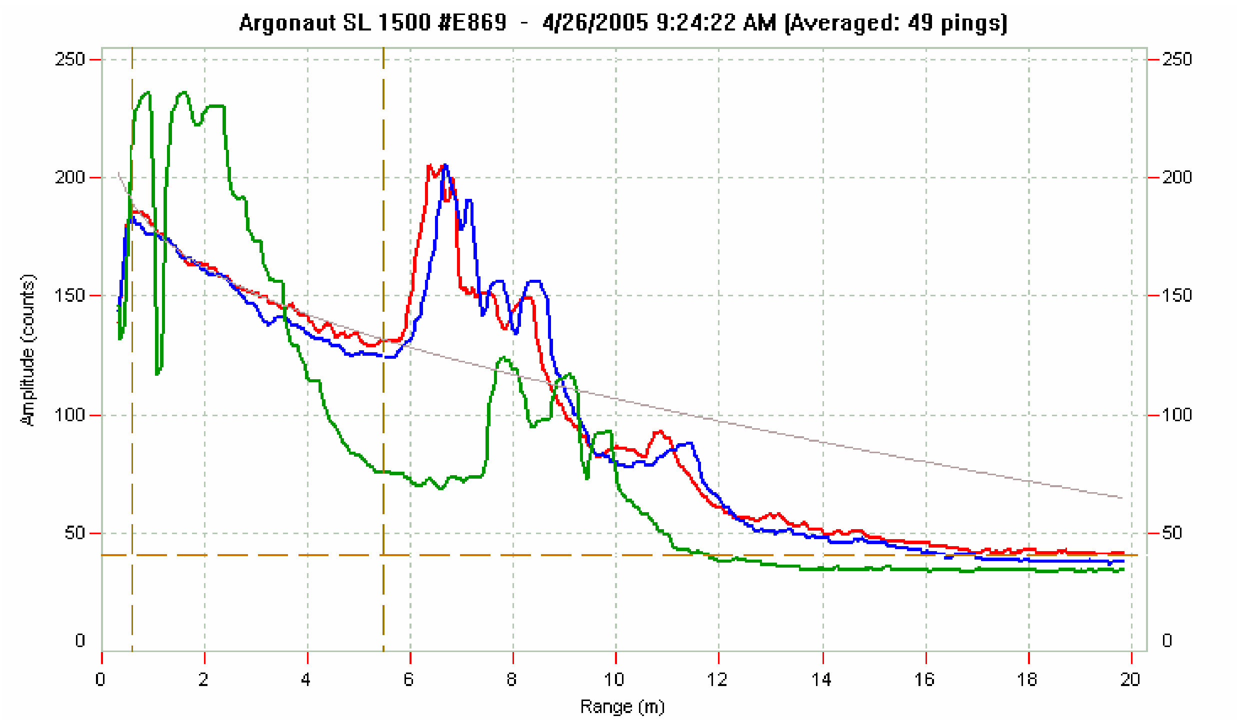

Figure 1. Beam check file for Argonaut SL at the B Canal

A second test was started to collect and record flow measurement data that will be used to index the site. The SonTek RiverCat ADCP measured an average flow rate of 80.5 cfs from 10:50 a.m. to 11:20 a.m. on April 26, 2005. The RDI StreamPro ADCP measured an average flow rate of 76.9 cfs from 11:30 a.m. to 11:50 a.m. The resulting average flow rate from both devices for this time period was 78.7 cfs. During the same time period, the average flow rate measured by the Argonaut SL was 74.9 cfs. Therefore, no adjustments to the existing indexing equation were made due to the closeness of the independently recorded values. Figure 2 shows the flow rate data recorded by the Argonaut SL for the 37 days prior to the visit.

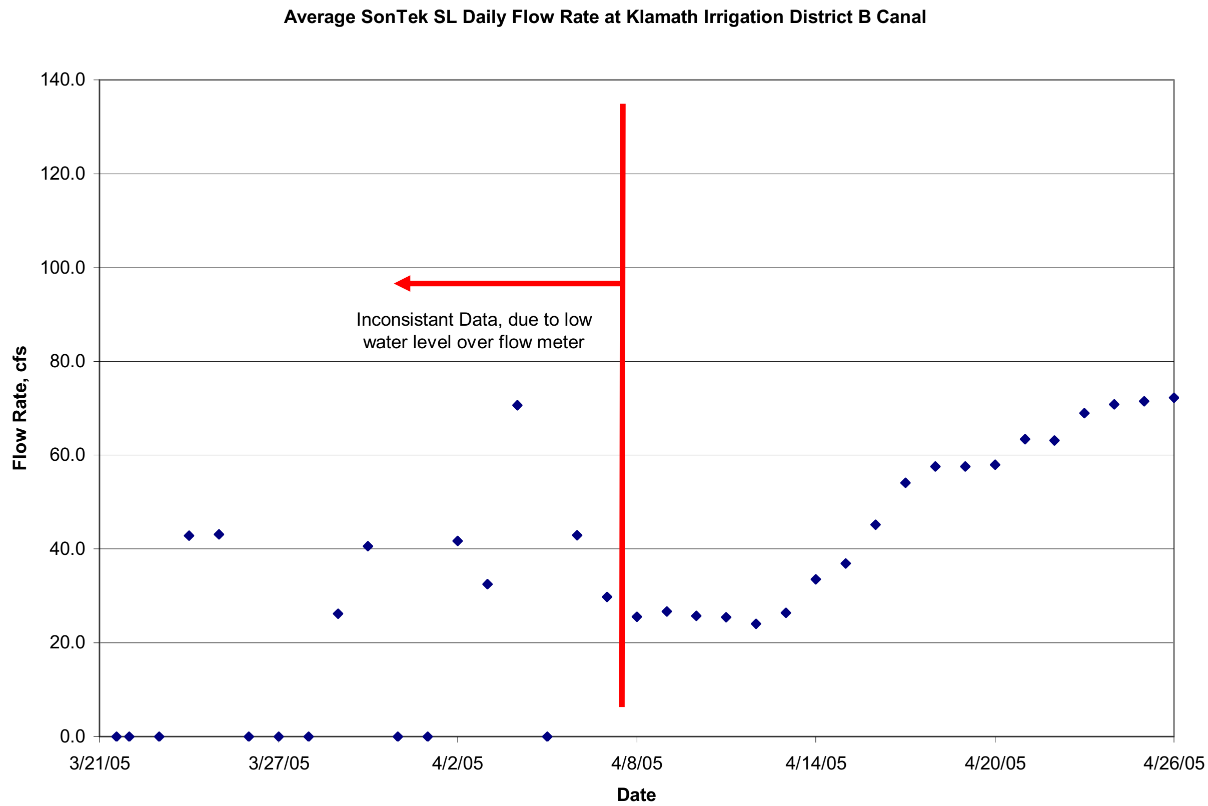

Figure 2. Average daily flow rate in the B Canal

C Canal

Klamath Irrigation District upgraded the flow measurement station in the C Canal by installing a SonTek Argonaut SL flow meter in 2004. Prior to this, flows were estimated using rating curves for the elevated flume located immediately downstream of the new station.

Data was downloaded from the flow meter and saved as KIDC001-KIDC021.arg. The SonTek diagnostics program was checked to verify that the current set-up and deployment parameters were correct (Refer to Appendix 2 for a copy of the deployment settings). A beam check was done to determine if the sensor was measuring the correct area of the channel, and no obstructions or irregularities were found to be interfering. Figure 3 shows the beam check graph from the test.

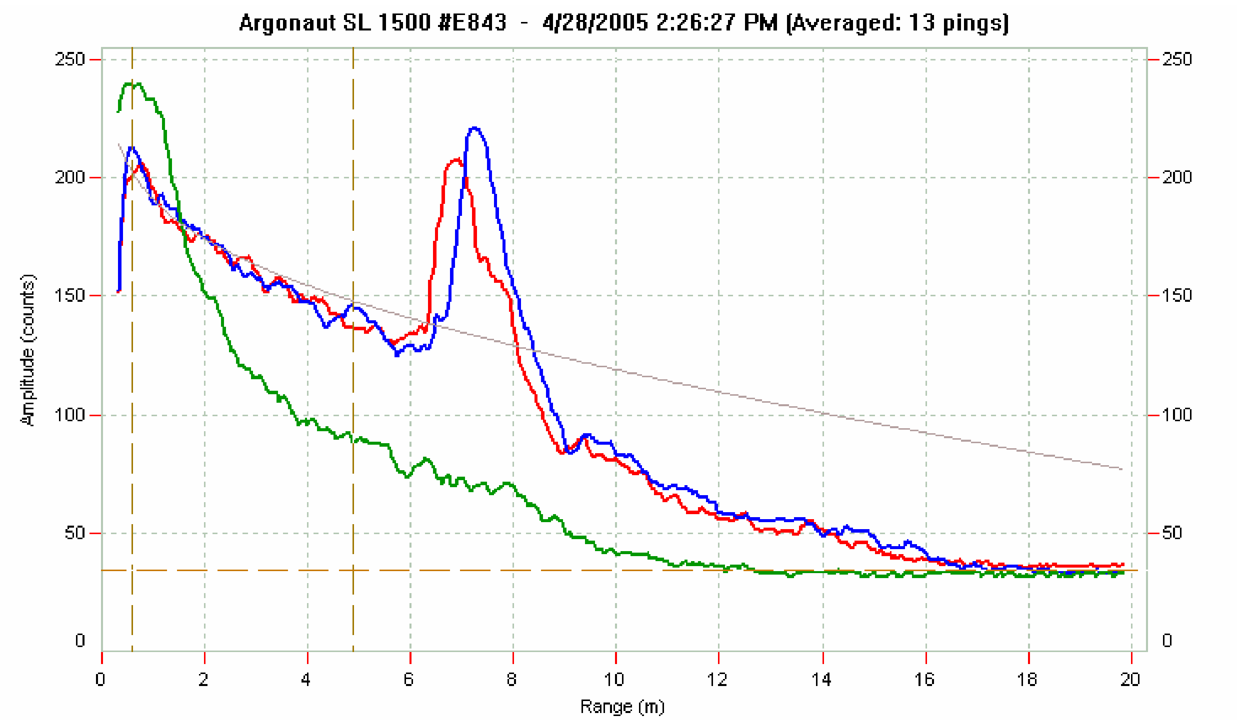

Figure 3. Beam check file for Argonaut SL at the C Canal

The beam test indicated that the sensor has just enough water over the meter to read an accurate flow rate. The data collected during the visit showed the depth reading bouncing in a 1-ft interval over a ten minute period. This irregularity is an indication that the meter probably needs to be lowered further down the bank so that low flows (shallow depths) can be measured accurately and reliably. When this is done a new indexing equation must be derived.

A second test was started to collect and record flow measurement data that will be used to index the site. Flow measurement data was collected using the ADCP's according to the ITRC indexing procedure. The SonTek RiverCat ADCP measured an average flow rate of 148.0 cfs during the test period from 2:50 p.m. to 3:10 p.m. on April 26, 2005. The RDI StreamPro ADCP measured an average flow rate of 149.2 cfs from 3:15 p.m. to 3:30 p.m. The resulting average flow rate measured from 2:50 p.m. to 3:30 p.m. was 148.6 cfs.

During the same time period, the average flow rate recorded by the Argonaut SL was 125.5 cfs. Therefore, an adjustment was made to the indexing equation: the indexing coefficient was modified by averaging the two indexing factors (last year's and this year's values). The new index factor for this flow meter is 0.717. Figure 4 shows the flow rate data recorded by the Argonaut SL for the 17 days prior to this visit.

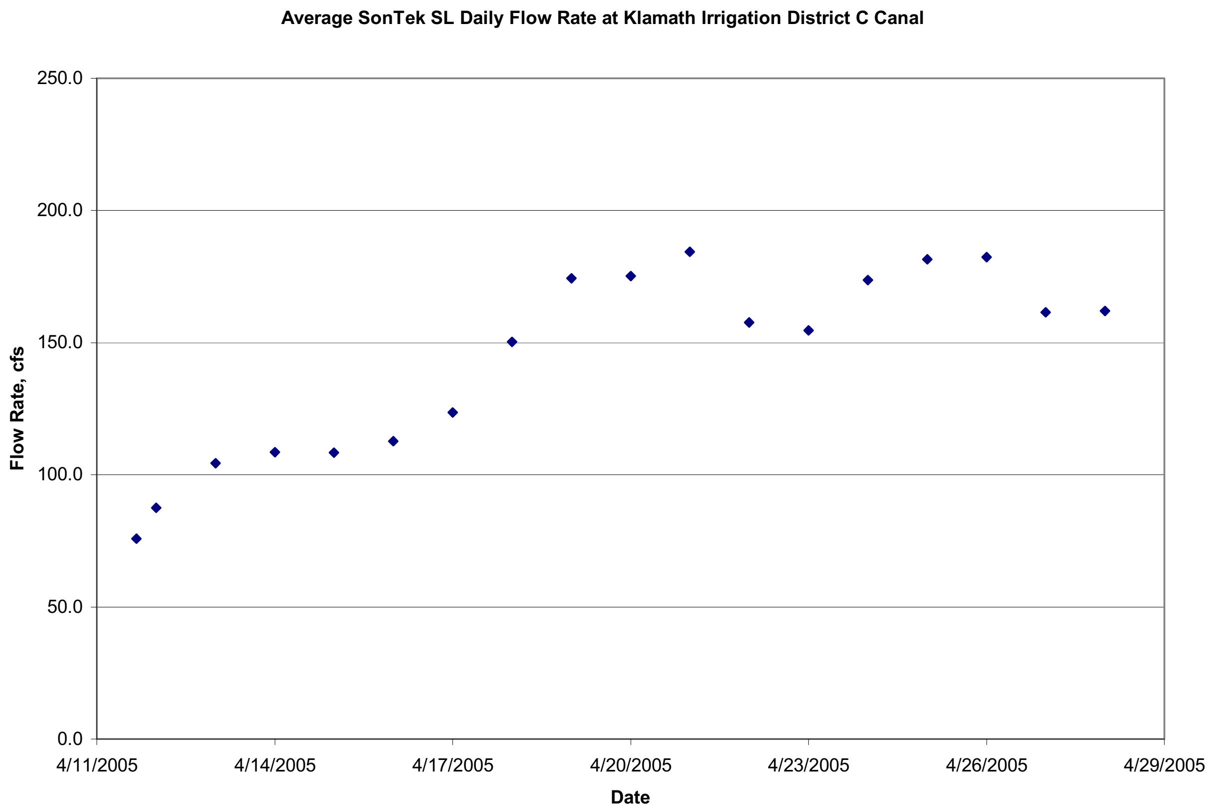

Figure 4. Average daily flow rate in the C Canal

D Canal

Klamath Irrigation District upgraded the flow measurement station in the D Canal by installing a SonTek Argonaut SL flow meter in 2004. Prior to this, flow rates were estimated by the operators using a weir board measurement at an upstream flashboard check structure.

Data was downloaded from the flow meter and saved as KIDD001-KID016.arg. The SonTek diagnostics program was checked to verify that the current set-up and deployment parameters were correct (Refer to Appendix 3 for a copy of the deployment settings). A beam check was done to determine if the sensor was measuring the correct area of the channel, and no obstructions or irregularities were found to be interfering. Figure 5 shows the beam check graph from the test.

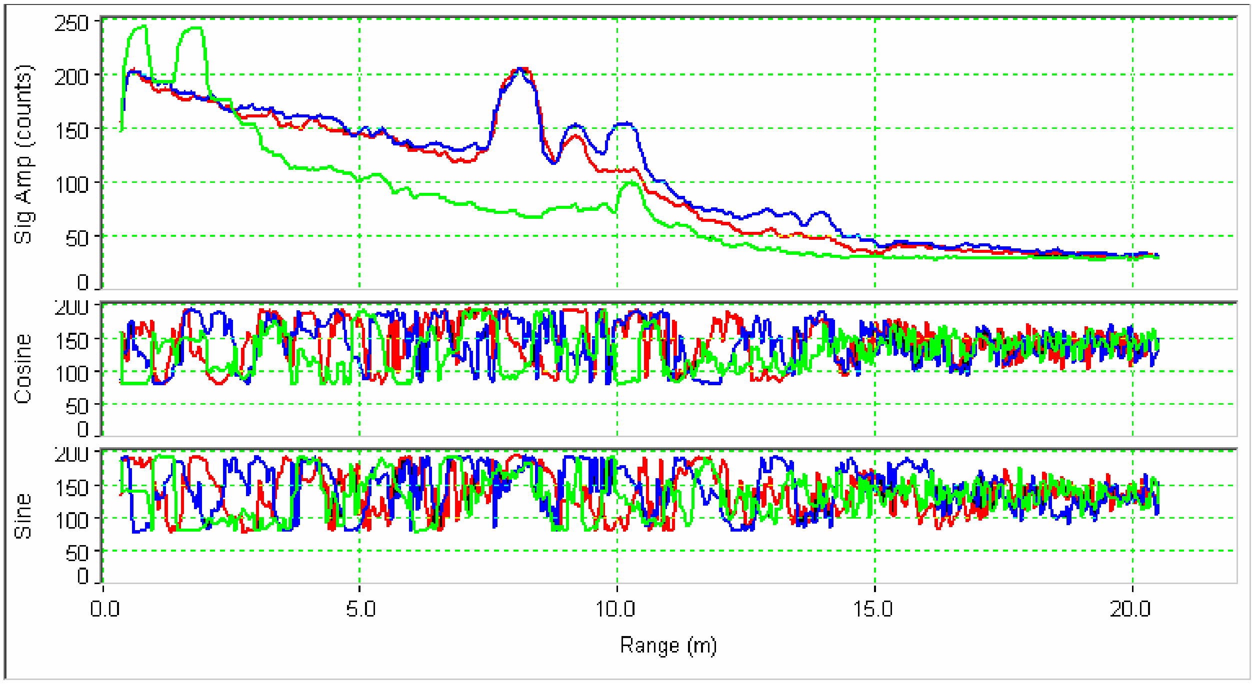

Figure 5. Beam check file for Argonaut SL at the D Canal

The beam test showed that the Argonaut SL was reading a reflection of the water depth at twice the actual water depth. This irregularity is an indication that the meter probably needs to be lowered further down the bank so that low flows (shallow depths) can be measured accurately and reliably. When this is done a new indexing equation must be derived.

A second test was started to collect and record flow measurement data that will be used to index the site. Flow measurement data was collected using the ADCP's according to the ITRC indexing procedure. The SonTek RiverCat ADCP measured an average flow rate of 79.6 cfs from 5:30 p.m. to 5:50 p.m. on April 28, 2005. The RDI StreamPro ADCP measured an average flow rate of 74.1 cfs from 5:55 p.m. to 6:10 p.m. The resulting average flow rate measured from 5:30 p.m. to 6:10 p.m. was 76.9 cfs. During the same time period, the average flow rate recorded by the Argonaut SL was 71.8 cfs. Therefore, an adjustment was made to the indexing equation. The indexing coefficient was modified by averaging the two indexing factors (last year's and this year's values). The new index factor for this flow meter is 0.85. Figure 6 shows the flow rate data recorded on the Argonaut SL for the 24 days prior to this visit.

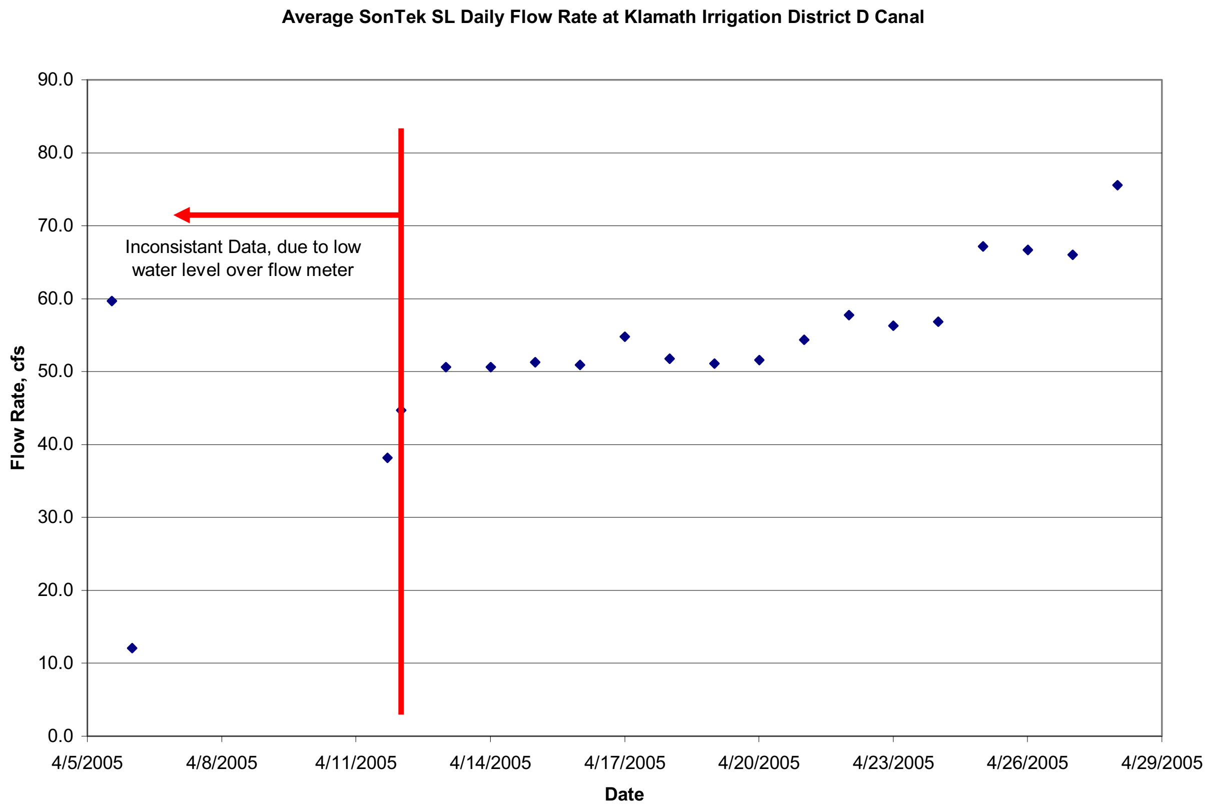

Figure 6. Average daily flow rate through the D Canal

Photographs

The following photographs were taken at Klamath Irrigation District on April 26-29, 2005.

Figure 7. Measuring the flow rate in the B Canal using RDI StreamPro ADCP

Figure 8. Measuring the flow rate in the D Canal using the SonTek RiverCat ADCP

Figure 9. District-standard SCADA RTU with a RUGID PLC at the D Canal

Figure 10. Typical SonTek SL aluminum mounting frame in a concrete-lined section

Figure 11. 900 MHz radio used to transfer Argonaut SL data to RTU located at the head of the B Canal

Recommendations

To improve the long-term measurement accuracy and reliability of the of the Argonaut SL flow meters in Klamath Irrigation District, ITRC recommends the following:

- When the flow meters are re-installed at the start of the next irrigation season, move the sensors in the C and D Canals further down the bank to an elevation of 2.5 ft from the bottom of the canal. This is equivalent to lowering them about 1.5 ft and 1 ft, respectively.
- Repeat the indexing procedure at the four sites over the entire range of flow rates.
- When more index values are determined, complete a two-variable rating equation instead of the current linear equation.

Appendix 1:
KID B Canal SonTek Program

```
Connected to COM1: at 9600
<BREAK>
WARNING: UNEXPECTED POWER DOWN. REAL-TIME MODE ASSUMED!
Checking Setup Parameters...

2555904 free bytes left in recorder.
Free space is sufficient for 188.82 days of operation.
Recorder mode is NORMAL.

Data will be recorded to file KIDB008.
OK
<BREAK>

Argonaut-SL
SonTek/YSI, Inc.
Copyright 1996-2002

Wake up initialization. Please wait...

>ai
Current averaging interval is 300 s.
>si
Current sample interval is 300 s.
>ai 30
OK
>si 30
OK
>savesetup
OK
>show geo
 ---------------------------------------------------
 Current Channel Geometry:
 Point  Horiz Dist(ft)  Elev (ft)
   1      0.0       6.59
   2      10.0      0.00
   3      26.9      0.00
   4      36.9      6.59
   5      BLANK     BLANK
   6      BLANK     BLANK
   7      BLANK     BLANK
   8      BLANK     BLANK
   9      BLANK     BLANK
  10      BLANK     BLANK
  11      BLANK     BLANK
  12      BLANK     BLANK
  13      BLANK     BLANK
  14      BLANK     BLANK
  15      BLANK     BLANK
  16      BLANK     BLANK
  17      BLANK     BLANK
  18      BLANK     BLANK
  19      BLANK     BLANK
  20      BLANK     BLANK

>show conf
```

```
HARDWARE CONFIGURATION PARAMETERS
---------------------------------
System Type -------------------- SL
Sensor serial # ---------------- E869
Sensor frequency - (kHz) ------- 1500
Number of beams ---------------- 2
Beam Geometry ------------------ 2_BEAMS
Vertical Beam ------------------ YES
Slant angle - (deg) ------------ 25.0
Compass Orientation ------------ SIDE
Compass installed  ------------- NO
Recorder installed ------------- YES
SDI-12  installed  ------------- YES
Temperature sensor ------------- YES
Pressure    sensor ------------- YES
PressOffset  - (dbar) ---------- -0.110310
PressScale  -- (dbar/count) ---- 0.000205
PressScale_2 - (pdbar/count^2) - 89
Ctd         sensor ------------- NO
Ext. Press. sensor ------------- NONE
YSI         sensor ------------- NO
Waves Option ------------------- NO
Internal SDI-12 Option --------- YES
Analog Output Option ----------- NO
Internal Flow Computations ----- YES
>Show System

CURRENT SYSTEM PARAMETERS
-------------------------
CPU Ver --- ARG 8.9
DSP Ver --- DSP 1.0
BoardRev -- REV G
Date ------ 2005/04/26
Time ------ 09:10:19
AutoSleep - YES
OutMode --- AUTO
OutFormat - ENGLISH
Recorder -- ON
RecMode --- NORMAL
ModemMode - NO

>Show setup

CURRENT SETUP PARAMETERS
------------------------
Temp ----------- 20.00 deg C
Sal ------------ 0.00 ppt
TempMode ------- MEASURED
Sound Speed ---- 1481.6 m/s
AvgInterval ---- 30 s
SampleInterval - 30 s
CoordSystem ---- XYZ
DataFormat ----- LONG
CellBegin ------ 0.61 m
CellEnd -------- 5.49 m
```

```
>Date 2005/04/26
OK
>Time 09:14:49
OK
>
Argonaut-SL
SonTek/YSI, Inc.
Copyright 1996-2002

Wake up initialization. Please wait...

>recorder
Recorder is ON.
>of
Current Output Format is ENGLISH.
>deployment
Current deployment name is: KIDB.
>tempmode
Temperature used for computing speed of sound is MEASURED.
>sal
Current salinity is 0.00.
>cb
Current Cell Begin is 0.61 meters.
>ce
Current Cell End is 5.49 meters.
>coordsystem

Current coordinate system is XYZ.
>ai
Current averaging interval is 30 s.
>si
Current sample interval is 30 s.
>date
2005/04/26
>time
09:27:27
Vertical Beam: YES.
>setargelevation
Current Argonaut elevation is 2.50 (ft).
>veq
 Current Flow Computation Equation is: INDEX:  Q= Vmean x Area, where
 Vmean = Vintercept + Vslope x Vmeas + LevelCoef x Level

 Current Index Velocity Coefficients Are:
 Vintercept:        0.00  (ft/s)
 Vslope:            0.859
 LevelCoef:         0.000 (1/s)

 ChangeFlowSign:      YES
>savesetup
OK
>saveflowdatum
OK
Current Index Velocity Coefficients Are:
 Vintercept:        0.00  (ft/s)
 Vslope:            0.859
```

```
LevelCoef:          0.000 (1/s)

ChangeFlowSign:      YES
Arg Elevation is:   2.50  (ft).
----------------------------------------------------
Current Channel Geometry:
Point  Horiz Dist(ft)  Elev (ft)
  1       0.0          6.59
  2      10.0          0.00
  3      26.9          0.00
  4      36.9          6.59
  5      BLANK         BLANK
  6      BLANK         BLANK
  7      BLANK         BLANK
  8      BLANK         BLANK
  9      BLANK         BLANK
 10      BLANK         BLANK
 11      BLANK         BLANK
 12      BLANK         BLANK
 13      BLANK         BLANK
 14      BLANK         BLANK
 15      BLANK         BLANK
 16      BLANK         BLANK
 17      BLANK         BLANK
 18      BLANK         BLANK
 19      BLANK         BLANK
 20      BLANK         BLANK

>start
Checking Setup Parameters...

4194304 free bytes left in recorder.
Free space is sufficient for 30.99 days of operation.
Recorder mode is NORMAL.

Data will be recorded to file KIDB001.
OK
```

Appendix 2:
KID C Canal SonTek Program

```
Connected to COM1: at 9600
<BREAK>

Argonaut-SL
SonTek/YSI, Inc.
Copyright 1996-2002

Wake up initialization. Please wait...

>Show conf

HARDWARE CONFIGURATION PARAMETERS
---------------------------------
System Type -------------------- SL
Sensor serial # ---------------- E843
Sensor frequency - (kHz) ------- 1500
Number of beams ---------------- 2
Beam Geometry ------------------ 2_BEAMS
Vertical Beam ------------------ YES
Slant angle - (deg) ------------ 25.0
Compass Orientation ------------ SIDE
Compass installed  ------------- NO
Recorder installed ------------- YES
SDI-12  installed  ------------- YES
Temperature sensor ------------- YES
Pressure    sensor ------------- YES
PressOffset  - (dbar) ---------- -0.110000
PressScale  -- (dbar/count) ---- 0.000203
PressScale_2 - (pdbar/count^2) - 128
Ctd         sensor ------------- NO
Ext. Press. sensor ------------- NONE
YSI         sensor ------------- NO
Waves Option ------------------- NO
Internal SDI-12 Option --------- YES
Analog Output Option ----------- NO
Internal Flow Computations ----- YES
>Show System

CURRENT SYSTEM PARAMETERS
-------------------------
CPU Ver --- ARG 8.9
DSP Ver --- DSP 1.0
BoardRev -- REV G
Date ------ 2005/04/28
Time ------ 14:08:33
AutoSleep - YES
OutMode --- AUTO
OutFormat - ENGLISH
Recorder -- ON
RecMode --- NORMAL
ModemMode - NO

>Show setup

CURRENT SETUP PARAMETERS
------------------------
```

```
Temp ----------- 20.00 deg C
Sal ------------ 0.00 ppt
TempMode ------- MEASURED
Sound Speed ---- 1481.6 m/s
AvgInterval ---- 600 s
SampleInterval - 600 s
CoordSystem ---- XYZ
DataFormat ----- LONG
CellBegin ------ 0.61 m
CellEnd -------- 4.88 m
>Show Deploy

CURRENT DEPLOYMENT PARAMETERS
-----------------------------
Deployment ------ KIDC
StartDate ------- 2004/09/03
StartTime ------- 10:58:00
AvgInterval ----- 600 s
SampleInterval -- 600 s
BurstMode ------- DISABLED
BurstInterval --- 1200 s
SamplesPerBurst - 1
Comments:



>Date 2005/04/28
OK
>Time 14:24:53
OK
>show fdatum
 ---------------------------------------------------
 Current Flow Computation Equation is: INDEX:  Q= Vmean x Area, where
 Vmean = Vintercept + Vslope x Vmeas + LevelCoef x Level

 Current Index Velocity Coefficients Are:
 Vintercept:        0.00  (ft/s)
 Vslope:            0.656
 LevelCoef:         0.000 (1/s)

 ChangeFlowSign:      NO
 Arg Elevation is:    3.92  (ft).
 ---------------------------------------------------
 Current Channel Geometry:
 Point  Horiz Dist(ft)  Elev (ft)
   1        0.0          7.99
   2       10.0          0.00
   3       26.9          0.00
   4       36.9          6.58
   5       BLANK         BLANK
   6       BLANK         BLANK
   7       BLANK         BLANK
   8       BLANK         BLANK
   9       BLANK         BLANK
  10       BLANK         BLANK
  11       BLANK         BLANK
```

```
  12    BLANK    BLANK
  13    BLANK    BLANK
  14    BLANK    BLANK
  15    BLANK    BLANK
  16    BLANK    BLANK
  17    BLANK    BLANK
  18    BLANK    BLANK
  19    BLANK    BLANK
  20    BLANK    BLANK

>ai
Current averaging interval is 600 s.
>si
Current sample interval is 600 s.
>ai 600
OK
>si 600
OK
>savesetup
OK
>recorder
Recorder is ON.
>setargelevation
Current Argonaut elevation is 3.92 (ft).
>start
Checking Setup Parameters...

2686976 free bytes left in recorder.
Free space is sufficient for 397.01 days of operation.
Recorder mode is NORMAL.

Data will be recorded to file KIDC021.
OK

Argonaut-SL
SonTek/YSI, Inc.
Copyright 1996-2002

Wake up initialization. Please wait...

>recorder
Recorder is ON.
>of
Current Output Format is ENGLISH.
>deployment
Current deployment name is: KIDC.
>tm
Temperature used for computing speed of sound is MEASURED.
>sal
Current salinity is 0.00.
>cb
Current Cell Begin is 0.61 meters.
>ce
Current Cell End is 4.88 meters.
>coordsystem
```

Current coordinate system is XYZ.
>ai
Current averaging interval is 600 s.
>si
Current sample interval is 600 s.
>date
2005/04/28
>time
15:47:26
>setargelevation
Current Argonaut elevation is 3.92 (ft).
>veq
Current Flow Computation Equation is: INDEX: Q= Vmean x Area, where
Vmean = Vintercept + Vslope x Vmeas + LevelCoef x Level

Current Index Velocity Coefficients Are:
Vintercept: 0.00 (ft/s)
Vslope: 0.656
LevelCoef: 0.000 (1/s)

ChangeFlowSign: NO
>save setup
ERROR: Unknown configuration [SETUP].
OK
>savesetup
OK
>savefdatum
ERROR: Command not recognized: SAVEFDATUM
>saveflowdatum
OK
>start
Checking Setup Parameters...

4194304 free bytes left in recorder.
Free space is sufficient for 619.73 days of operation.
Recorder mode is NORMAL.

Data will be recorded to file KIDC001.
OK

Disconnected

Appendix 3:
KID D Canal SonTek Program

```
Connected to COM1: at 9600
<BREAK>

Argonaut-SL
SonTek/YSI, Inc.
Copyright 1996-2003

Wake up initialization. Please wait...
>Show conf

Hardware Configuration
----------------------
System Type -------------------- SL
Sensor serial # ---------------- E720
Sensor frequency - (kHz) ------- 1500
Number of beams ---------------- 2
Beam Geometry ------------------ 2_BEAMS
Vertical Beam ------------------ YES
Slant angle - (deg) ------------ 25.0
System Orientation ------------- SIDE
Compass installed  ------------- NO
Recorder installed ------------- YES
Temperature sensor ------------- YES
Pressure    sensor ------------- YES
PressOffset  - (dbar) ---------- -0.110000
PressScale  -- (dbar/count) ---- 0.000207
PressScale_2 - (pdbar/count^2) - 44
Ctd         sensor ------------- NO
Ext. Press. sensor ------------- NONE
YSI         sensor ------------- NO
Waves Option ------------------- NO
Internal SDI-12 Option --------- YES
Internal Flow Computations ----- YES
Analog Output Option ----------- NO
Multi-cell Profiling Option ---- NO
>Show System

System Parameters
--------------------
CPU Ver ------------ ARG 10.2
BoardRev ----------- REV G
Date --------------- 2005/04/28
Time --------------- 17:17:04
AutoSleep ---------- YES
VoltageProtecttion - NO
OutMode ------------ AUTO
OutFormat ---------- ENGLISH
Recorder ----------- ON
ModemMode ---------- NO

>Show setup
Setup Parameters
----------------
Temp ----------- 20.00 deg C
Sal ------------ 0.00 ppt
TempMode ------- MEASURED
```

```
Sound Speed ---- 1481.6 m/s
AvgInterval ---- 600 s
SampleInterval - 600 s
CellBegin ------ 0.50 m
CellEnd -------- 6.00 m
CoordSystem ---- XYZ
RevXVelocity --- YES
>show fdatum
Flow equation type is: INDEX
 Q     = Vmean x Area
 Vmean = Vintercept + Vmeas x (Vslope + (StageCoef x Stage))

 Index coefficients:
   Vintercept:    0.000 (ft/s)
   Vslope:        0.820
   StageCoef:     0.000 (1/ft)
Arg Elevation is:    3.150  (ft).
Flow channel type: IRREGULAR
 Point  Horiz Dist(ft)  Elev (ft)
   1        0.0           6.85
   2        9.9           0.00
   3       30.8           0.00
   4       40.7           6.84
   5       BLANK         BLANK
   6       BLANK         BLANK
   7       BLANK         BLANK
   8       BLANK         BLANK
   9       BLANK         BLANK
  10       BLANK         BLANK
  11       BLANK         BLANK
  12       BLANK         BLANK
  13       BLANK         BLANK
  14       BLANK         BLANK
  15       BLANK         BLANK
  16       BLANK         BLANK
  17       BLANK         BLANK
  18       BLANK         BLANK
  19       BLANK         BLANK
  20       BLANK         BLANK
>ai
Current averaging interval is 600 s.
>si
Current sample interval is 600 s.
>start
Checking Setup Parameters...

4194304 free bytes left in recorder.
Free space is sufficient for 582.54 days of operation.

Data will be recorded to file KIDD001.
OK

Disconnected

><BREAK>
```

```
Argonaut-SL
SonTek/YSI, Inc.
Copyright 1996-2003

Wake up initialization. Please wait...

>setindexcoef
Flow equation type is: INDEX
 Q     = Vmean x Area
 Vmean = Vintercept + Vmeas x (Vslope + (StageCoef x Stage))

 Index coefficients:
   Vintercept:    0.000 (ft/s)
   Vslope:        0.820
   StageCoef:     0.000 (1/ft)
>setindexcoef 0 .85 0
OK
>savesetup
OK
>saveflowdatum
OK
>start
Checking Setup Parameters...

4194304 free bytes left in recorder.
Free space is sufficient for 582.54 days of operation.

Data will be recorded to file KIDD001.
OK
```

F-7: Merced Irrigation District Site Visit Report

Irrigation Training and Research Center
BioResource and Agricultural Engineering Department
California Polytechnic State University
San Luis Obispo, California 93407
Tel (805) 756-2434 Fax (805) 756-2433 www.itrc.org

SITE VISIT REPORT

Date: September 6, 2006

To: Stuart Styles, ITRC Director

From: Bryan Busch, Irrigation Support Engineer

Subject: Merced Irrigation District
Site Visit Report: August 4, 2004 and August 31, 2005

A site visit was conducted to the Merced Irrigation District on August 4, 2004 and August 31, 2005. The purpose of the site visit was to determine the accuracy of two Acoustic Doppler Current Profilers (ADCP's) and a Replogle flume. The trip was coordinated with Jerrid Fletcher from Merced ID. This site visit report includes photographs and a summary of the results.

Contact Information

Merced Irrigation District
744 W. 20th Street
Merced, CA 95340.
Phone: (209) 722-5761
Fax: (209) 722-6421

Jerrid Fletcher, Hydrologist
email: jfletcher@mercedid.org

Itinerary

Aug 4, 2004 Collected flow rate data with Acoustic Doppler Profiling boats. Determine flow rate over Replogle flume from Merced ID. Installed Telog water level transducers upstream and downstream of the flume.

Aug 31, 2005 Collected flow rate data with the SonTek ADP boat, and the Replogle flume.

Data and Results

On August 4, 2004 and August 31, 2005 data were collected at the site. **Table 1** shows the results of the evaluation comparing the Replogle flume (as the standard structure) to the SonTek and RDI.

Table 1. Summary comparison of average discharge data from the SonTek and RDI to the Replogle flume as the standard structure.

	Average Flow Rate (cfs)			Discrepancy (%)	
Date	**SonTek**	**RDI**	**Replogle Flume**	**SonTek**	**RDI**
8/4/2004	1217	1207	1252	-3%	-4%
8/31/2005	1106	* * *	1100	1%	* * *

The percent discrepancy shown in **Table 1** was calculated as follows:

$$\text{Discrepancy (\%)} = \frac{\text{measured - standard}}{\text{standard}} \times 100$$

The results shown in **Table 1** suggest consistent flow rate measurements between the two profiling boats. Negative percent discrepancies represent the profiling boats measuring flow rates lower than the Replogle flume. Conversely, positive percent discrepancies represent the profiling boats measuring flow rates higher than the Replogle flume.

Table 2 shows the actual field data collected by the boats for each transect. There is a significant amount of variation in the individual transect discharge measurements. This variation in flow rate measurements validates the need to utilize the stationary measurement method to obtain accurate measurement readings. The stationary, or section by section method, was not yet developed at the time of these site visits.

Table 2. SonTek and RDI discharge measurements for each transect.

Transect	8/4/2004		8/31/2005
	SonTek ADP (cfs)	**RDI ADCP (cfs)**	**SonTek ADP (cfs)**
1	1317	1237	1133
2	1141	1190	1071
3	1239	1231	1120
4	1153	1188	1101
5	1251	1214	
6	1226	1192	
7	1214	1197	
8	1191	1209	
Average	**1217**	**1207**	**1106**

Photographs

The following photographs were taken at Merced ID during the site visit in August 2004 and 2005.

Figure 1. Replogle flume at Merced Irrigation District's main diversion.

Figure 2. SCADA system at MID's Replogle flume.

Figure 3. Using SonTek RiverSurveyor to measure flow rate at MID.

F-8: Patterson Irrigation District Site Visit Report

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SITE VISIT REPORT

Date: September 6, 2006

To: Stuart Styles, ITRC Director

From: Bryan Busch, Irrigation Support Engineer
Marcus Cardenas, Irrigation Support Engineer

Subject: Patterson Irrigation District
SonTek and Replogle Flume Data

Site visits were conducted to the Patterson Irrigation District in 2004 and 2005. The purpose of the site visits was to compare the flow rate data collected with the Acoustic Doppler Profiling (ADP) boat to the flow rate measured by a Replogle flume. The site visits were coordinated with John Sweigard from Patterson ID. This report includes photographs of the installations and a summary of the results.

Acoustic Doppler meters are capable of providing extremely accurate flow measurement data if calibrated properly in the field against a standard device. According to the data from this site visit, the volumetric accuracy of an acoustic flow measurement device can provide measurements that vary less than 1% from a standard flow measurement device. The ITRC strongly emphasizes the need to calibrate any non-standard structure or device such as a hydroacoustic meter. Without proper field calibration, the potential for measurement error is significant.

Contact Information

Patterson Irrigation District
22 Del Puerto Ave.
Patterson, CA 95363-0685
Tel: 209.892.6233
Fax: 209.892.4013

John Sweigard
email: patwater@evansinet.com

Acoustic Doppler Profiling Boats

The Acoustic Doppler Profiling boats use high frequency sound waves and the Doppler effect to measure the flow rate in an open channel. The boats must traverse across the channel, perpendicular to the flow, to collect velocity and depth readings. Using that data, the software calculates the flow rate. A rope and pulley system is typically used to guide the boats across the channel.

The Irrigation Training and Research Center (ITRC) has been investigating the usefulness of ADP boats in calibration of standard and non-standard flow measurement structures. The cross sectional area of the channel determined when using the ADP boats is very accurate and can be used when programming Doppler meters such as the SonTek SL and SonTek SW.

Results

On May 25, 2005, there was a discrepancy of -7% in measured flow rates when comparing the flow rate recorded by the ADP boat to the Patterson ID Replogle flume. This discrepancy was caused by the ADP boat recording "bad" data points in their transects due to the excessive vegetation growth on the banks and bottom of the canal. The vegetation creates a "moving bottom condition" which confuses the ADP, thus recording a bad data point. **Figure 1** illustrates the excessive vegetation growth at Patterson ID.

Figure 1. Vegetative growth at Patterson ID causing poor ADP boat flow rate measurements

SonTek SL and Replogle Flume Comparison

Table 1. Comparison of the SonTek ADP to the Replogle flume (standard)

	Average Flow Rate (cfs)		Discrepancy (%)
Date	**SonTek ADP**	**Replogle Flume**	**SonTek**
5/25/2005	98.5	106.4	-7%

The SonTek SL was field-calibrated against the Replogle flume. Flow measurement data was recorded over a two month period for the comparison shown in Figure 2.

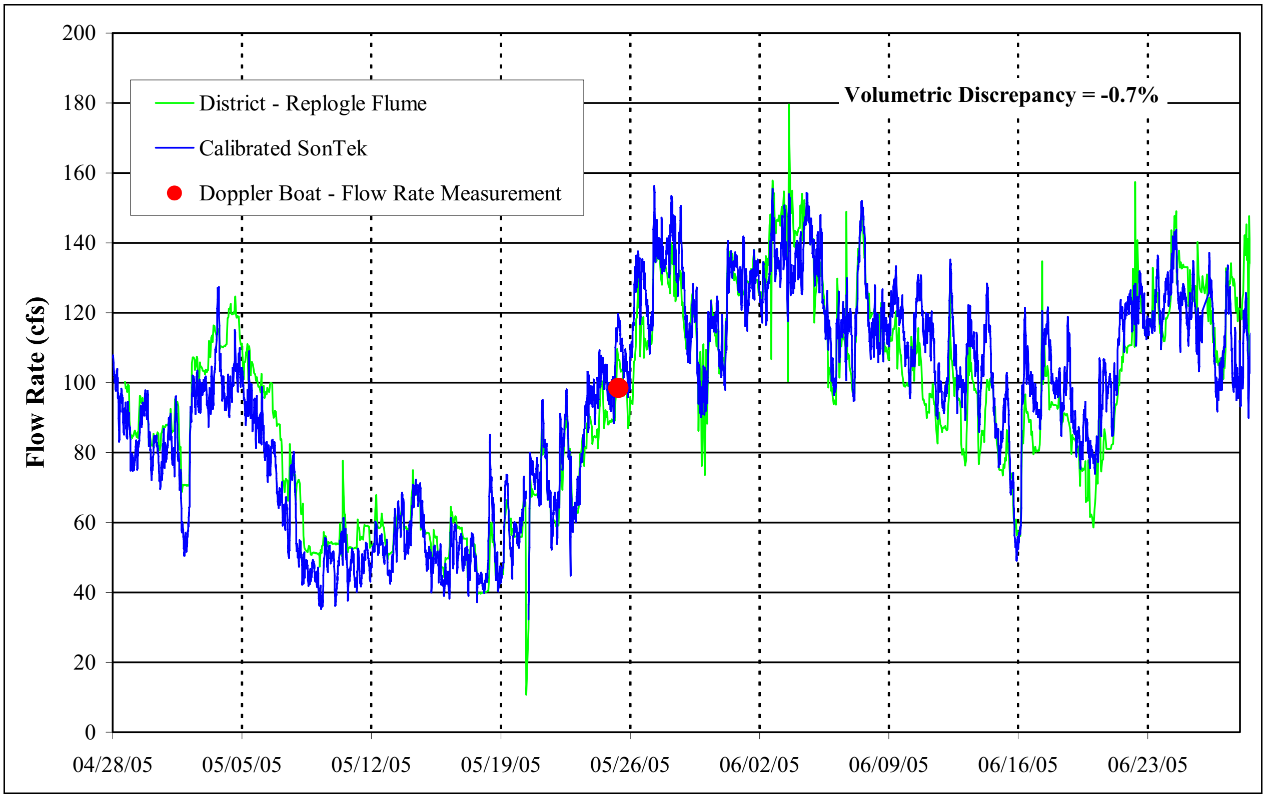

Figure 2. Flow rate comparison of the SonTek SL and Replogle flume

Also shown on **Figure 2** is the data point corresponding to the time when the ADP boat was used to collect the data shown in **Table 1**.

Figure 3 shows the accumulated volumetric comparison of the SonTek SL and the district's Replogle flume. The discrepancy between the accumulated volumes, using the flume as the standard was -0.7% for the time period analyzed.

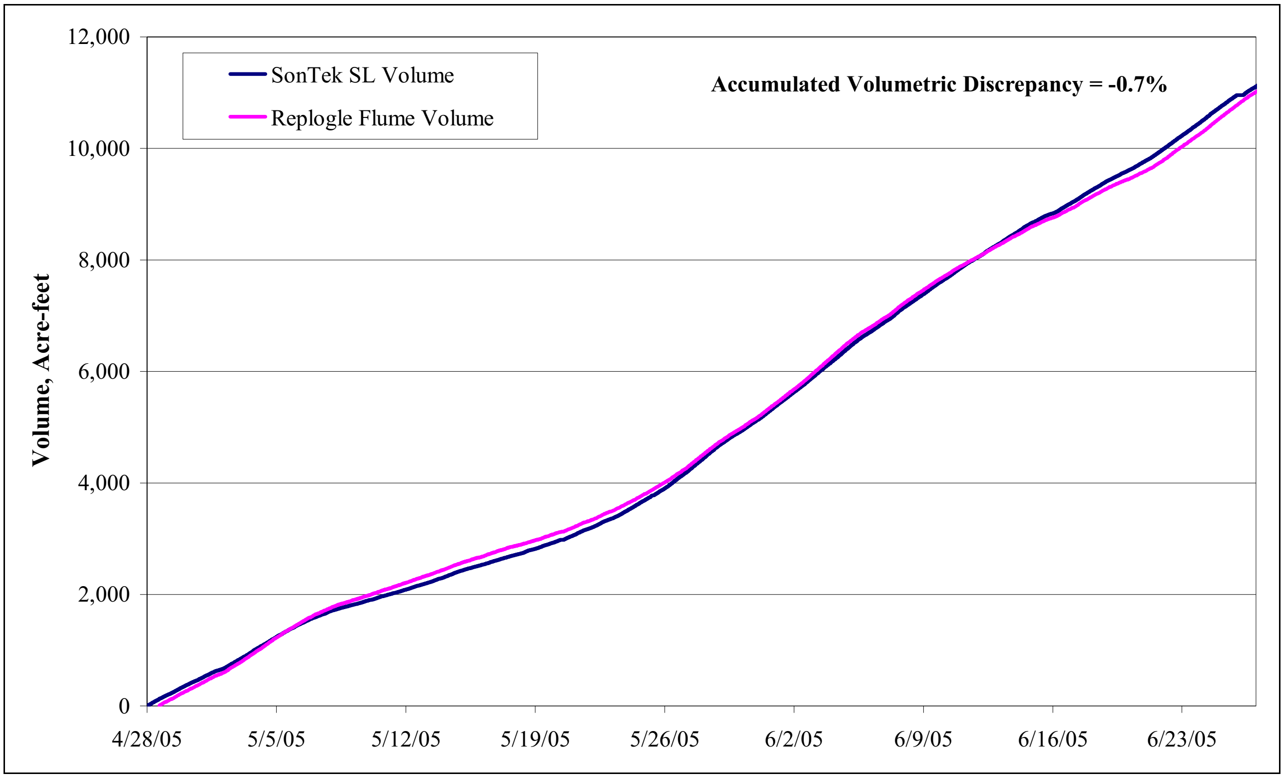

Figure 3. Accumulated volume comparison between the SonTek SL and Replogle flume

Conclusion

- Acoustic Doppler meters are capable of providing extremely accurate flow measurement data if calibrated properly in the field against a standard device.

- According to the data from this site visit, the volumetric accuracy of an acoustic flow measurement device can provide measurements that vary less than 1% from a standard flow measurement device.

- The ITRC strongly emphasizes the need to calibrate any non-standard structure or device such as a hydroacoustic meter. Without proper field calibration, the potential for measurement error is significant.

Photographs

The following photographs were taken during the site visits at Patterson ID.


Figure 4. The location of the PID flume, installed SonTek SL, and ADP flow measurement

Figure 5. The location of the Telog installed upstream of the flume


Figure 6. Rope and pulley system typically used to guide the ADP boats across the channel

F-9: Sutter Mutual Water Company Site Visit Report

IRRIGATION TRAINING AND RESEARCH CENTER
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SITE VISIT REPORT

Date: October 11, 2005

To: Stuart Styles, ITRC Director

From: Bryan Busch, Irrigation Support Engineer

Subject: Sutter Mutual Water Company
Site Visit Report: August 17, 2004 and September 12, 2005

A site visit was conducted to the Sutter Mutual Irrigation District on August 17, 2004 and September 12, 2005. The purpose of the site visit was to install and index an acoustic Doppler flow meter in the district. The trip was coordinated with Kevin Kibby from USBR. This site visit report includes photographs of the installations.

Contact Information

Kevin Kibby, Hydrologist
Tel: (530) 200-4649

Itinerary

Aug 17, 2004 Installed SonTek SL downstream of pumping plant #2. Collected flow rate data with Acoustic Doppler Profiling boats. Data was downloaded by Kevin from the SonTek SL. The flow rate from the Doppler boats were compared. The visit included comparing both of the USBR and ITRC SonTek boats and the ITRC RDI boat.

Acoustic Doppler Flow Meter

The current SonTek SL Doppler flow meter was installed by ITRC in 2004 downstream of the SMWC #2 pumping plant. After installation the flow rate was measured to start the indexing procedure. The SonTek SL has been recording for the last years and been maintained by Kevin Kibby and the USBR. The data from the SonTek units was downloaded and given to Kevin to complete the indexing procedure. The data collected from the unit will be used by the district to measure flows from the pumping plant, also the field installation has a display unit that will be used for controlling the canal.

Programming and Index-Rating

The SonTek software is easy to use, and can be set up in less than 15 minutes. To program the unit to perform flow calculations, a cross-sectional survey and index rating must be completed. Further information about programming the SonTek is available from the ITRC and the manufacture.

A cross-section of the canal was obtained by using the surveyed data provided by the district. The SL unit is calibrated by developing a rating curve using data from the acoustic Doppler profiler (ADP) boat at multiple flow rates. To develop a rating curve the channel must be current metered at ten different flow rates to develop a representative curve. The ITRC has prepared guidelines on doing the index rating for hydroacoustic flow meter installations.

Data

On both August 17, 2004 and September 12, 2005 data was collected at the site and the unit was reset to continue taking data for the next 3 months. The unit can record and store 15-minute data for over 12 months. The data from the SonTek is being used by the USBR to develop an index rating using the ITRC procedures.

Photographs

These photographs were taken at SMWC during the site visit.

Figure 1. SonTek SL installed downstream of Pumping Plant #2

Figure 2. Flow rate display in cfs at the SonTek SL site.

Figure 3. Kevin Kibby next to the SonTek SL site.

F-10: Tulelake Irrigation District Site Visit Report

IRRIGATION TRAINING AND RESEARCH CENTER
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Site Visit Report

Date: May 16, 2005

To: Dr. Stuart Styles, ITRC Director

From: Bryan Busch, Irrigation Support Engineer

Subject: Tulelake Irrigation District
Site Visit Report: April 29, 2005

ITRC conducted a site visit to Tulelake Irrigation District (TID) on April 29, 2005 as part of the Klamath Project, on behalf of the U.S. Bureau of Reclamation, Klamath Basin Area Office. The purpose of the site visit was to inspect and index the Argonaut SW flow meter in Drain 10. The trip was coordinated with Gerald Pyle, Assistant Manager of TID. This report includes the collected flow rate data, diagnostic data, and recommendations.

Contact Information

Tulelake Irrigation District (TID) – Hwy 39 Havlina Rd. Tulelake, CA 96134-0699

Gerald Pyle, Assistant Manager TID
Tel: 541.667.2249
Fax: 541.667.2248
Email: tid@cot.net

Itinerary

April 29, 2005 Arrived at TID and inspected the Argonaut SW flow meter and the RTU. The SonTek SW was working but was not connected to the RTU. The data sets with the cross section dimensions, recording intervals, date/time, etc. were downloaded. Flow measurement with the RDI StreamPro ADCP was completed for indexing.

Drain 10

Tulelake Irrigation District is upgrading its flow measurement stations in the drains that cross its boundaries with neighboring Klamath Irrigation District. Upon initial inspection at the site, the Argonaut SW was operating normally; however, the unit had not yet been connected to the RUGID RTU for transmission of the real-time data back to the headquarters.

Data was downloaded from the meter and saved using ViewArgonaut software as TL001-TL004.arg. The internal program settings and flow parameters were checked to verify that the meter was set up properly. Appendix 1 shows the downloaded program details from the meter.

A beam check was completed to determine if the sensor was measuring the correct area of the drain pipe, and it was found that no obstructions or irregularities are affecting measurements. Figure 1 shows the beam check graph from Drain 10.

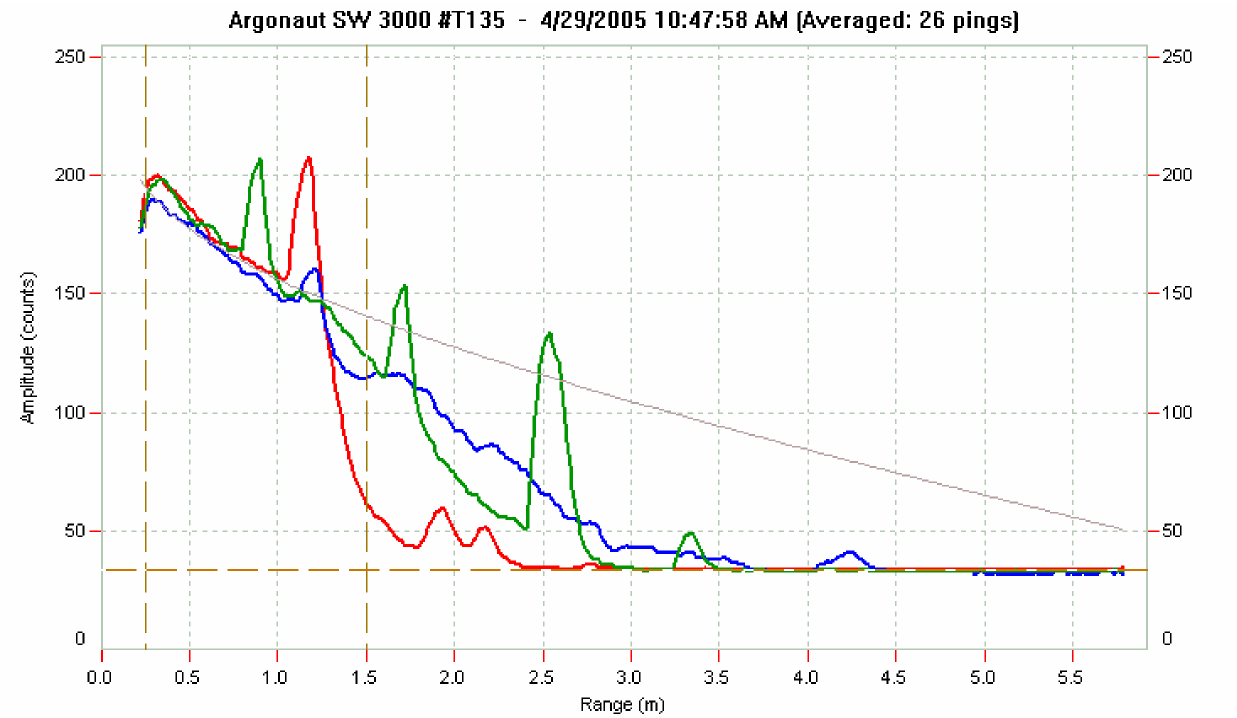

Figure 1. Beam check file for SonTek SW

A second test was started to collect and record flow measurement data that will be used to index the site. Independent discharge records were compiled using the RDI StreamPro ADCP to provide a corresponding mean channel velocity for post-processing. The RDI StreamPro ADCP measured an average flow rate of 24.9 cfs from 11:00 a.m. to 11:20 a.m. The corresponding average flow rate recorded by the Argonaut SW during the same time period was 22.5 cfs. Figure 2 is a graph showing the flow rates measured by the meter during the site visit.

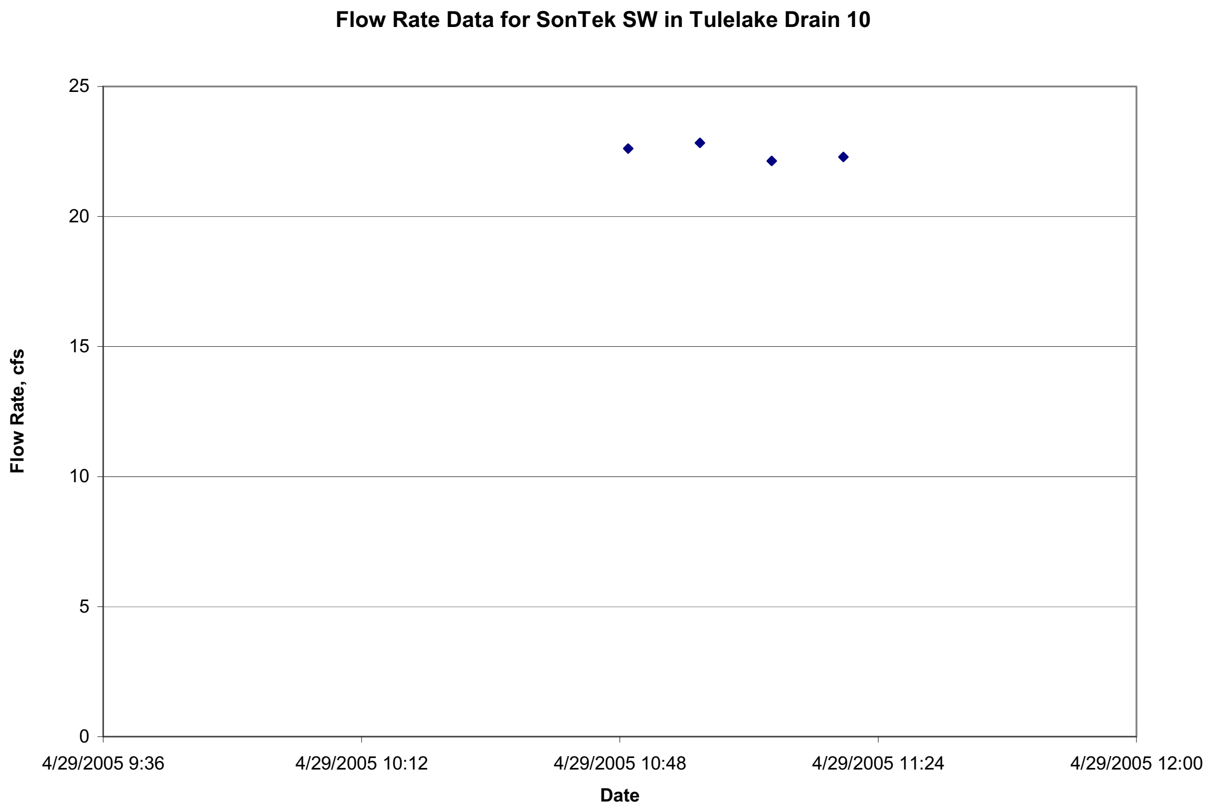

Figure 2. Average daily flow rate measured by the SonTek Argonaut SW, Drain 10.

Recommendations

The Argonaut SW at Drain 10 was functioning properly and the correct deployment settings were verified by ITRC. For the long-term accuracy and reliability of the discharge measurements being collected at this site, ITRC recommends:

- When the sensor is connected to the RUGID RTU/PLC, the deployment settings should be checked against those in Appendix 1.
- Additional indexing of the site should be continued over a range of flow rates in order to establish a good rating curve for the flow meter.
- When more indexing data is collected, a two-variable rating equation should eventually be used instead of the current linear equation.

Appendix 1
SonTek SW Program

```
Connected to COM1 at 9600
<BREAK>

Argonaut-SW
SonTek/YSI, Inc.
Copyright 1996-2002

Wake up initialization. Please wait...

>Show conf

Hardware Configuration
----------------------
System Type -------------------- SW
Sensor serial # ---------------- T135
Sensor frequency - (kHz) ------- 3000
Number of beams ---------------- 2
Beam Geometry ------------------ 2_BEAMS
Vertical Beam ------------------ YES
Slant angle - (deg) ------------ 45.0
System Orientation ------------- UP
Recorder installed ------------- YES
Temperature sensor ------------- YES
Internal SDI-12 Option --------- YES
Internal Flow Computations ----- YES
Analog Output Option ----------- NO
Multi-cell Profiling Option ---- NO
>Show System

System Parameters
-----------------
CPU Ver --- ARG 9.5
BoardRev -- REV G
Date ------ 2005/04/29
Time ------ 10:30:04
AutoSleep - YES
OutMode --- AUTO
OutFormat - ENGLISH
Recorder -- ON
RecMode --- NORMAL
ModemMode - NO

>Show setup

Setup Parameters
----------------
Temp ----------- 20.00 deg C
Sal ------------ 0.00 ppt
TempMode ------- MEASURED
Sound Speed ---- 1481.6 m/s
AvgInterval ---- 600 s
SampleInterval - 600 s
CellBegin ------ 0.25 m
CellEnd -------- 0.90 m
DynBoundAdj ---- NO
CoordSystem ---- XYZ
```

```
RevXVelocity --- NO
>Date 2005/04/29
OK
>Time 10:41:37
OK
>recorder
Recorder is ON.
>deployment
Current deployment name is: TL10.
>show fdatum
Flow equation type is: THEORY
 Q = ScaleFactor x Vmeas x Area
 ScaleFactor is based on channel geometry and measurement location.
Arg Elevation is:    0.300  (ft).
Flow channel type: ROUND
 Pipe diameter:     3.950 ft
>dynboundadj yes
OK
>ce
Current Cell End is 0.90 meters.
>ce 1.5
OK
>savesetup
OK
>start
Checking Setup Parameters...

4063232 free bytes left in recorder.
Free space is sufficient for 421.15 days of operation.
Recorder mode is NORMAL.

Data will be recorded to file TL10003.
OK

Disconnected
```

ATTACHMENT G

STATIONARY MEASUREMENT METHOD – SACRAMENTO VALLEY SITE VISIT REPORT

IRRIGATION TRAINING AND RESEARCH CENTER
BioResource and Agricultural Engineering Department
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MEMORANDUM

Date: July 17, 2006

To: Stuart Styles, ITRC Director

From: Bryan Busch, Irrigation Support Engineer
Marcus Cardenas, Irrigation Support Engineer

Subject: Evaluating ADCP Boats with Stationary and Section-by-Section Software Site Visit Report: 6/26/06 to 6/30/06

A site visit was conducted to the Sacramento Valley on the week of June 26, 2006. The purpose of the site visit was to evaluate and document procedures for the use of upgraded Acoustic Doppler Current Profiling boats using the procedure outlined by the ISO/USGS "Mid-Section Method". The trip was coordinated with Kevin Kibby, from the USBR. This report includes the collected flow rate data and photographs of the tests.

The section by section method generates very consistent cross sectional transects which increase the confidence in the flow rate measurement. Section by section measurements taken with either the RDI or SonTek consistently measured flow rates similar to district measurements. The ITRC used the SonTek meter with section by section software as the standard flow measurement whenever applicable. Unlike the Stream Pro and River Surveyor, flow measurements taken when using the section by section method are not adversely affected by moving bottom conditions.

Contact Information

Kevin Kibby, Hydrologic Technician
Tel: 530.934.1377
Fax: 530.934.1302
email: kkibby@mp.usbr.gov

Itinerary

June. 26, 2006 Measured flow rate at two Provident Irrigation District canals. The test included using the RDI StreamPro and SonTek River Surveyor simultaneously to determine the flow rate.

June 27, 2006 Downloaded data at Sutter Mutual Water Company from a previously installed SonTek SL. Measured the flow rate using both the RDI and SonTek boats.

June. 28, 2006 Measured the flow rate at three irrigation canals in Biggs West Gridley ID. The test was compared to a SonTek SL, and Mace flow meters.

June 29, 2006 Compared data from Anderson Cottonwood Irrigation District's ADFM to the RDI StreamPro and SonTek River Surveyor.

June 30, 2006 Measured the flow rate at Glenn Colusa Irrigation District's main canal.

Acoustic Doppler Flow Meters

The ITRC has worked with manufacturers and users of high-precision acoustic Doppler flow meters for several years to improve their performance by incorporating important design and software features that make them more user-friendly and robust. Previous Acoustic Doppler Current Profiling (ADCP) boat measuring techniques used a method of tracking the bottom to determine the cross sectional area. In some conditions it would give unstable measurements due to a changing bottom condition caused by pond weed.

With the new ISO/USGS "Mid-Section Method" measurement software, water velocity and depth data is actually acquired at a series of fixed locations across the measured body of water. Therefore the acoustic Doppler current profilers do not have to track the bottom, instead they acquire the canal width by user measurements. The boats measure the depth and the velocity profile at up to twenty points in each vertical.

RDI Stream Pro vs. Section-by-Section

In Stream Pro, transects are completed by crossing from bank to bank of the canal. In Section-by-section, transects are done by measuring at different user selected points across the canal. With the use of section-by-section software the cross-sectional areas are more uniform, which translates into a smaller percent error between transects. Stream Pro uses bottom tracking for velocity and section-by-section does not use a bottom track reference. This makes it possible to use section-by-section software to measure discharge in streams with moving beds.

Many of the display screens between the two software modes are similar and sometimes identical. In section-by-section, configuration files are created using the site configuration wizard. In Stream Pro, configuration files are based on the factory default setting, which may be changed as needed. Data files are different between Stream Pro and section-by-section. Each software mode requires the proper program to play back data, they are non interchangeable.

The time required to complete one section-by-section transect generally takes about the same time as completing 3 to 4 transects using the Stream Pro. In each case it is required to take measurements perpendicular to the flow. **Figure 1** shows screen shots of section-by-section, and **Table 1** shows data collected at Glenn Colusa Irrigation District's main canal. **Figure 2** shows a screen shot of data collected using the RDI Stream Pro software at the same canal.

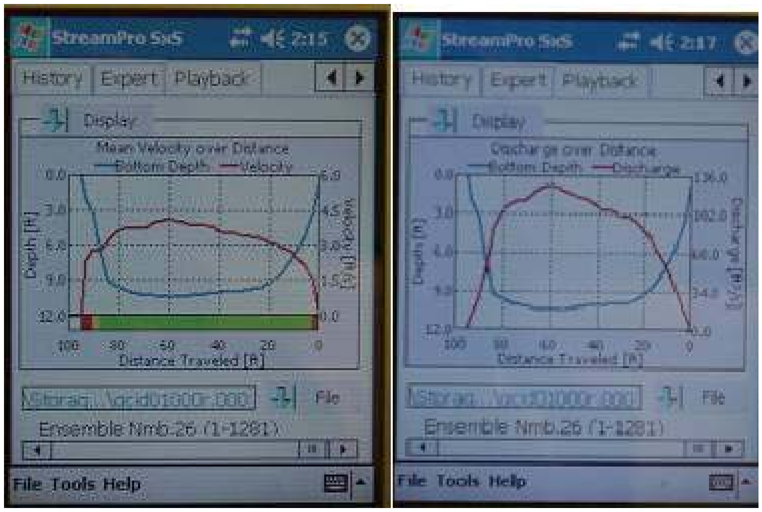

Figure 1. Screen shots of RDI Section-by-section software.

Table 1. Sample field data collected at GCID main canal using RDI section-by-section software.

StreamPro_Section_by_Section Summary

Name	Stn_Q	%_Tot	Start_T	Meas_T	%_Good	Avg_V	CV	Dist	Depth	Width	Area	Ang_Cf	Ice_Th
Station_001	0	0	14:00:34	38	94.87	0	0	0	0	1.499	0	1	99.999
Station_002	16.295	0.57	14:00:34	38	94.87	1.591	13.483	2.999	3.413	3	10.24	1	99.999
Station_003	33.847	1.19	14:01:25	40	95.12	2.149	8.714	6.001	5.249	3	15.749	1	99.999
Station_004	47.549	1.67	14:02:23	40.01	95.12	2.445	5.694	8.999	6.482	3	19.448	1	99.999
Station_005	61.348	2.16	14:03:18	40	92.68	2.733	5.756	12.001	7.481	3	22.445	1	99.999
Station_006	70.873	2.49	14:04:25	40	92.68	2.84	4.336	15	8.322	2.999	24.954	1	99.999
Station_007	82.881	2.91	14:05:33	39	92.5	3.084	4.614	17.999	8.956	3	26.872	1	99.999
Station_008	90.268	3.17	14:06:36	39	92.5	3.208	4.639	21.001	9.38	3	28.143	1	99.999
Station_009	97.179	3.42	14:07:34	40	92.68	3.341	3.453	23.999	9.693	3	29.083	1	99.999
Station_010	100.045	3.52	14:08:32	39	92.5	3.407	3.519	27.001	9.787	3	29.364	1	99.999
Station_011	101.48	3.57	14:09:27	40	92.68	3.413	3.97	30	9.914	2.999	29.729	1	99.999
Station_012	104.624	3.68	14:10:22	39	92.5	3.504	5.867	32.999	9.951	3	29.855	1	99.999
Station_013	104.597	3.68	14:11:23	40	92.68	3.487	4.83	36.001	9.996	3	29.992	1	99.999
Station_014	105.987	3.73	14:12:28	39	92.5	3.513	6.409	38.999	10.055	3	30.169	1	99.999
Station_015	113.228	3.98	14:13:28	39	77.5	3.744	4.04	42.001	10.08	3	30.245	1	99.999
Station_016	115.731	4.07	14:14:26	39	90	3.818	3.908	45	10.109	2.999	30.315	1	99.999
Station_017	117.256	4.12	14:15:22	39	92.5	3.829	3.227	47.999	10.208	3	30.626	1	99.999
Station_018	119.244	4.19	14:16:23	40	92.68	3.854	3.88	51.001	10.312	3	30.939	1	99.999
Station_019	122.6	4.31	14:17:23	40	92.68	3.939	3.99	53.999	10.374	3	31.125	1	99.999
Station_020	126.007	4.43	14:18:16	39	92.5	4.04	3.209	57.001	10.396	3	31.191	1	99.999
Station_021	127.488	4.48	14:19:11	40.01	95.12	4.091	3.709	60	10.392	2.999	31.162	1	99.999
Station_022	126.671	4.45	14:20:07	40	92.68	4.057	3.649	62.999	10.407	3	31.224	1	99.999
Station_023	122.496	4.31	14:21:03	42	93.02	3.958	4.537	66.001	10.315	3	30.948	1	99.999
Station_024	116.531	4.1	14:22:01	42	93.02	3.798	5.847	68.999	10.226	3	30.681	1	99.999
Station_025	113.525	3.99	14:23:11	42	93.02	3.741	4.077	72.001	10.114	3	30.344	1	99.999
Station_026	112.59	3.96	14:24:14	43	93.18	3.766	5.75	75	9.97	2.999	29.898	1	99.999
Station_027	109.135	3.84	14:25:16	42	93.02	3.725	6.764	77.999	9.764	3	29.295	1	99.999
Station_028	101.788	3.58	14:26:16	42	93.02	3.556	4.788	81.001	9.539	3	28.621	1	99.999
Station_029	88.95	3.13	14:27:21	42	93.02	3.238	5.523	83.999	9.156	3	27.47	1	99.999
Station_030	54.695	1.92	14:28:25	42	93.02	2.769	9.186	87.001	6.583	3	19.751	1	99.999
Station_031	27.149	0.95	14:29:30	42	95.35	2.793	6.533	90	3.241	2.999	9.72	1	99.999
Station_032	11.644	0.41	14:30:38	42	95.35	2.33	11.816	92.999	1.999	2.5	4.997	1	99.999
Station_033	0	0	14:30:38	42	95.35	0	0	95	0	1.001	0	1	99.999
Total	**2843.701**												

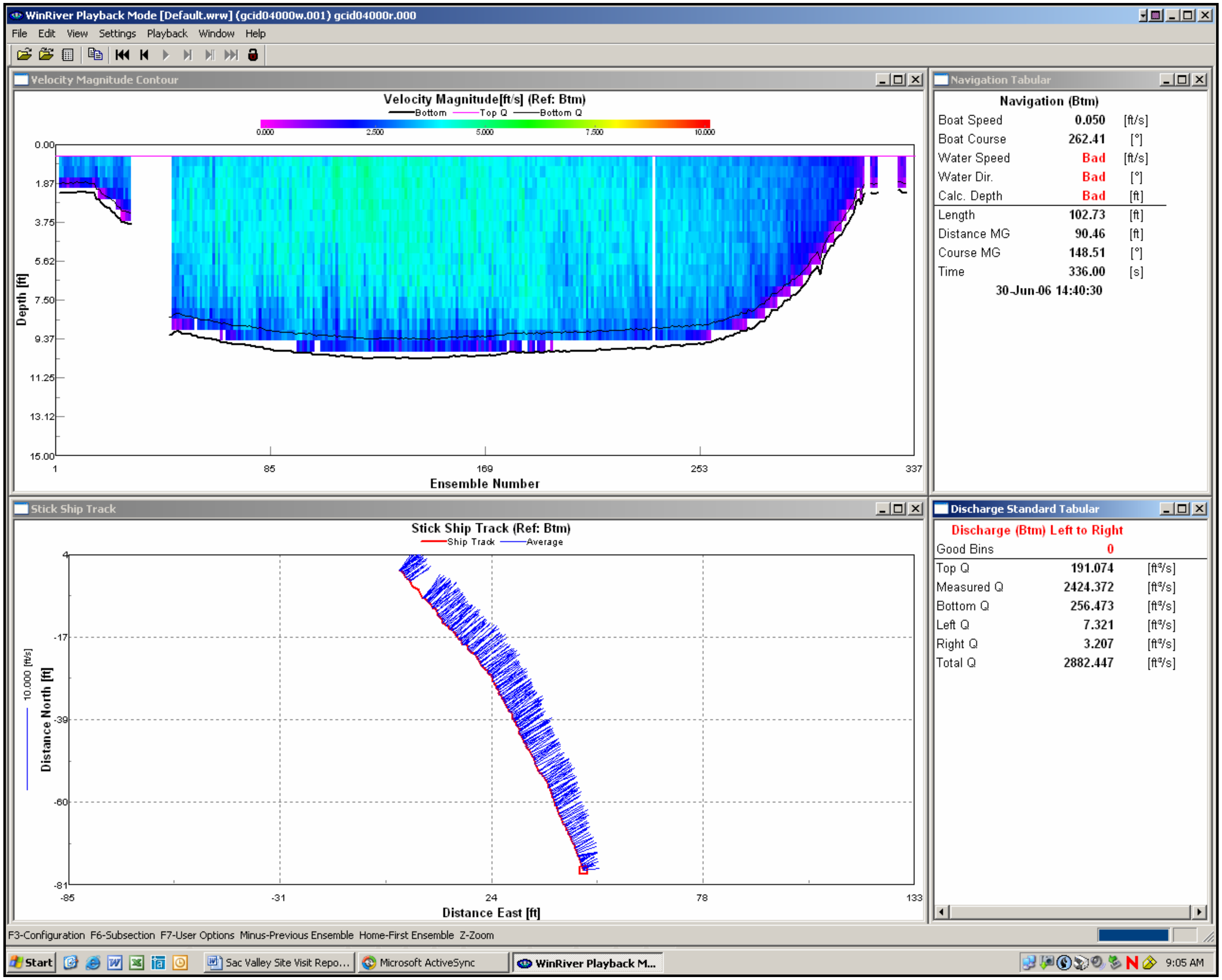

Figure 2. Screen shot of RDI Stream Pro at GCID main canal on June 30, 2006.

SonTek River Surveyor vs. Stationary Measurement

A transect is completed using River Surveyor by pulling the boat from one side of the canal to the other. In Stationary measurement mode, transects are done by measuring at different user selected points along the canal. With the use of stationary measurement software the cross-sectional area is more uniform, which translates into a smaller percent error between transects. River Surveyor uses bottom tracking for velocity and stationary measurement does not use a bottom track reference. This makes it possible to use stationary software to measure discharge in streams with moving beds.

Many of the display screens between the two software modes are similar. If the user is familiar with the software for the River Surveyor, the software for stationary measurement method should be very intuitive. However, data files are different between the River Surveyor and stationary measurement. Each software mode requires the proper program to play back the data. The two sets of data are non interchangeable.

It takes approximately the same amount of time to complete one transect using the stationary method as it does to complete 2 or 3 transects using the River Surveyor. In either measurement technique, it is required to pull the boat across the canal perpendicular to the flow.

Figure 3 shows a screen output from the SonTek stationary software at the Glenn Colusa Irrigation District's main canal. **Figure 4** shows a screen output from the SonTek River Surveyor software at the Glenn Colusa Irrigation Districts main canal at the same day and flow rate.

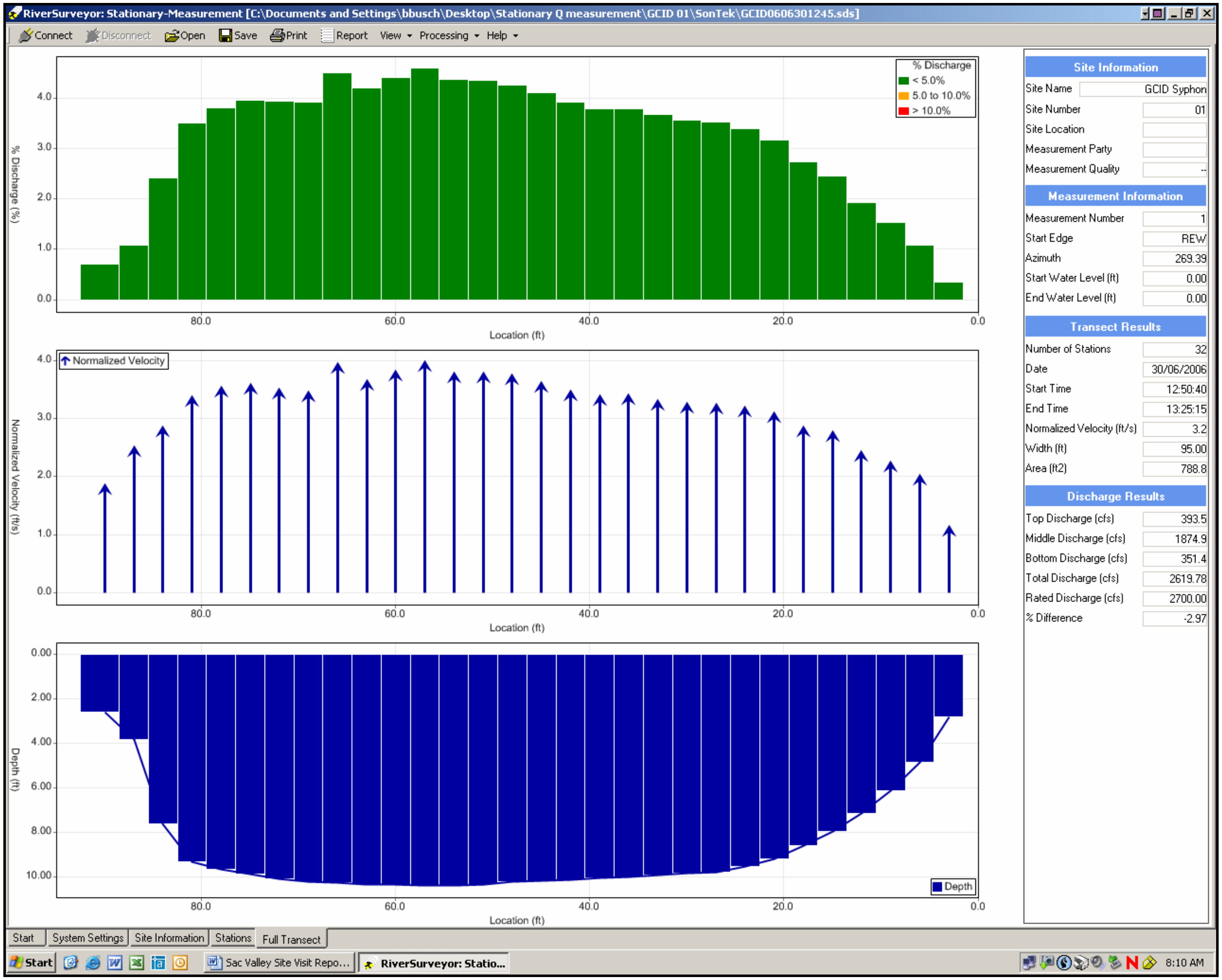

Figure 3. Screen shot of SonTek Stationary Measurement at GCID main canal on June 30, 2006

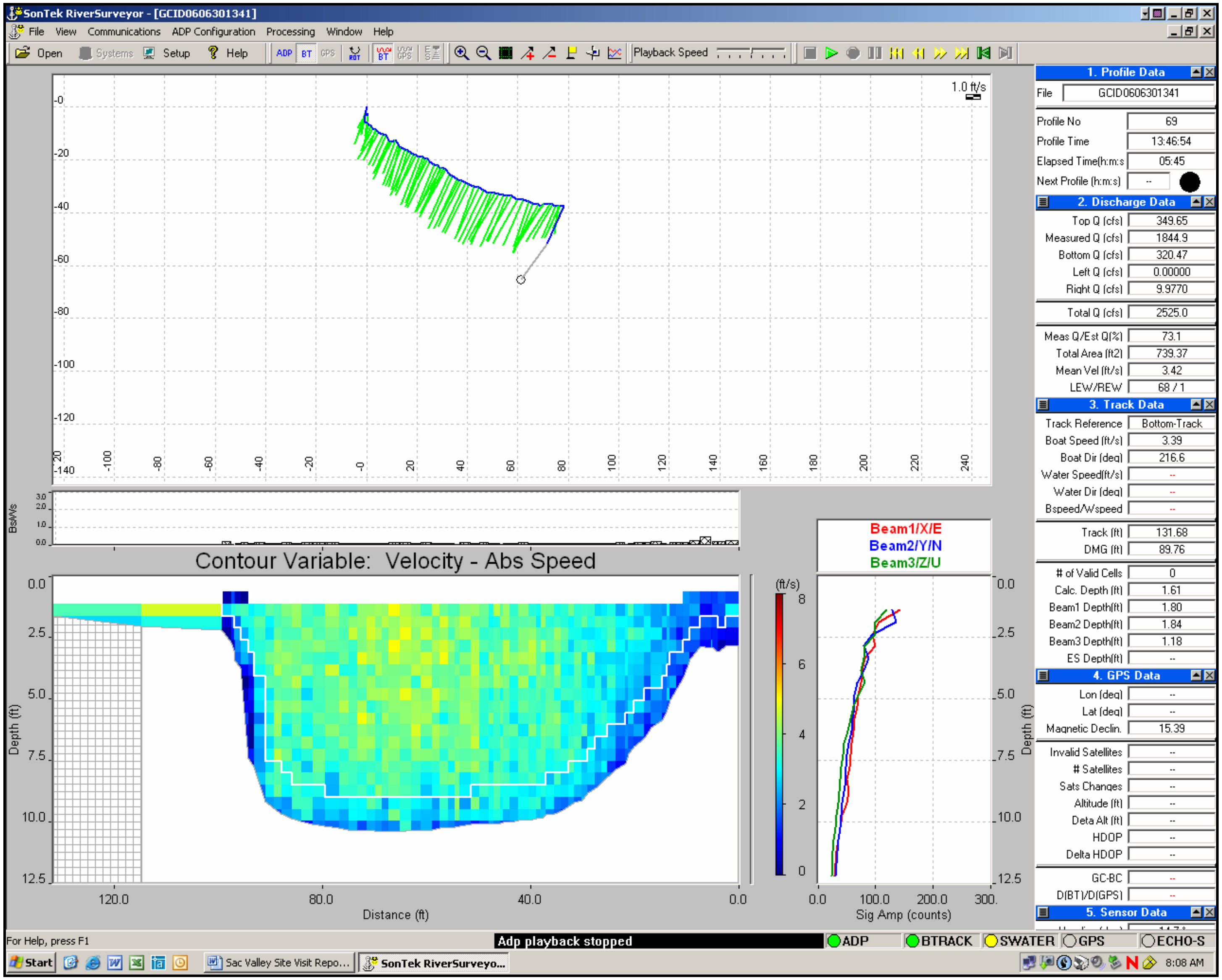

Figure 4. Screen shot of SonTek River Surveyor at GCID main canal on June 30, 2006

Photographs

Photographs were taken during the collection of data at the irrigation districts. The following photographs show the setup used for taking flow measurements using the stationary and bottom tracking methods.

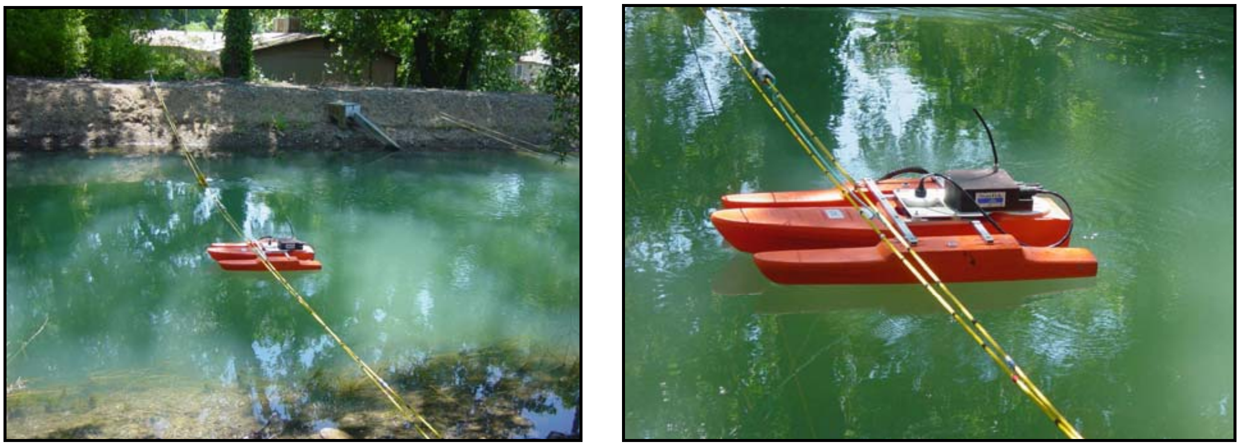

Figure 5. Measuring Flow rate with SonTek at Anderson Cottonwood ID

Figure 6. Measuring Flow rate with RDI at Glenn Colusa Irrigation District

Data

A summary of the flow rates measured by the ITRC and the district's are shown in **Table 2**. The flow rates reported by the ITRC were measured using the section by section method. Flow rates reported by the district's were measured by either a SonTek SL, an Accusonic flow meter, or an MGD flow meter.

Table 2. Summary of section by section flow rate data

Date	Location	Section by Section		Discrepancy (%) SxS	District (cfs)	Discrepancy (%) - District	
		RDI (cfs)	SonTek (cfs)			RDI	SonTek
6/26/2006	PID	219	212	3.3%	202	-8.0%	-5.0%
6/27/2006	SMWC	810	792	2.3%	821	1.4%	3.7%
6/28/2006	BWGID	472	457	3.3%	462	-2.1%	1.1%
6/29/2006	ACID	241	251	-4.2%	233	-3.1%	-7.1%
6/30/2006	GCID	2844	2620	8.5%	2700	-5.1%	3.1%

The percent discrepancy shown in **Table 2** was calculated as follows:

$$\text{Discrepancy (\%)} = \frac{\text{measured - standard}}{\text{standard}} \times 100$$

When calculating the percent discrepancy between the RDI and the SonTek, the SonTek meter was the 'standard' and the RDI was the 'measured' value. When the percent discrepancy was calculated between the section by section methods and the district's method, the district flow rates were considered the 'measured' value and the ultrasonic meters were the 'standard'. The largest percent discrepancy recorded between the RDI and SonTek unit was on 6/30/2006 at Glenn-Colusa ID. The percent discrepancy was recorded as a positive 8.5%, which means that the RDI was measuring a larger flow rate than the SonTek.

The largest recorded percent discrepancy between the section by section methods and the district measurement method took place on 6/26/2006 at Provident ID. The percent discrepancy was calculated to be -8.0%. At this site, both the RDI and the SonTek units measured flows higher than the district's Accusonic meter. According to Kevin Kibby of the USBR, the Accusonic meter at this site is due to be replaced in the winter of 2006. Apparently the electronic cables on the meter are failing and are causing erroneous flow rate readings. This is a possible explanation for such a large percent discrepancy between district measurements and section by section measurements.

Flow rates measured using the RDI Stream Pro and SonTek River Surveyor are shown in **Table 3**. These techniques are referred to as 'bottom tracking'.

Table 3. Summary of bottom tracking flow rate data

Date	Location	Bottom Tracking		Discrepancy (%) SxS	District (cfs)	Discrepancy (%) - District	
		RDI (cfs)	SonTek (cfs)			RDI	SonTek
6/27/2006	SMWC	782	792	-1.2%	821	5.0%	3.7%
6/30/2006	GCID	2818	2673	5.4%	2700	-4.2%	1.0%

Results

Figure 7 is a graphical representation of the section by section flow rate data shown in **Table 2**. The three independent measurement techniques produce very similar flow rate data.

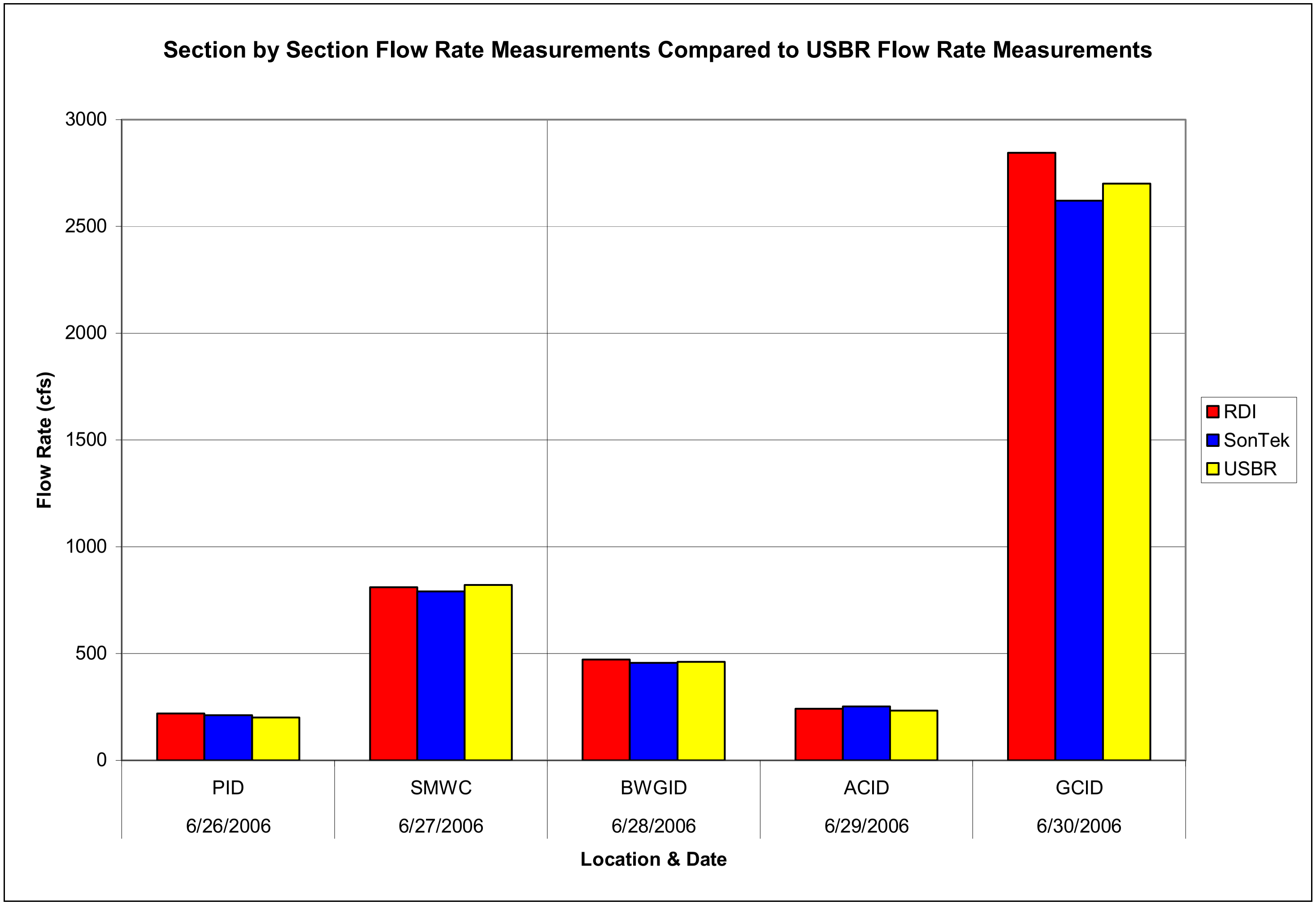

Figure 7. Section by section flow rate measurements compared to USBR flow rate measurements

Conclusions

- Section by section measurements taken with either the RDI or SonTek consistently measured flow rates similar to district measurements.
- The ITRC used the SonTek meter with section by section software as the standard flow measurement whenever applicable.
- Unlike the Stream Pro and River Surveyor, flow measurements taken when using the section by section method are not adversely affected by moving bottom conditions.
- The section by section method generates very consistent cross sectional transects which increase the confidence in the flow rate measurement.
- The cross sectional area of the channel determined when using the section by section method is very accurate and can be used when programming a Doppler meter.
- The ITRC recommends sing stationary or section-by-section software whenever possible.
- The ITRC recommends using a pulley system to minimize boat movement while section measurements are being recorded.