

NON-STANDARD STRUCTURE FLOW MEASUREMENT EVALUATION USING THE FLOW RATE INDEXING PROCEDURE — QIP

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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.

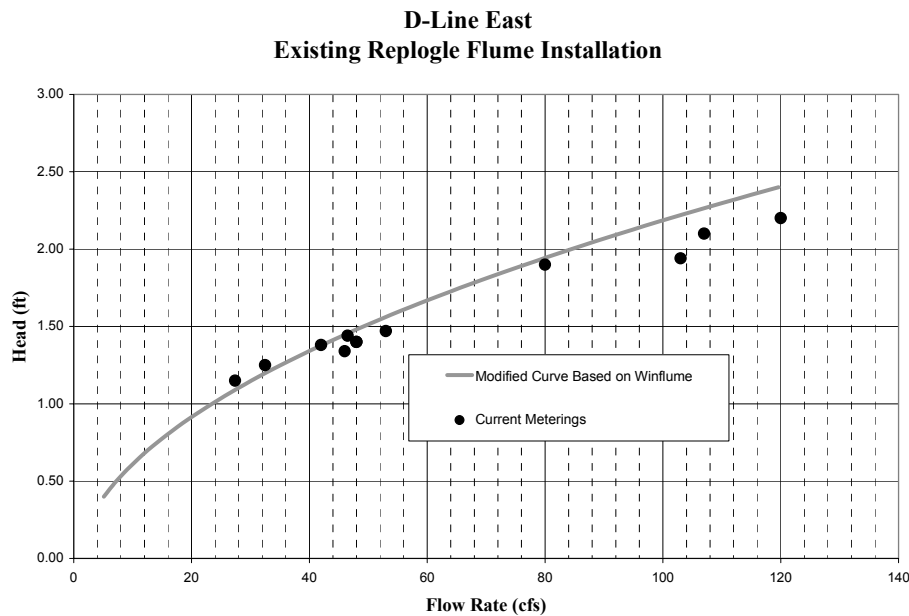


Figure 2. Plot of current metering data and head-discharge curve

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 be 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 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.

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. At least ten widths of the canal away from bends or turbulences.
2. At a concrete-lined section of the canal that is well surveyed.
3. 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 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 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.

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.

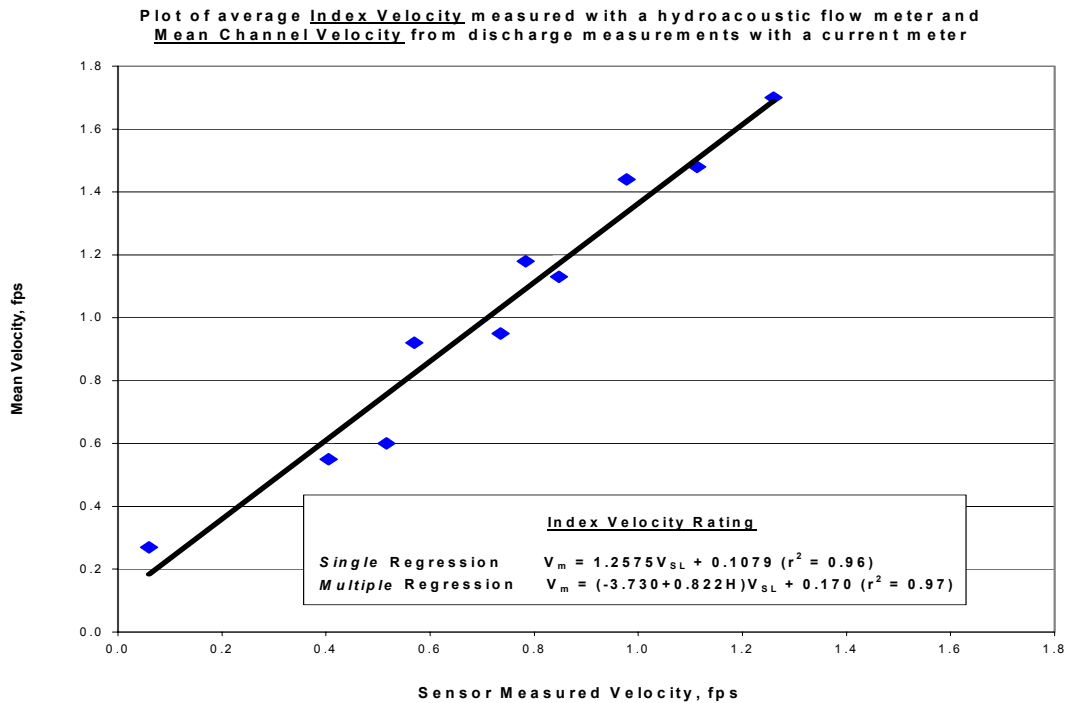


Figure 3. Example scatterplot of an index velocity rating for single and multiple linear regression ($r^2 \geq 0.96$)

Index Velocity Ratings

Table 1 summarizes the deployment of equipment and field data collection used for index velocity ratings at the cooperating water agencies.

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	Index Velocity Rating Procedure	Rating Development for Discharge Records
Alta Irrigation District		√	√	√	√
Contra Costa Water District	√		√	√	
Dunnigan Water District			√		√
Klamath Irrigation District	√			√	
Madera Irrigation District		√	√	√	
Merced Irrigation District			√√		√
Patterson Irrigation District	√		√√	√	√
Sutter-Mutual Water Company					
Tulare Irrigation District	√√	√	√√√√		√√
Colorado River Indian Tribes	√			√	
Lower Colorado River Authority	√			√	
Paradise Valley Irrigation District	√			√	
Yuma Co. Water Users Assoc.	√			√	

Summary Error 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 average percent error of discharge records collected at sites before the QIP index velocity rating was applied was 12.7% with average errors ranging from 25% to -25%. The results from the QIP evaluation at the demonstration sites improved the average error at all the demonstrations to at most 0.5%.

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

Before OIP (sensor measured discharge)

$$\text{Percent Error} = \frac{\text{Sensor Measured Discharge} - \text{Mean Discharge}}{\text{Mean Discharge}} \times 100$$

With OIP

$$\text{Percent Error} = \frac{\text{Computed Discharge w/ Index Velocity Rating} - \text{Mean Discharge}}{\text{Mean Discharge}} \times 100$$

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.

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