FLOW CALIBRATION OF THE BRYAN CANAL RADIAL GATE AT THE UNITED IRRIGATION DISTRICT

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ABSTRACT

In an effort to improve the management of the Bryan Canal, the United Irrigation District in South Texas installed a radial gate in place of a pre-existing vertical slide gate structure with the objectives of establishing telemetry and remote control capabilities, and providing the District the ability to control the gates based on flow.

This paper discusses the calibration of the radial gate for flow based on the head differential and gate opening. Details are provided on the equipment and instrumentation used, which included pressure transducers for upstream and downstream water levels, gate opening sensor, and doppler and velocity flow meters. The calibration of the doppler flow meter will be discussed along with the methods used to determine actual radial gate opening from sensor data and the problems caused by hysteresis.

Flow rate was calculated from the head differential across the gate and gate opening using a submerged orifice equation. By adjusting the discharge coefficient, the equation was calibrated in such a way that total calculated flow matched the total measured flow. The flow data was further analyzed for individual flow events. Data was collected continuously over three months. This paper discusses the process of analyzing data and determining the conditions for which the equation is valid.

INTRODUCTION

Study Area

United Irrigation District (District) is located in the southernmost region of Texas, commonly known as the Lower Rio Grande Valley (Valley). The District is one of the 28 irrigation districts that calls the Valley home (Fig. 1). The District covers 37,800 acres of which 47% has now been lost to urban expansion, and holds 57,000 acre-feet

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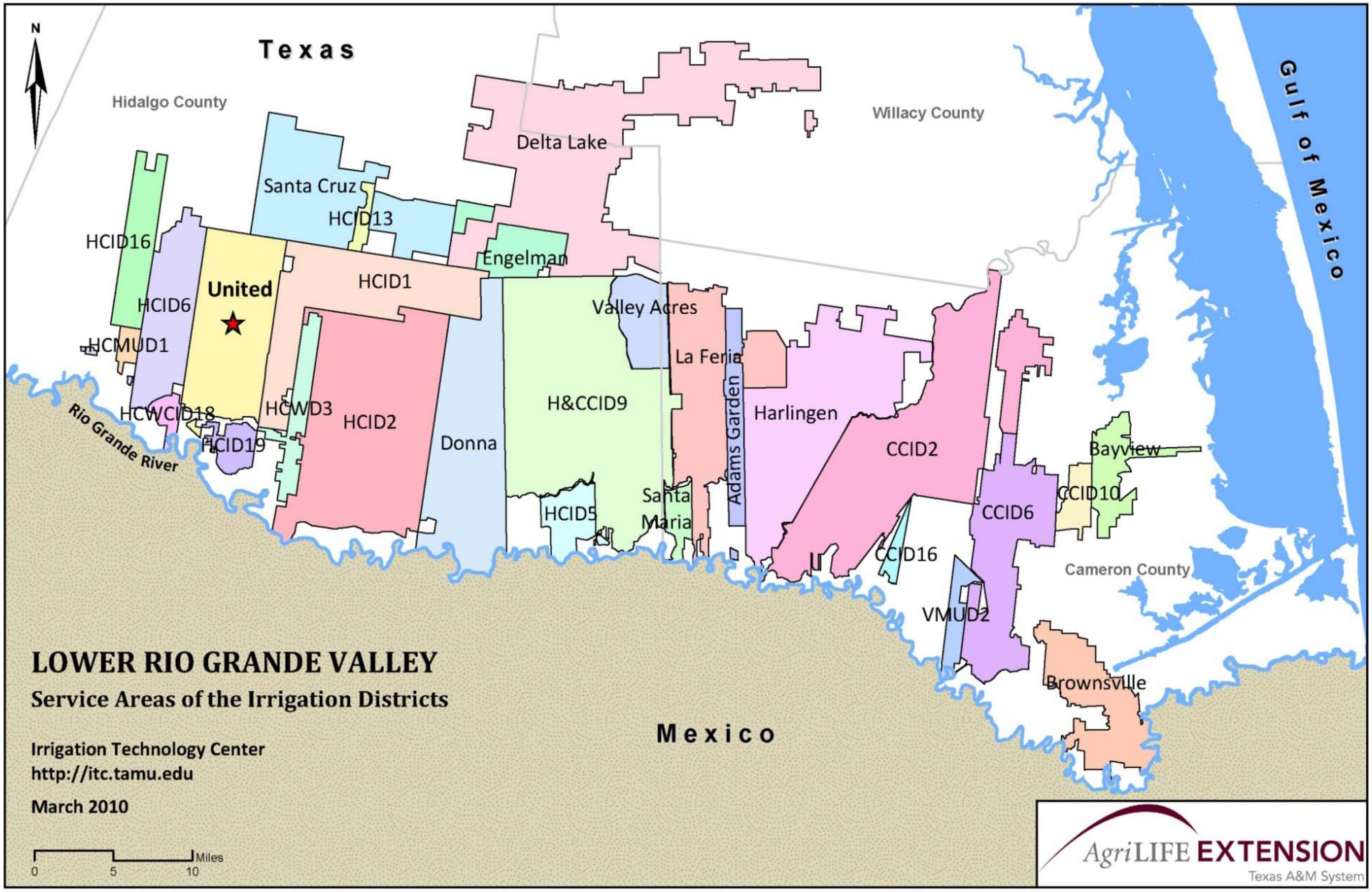

Figure 1. Service areas of the irrigation districts in the Lower Rio Grande Valley of Texas.

of Class A water rights from the Rio Grande River. The District distribution network is made up of approximately 50 miles of lined and unlined canals and 115 miles of gravity fed pipeline, with small hydraulic gradients.

The District's Bryan Canal is the main artery for the eastern portion of the District, delivering approximately 10,000 acre-feet/yr of irrigation water and 23,000 acre-feet/yr for municipal consumption to Sharyland Water Supply Company and the North Water Plant for the City of McAllen. The canal begins near the District office, just upstream of the third re-lift pump station, and flows east off the main canal and along Mile 2 N Road. On average, the Bryan canal carries 30% of total water distributed by the District.

Project Description and Objectives

In 2007, as part of the Irrigation District Engineering and Assistance (IDEA) program of the Irrigation Technology Center, we initiated a demonstration project with United Irrigation District to improve the efficiency of Bryan Canal by replacing the head vertical slide gate (Fig. 2) with a new radial gate (Fig. 3).

Figure 2. Pre-existing head slide vertical gate structure of the Bryan canal.

Figure 3. New radial gate and structure.

The objectives of the project were to:

- Establish telemetry and remote control capabilities
- Give the District the ability to control the gates based on specific water levels and flow rate set points
- Demonstrate the use of SCADA equipment and control systems

The pre-existing vertical slide gates and structure were in poor condition (Fig. 2). Only two of the three gates were operable and the bottoms of all the gate slots were blocked with concrete, providing a limited range of control. The radial gate was recommended to the District due to the known advantages of needing a small force for lift and operation, and good hydraulic discharge characteristics that are more favorable when calibrating a gate to serve as a flow measurement device (Bos, 1976; Wahl, 2004).

METHODS AND MATERIALS

Site Description

Bryan Canal is a trapezoidal concrete-lined canal with a capacity of 225 cfs with cross-section dimensions of 7 feet deep, 18 feet top width, 4 feet bottom width, and side slope of 1:1. The new housing for the radial gate is a rectangular structure 24 feet long and 10 feet wide. The gate has a radius of 7 feet, vertical height of 7 feet, and pinion height of 3.5 ft. Its opening ranges from 0 to approximately 5 feet. The gate leaf edges have hard bar-shaped rubber seals. All these structural details have a relevant influence on the calibration procedure (Wahl, 2005).

Equipment and Instrumentation

Pressure transducer sensors were positioned to record/measure the upstream and downstream water levels of the gate. The gate can be operated manually or remotely with the use of a built in gate position sensor in the actuator. A doppler flow meter (Argonaut-SW) was installed downstream of the radial gate and mounted on the bottom of the canal. A Campbell Scientific CR 1000 datalogger and a SDM-CVO4 control module control and record all activities at the site and are hard-wired to the District office. A schematic of the instrumentation installed to monitor flow is shown in Fig. 4.

For the calibration analysis, flow data was continuously recorded from January 13, 2009, through April 5, 2009, for a total of 80 days. The polling interval for the datalogger programming was set to 5 seconds. Data was automatically averaged every 30 minutes.

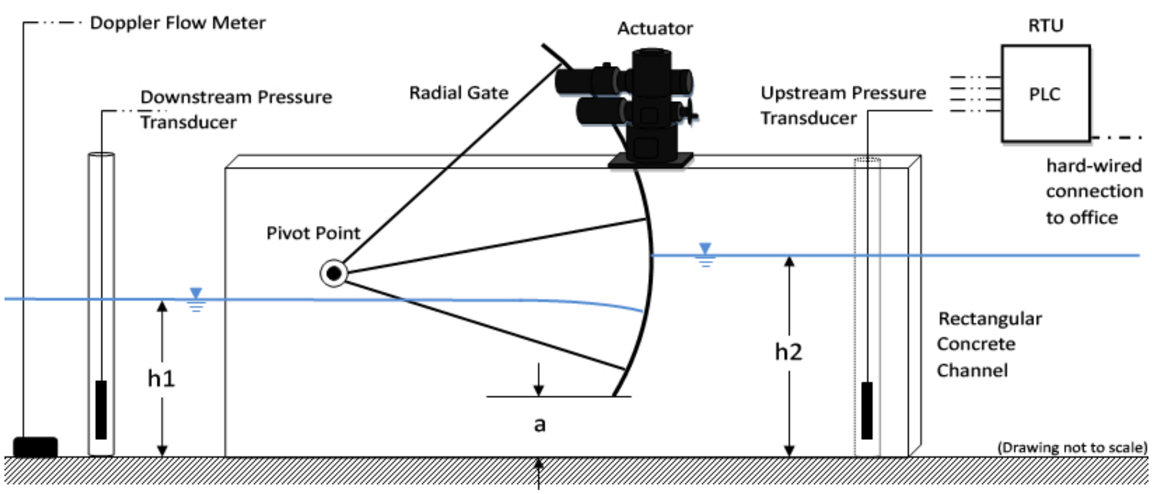

Figure 4. Instrumentation installed in the Bryan canal radial gate to monitor flow.

<u>Water Level Sensors</u> Two Keller America Acculevel pressure transducer sensors were installed as shown in Fig. 4. The upstream sensor was placed 10 feet from the gate pinion in a two-inch PVC stilling-well built into the vertical wall of the radial gate's rectangular control structure. The downstream sensor was housed 30 feet from the gate pinion in a 16-inch PVC stilling-well with the bottom open to the canal flow.

Actuator The actuator used for this project is an AUMA multi-turn actuator (Model SA 10.1-54B/GSD100.3) with built in 4-20mA input/output control signals. It features a single phase motor, 120 VAC, 60 Hz, 2 gear train limit switch with 8 contacts, a dual position potentiometer, and a RWG position transmitter (4-20mA DC output). The District purchased the actuator, and AUMA engineers helped with original calibration and set up.

Doppler Flow Meter The Argonaut-SW specifications state that it is accurate to ± 0.1% for water level when used in depths less than 16-feet and has an accuracy of ± 1% of water velocity for velocities up to 16 feet/second. The meter was installed in the middle of the canal about 30 feet downstream of the gate structure, and readings were recorded in 2-minute intervals.

Field Equipment Verification and Calibration

Current Meter vs. Doppler Meter Flow Verification We performed a series of flow measurements using Price Type AA current meter to verify the readings from the Argonaut-SW flow meter. Tests were carried out with maximum and very low flow. The measurement cross section was immediately upstream of the Argonaut-SW position. The USGS recommended procedures were followed, using the two-point method in measuring the velocities at 20% and 80% of total water depth of the canal cross-section (USBR, 2001).

Calibration of Vertical Gate Opening vs Actuator Position and Data logger Input The control range of the actuator (4-20 mA) was set to 0-100% scales, which corresponds to 0-5 ft of gate opening. The gate was then operated to different vertical opened positions based on a graduated input percentage set in the data logger during both the opening and closing to the gate. The chosen gate positions were every 0.5 ft of theoretical vertical opening. At each percentage, the actual vertical opening of the gate and the position of actuator were measured.

Flow Estimation

The submerged orifice flow equation was chosen to establish a head-discharge relationship for the Bryan radial gate. This equation is derived from the general Bernoulli equation used to estimate flow through an underflow gate, and is applicable to radial gates in case of slow and very submerged flow (Ghetti, 2006), which may be written:

$$Q = a * L * C_q * \sqrt{2 * g * (h_1 - h_2)} \qquad (1)$$

Where:
Q = discharge
C_q = discharge coefficient
a = gate opening
L = gate width
g = gravitational constant

h_1 = upstream level
h_2 = downstream level
h_1 - h_2 = head differential (Fig. 4)

As suggested by USBR (2001) and Buyalski (1983) “approaching flow should be tranquil…10 average approach flow widths of straight, unobstructed approach are required.” The old gate structure might therefore have slightly affected the accuracy of results.

In this study, Equation (1) was fitted to the measured flow data in order to calibrate the gate. To evaluate the accuracy of flow calculated with Equation (1), we used the coefficient of determination (R^2) for the regression functions on all data, and the relative sample standard deviation for individual events. In the latter case, we treated the calculated flow and the measured flow as two samples from a population normally distributed, with the goal to calculate the error on estimating the real flow with the two methods, calculated as:

$$s = \frac{1}{\bar{x}} \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2} \tag{2}$$

Where:
s = relative sample standard deviation
N = number of samples
x_i = sample
$\bar{x}$ = mean of all samples

RESULTS

Current Meter vs. Doppler Meter Flow Verification

Maximum measured flow reached 116 cfs and a velocity of 1.7 feet/second, which was well under the Argonaut-SW factory accuracy limits. In all tests carried out the average flow rate measured with the Argonaut-SW was 3% less than the average flow rate measured with the current flow meter. The Argonaut data was therefore corrected according to the finding.

Calibration of Vertical Gate Opening vs Actuator Position and Data Logger Input

Actuator position signal vs gate opening The correlation between actuator position signal and gate opening differed depending upon whether the motion was set upward or downward. So, at a given actuator position the gate opening was greater when the gate was operated upward compared to downward (Fig. 5). This hysteresis phenomenon accounted for up to 0.1 ft difference, corresponding to about 4.4 cfs. Data from two measured series of observations on upward and downward motion were fitted by 2nd degree polynomial regression. Both equations are used depending upon whether The identified equations were used to convert actuator signal into gate opening.

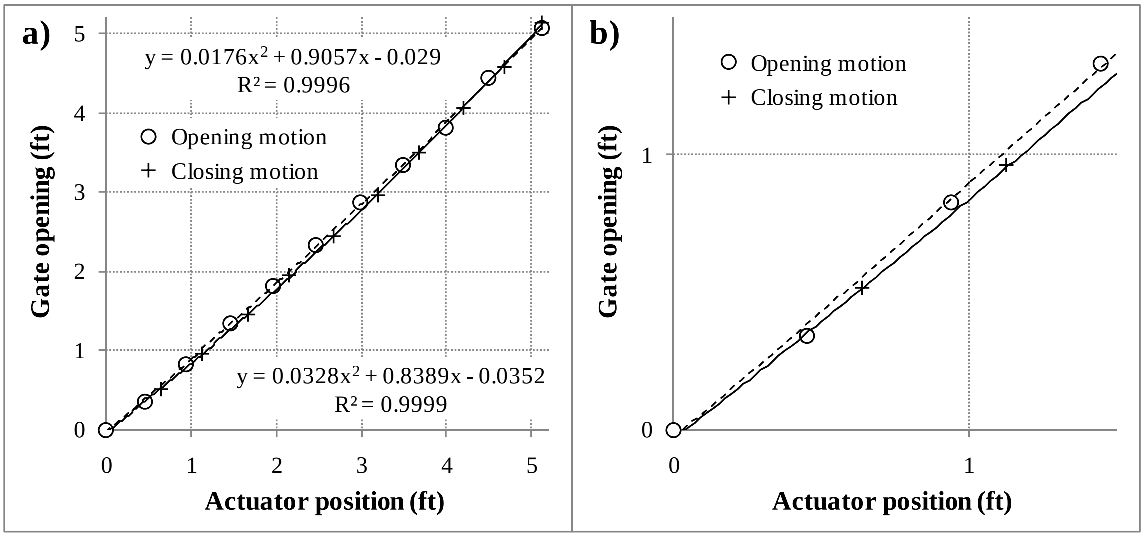

Fig. 5. Hysteresis identified between Actuator position and Gate opening: a) full gate opening range; b) detail for observed gate opening range.

<u>Data logger input percentage vs Actuator position</u> The correlation between gate opening input percentage and actuator position reading differed depending whether it was moving upward or downward. So, at a given gate opening input percentage the actuator position reading was lower when the gate was operated upward compared to downward (Fig. 6). This second hysteresis phenomenon was up to 0.5 mA, corresponding to 0.16 ft, and to 7.1 cfs in average. Thus, for gate calibration, the actuator readings were used instead of the data logger input.

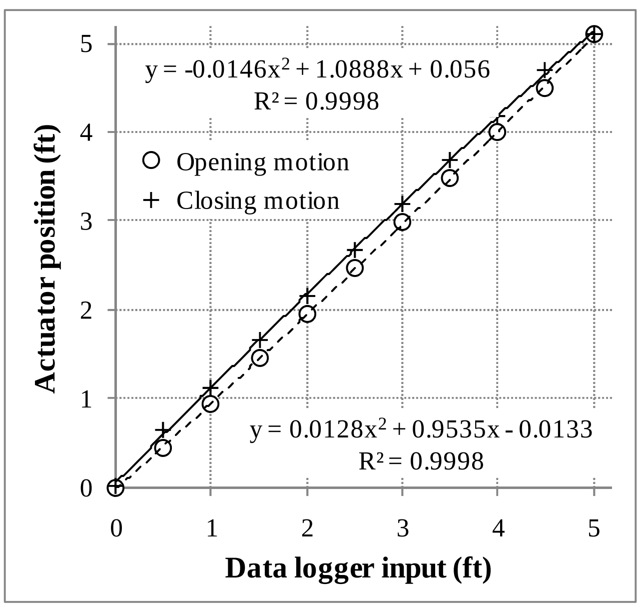

Fig. 6. Hysteresis identified between data logger input and actuator position.

<u>Calculated and Measured Flow Rate</u>

The radial gate was completely closed every Friday, except twice in the second half of February. There were an average of about four gate movements per week greater than 2 inches, mainly Monday through Wednesday, and the maximum observed opening was 1.5 feet. Downstream level was, in the average, one (1) foot lower than the upstream level, and such that flow conditions were always submerged. Table 1 summarizes the range in conditions that were observed.

Table 1. Range in conditions that were observed.

Parameter	Abbreviation	Max	Average	Min
Opening (ft)	a	1.5	0.5	0.0
Upstream level (ft)	h_1	7.0	5.4	3.9
Downstream level (ft)	h_2	5.4	4.2	2.2
Upstream level - Downstream level (ft)	h_1-h_2	2.8	1.2	0.0

The calibration process proceeded as follows. First, Equation (1) was re-written with the values corresponding to the dimensions of the radial gate:

$$Q = a * 10 * C_q * \sqrt{2 * 32.174 * (h_1 - h_2)} \tag{3}$$

Where:
Q = discharge,
a = gate opening,
h_1 = upstream level,
h_2 = downstream level.

Next, by trial and error, we selected values for C_q and solved Equation (3) until the cumulative flow converged with the measured values. A single discharge coefficient C_q = 0.71 was found to be able to predict all events, and matched measured flow with an average error of 3.2 % (Fig. 7).

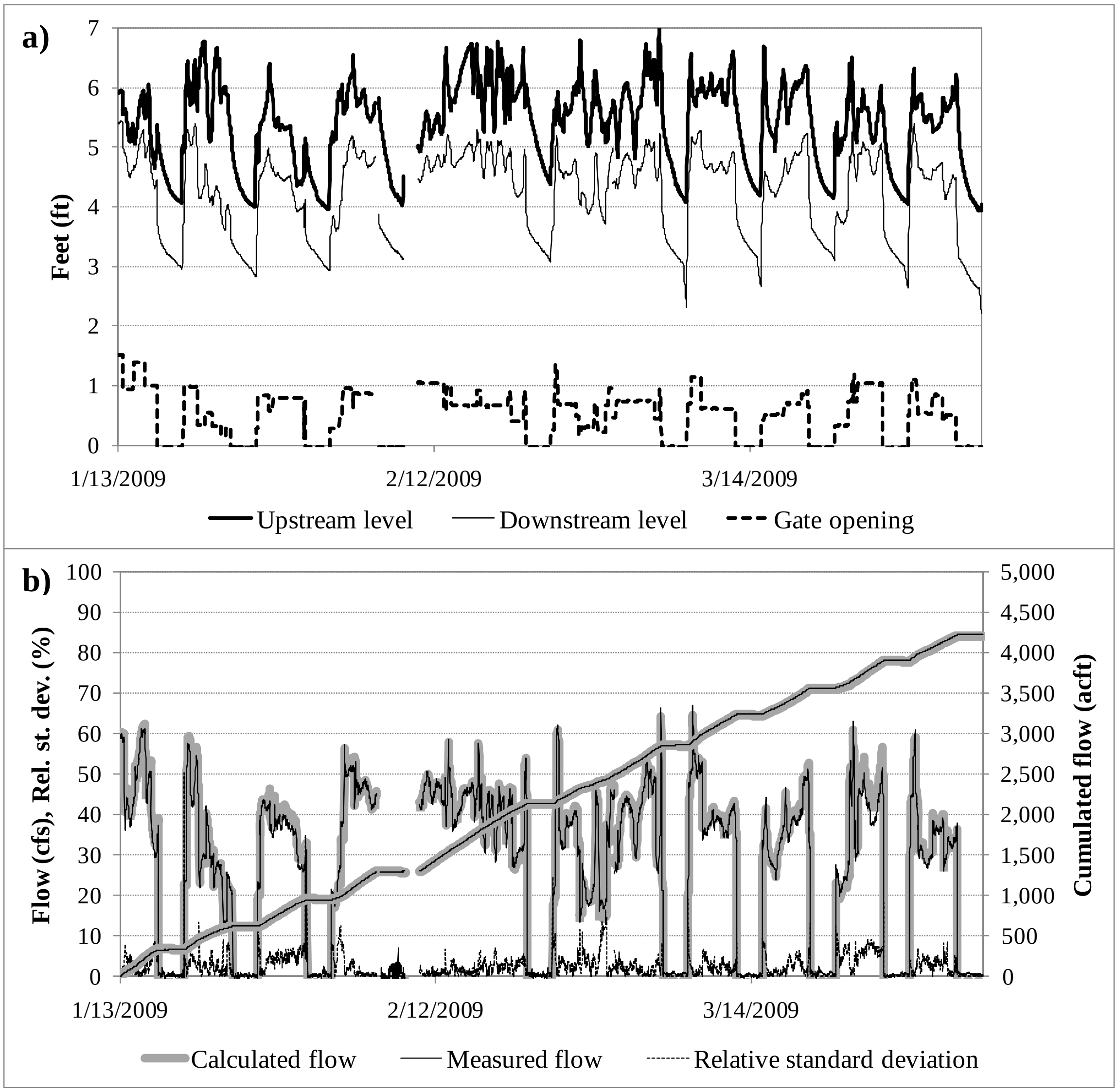

Figure 7. a) Gate opening and water level upstream and downstream the gate; b) Comparison of calculated flow and measured flow.

The relation between individual events of measured and calculated flow was well fitted by a linear regression function, as shown in Fig. 8. By comparing these events before hysteresis correction, we were able to identify two separated groups of data corresponding to opening and closing motion of the gate (Fig. 9). The linear regressions fitting the two groups of data were tested for parallelism, and the slopes resulted statistically different from each other.

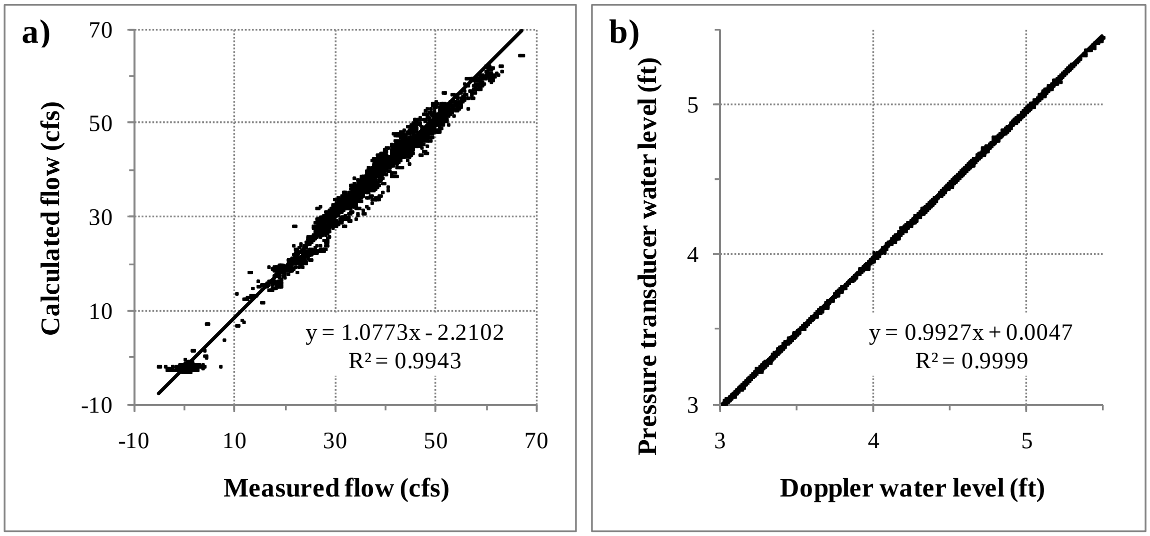

Figure 8. a) Calculated vs measured flow for individual events. b) Comparison of water level measured with doppler flow meter and pressure transducer.

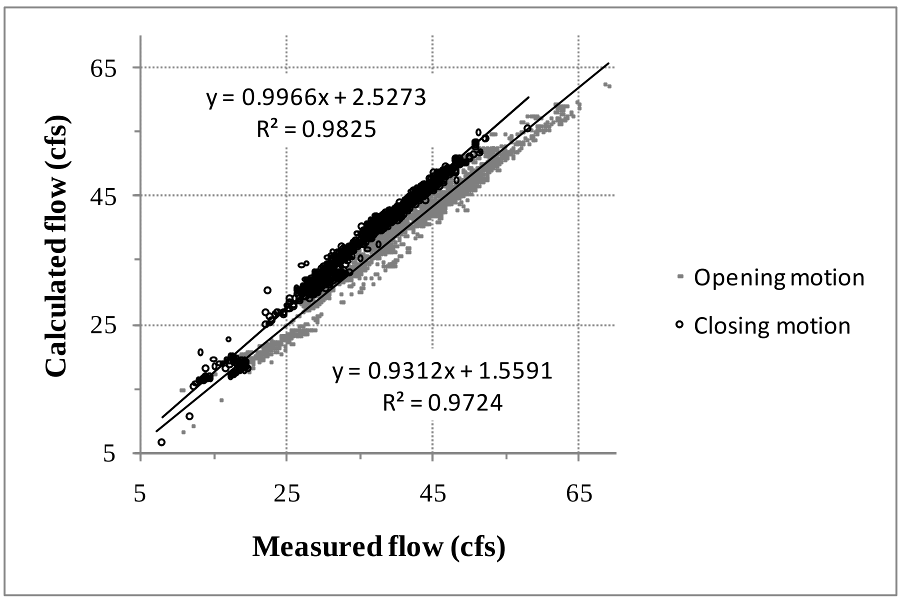

Figure 9. Identified groups of data corresponding to opening and closing motion of the gate by comparing calculated vs measured flow before correction for hysteresis.

CONCLUSIONS

The gate was calibrated for flow by inputting data on gate position and head differential across the gate into the submerged orifice equation. The coefficient of discharge (Cq) was adjusted to 0.71 in the equation for the total calculated flow to match the total measured flow of the doppler flow meter. A good correlation was found between each calculated flow event (every 30 minutes) and the corresponding measured doppler flow data. This correlation was described by a linear regression with slope equal to 1.08 and a R^2 equal to 0.994.

The doppler flow meter (Argonaut-SW) was very useful in the process because of the high accuracy and large amount of data obtained in a short period of time. The curve obtained is only valid for the flow conditions observed in this study. Such conditions were:

1) gate opening <1.5 ft;
2) gate always under submerged flow condition, with downstream level >2.2 ft, with maximum head differential 2.8 ft;
3) maximum flow 68.9 cfs.

Further calibration is needed for other ranges of flow.

A problem of hysteresis was identified in the gate position management. This was due to a difference between input and out signals to and from the actuator, and between the actuator signal and the real gate opening. While the former was not a factor in the flow calibration process because only the output signal of the gate setting was used, the latter required the use of separate equations to convert actuator signal into gate opening whether the motion was upward or downward.

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