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DESIGN AND EVALUATION OF AN AUTOMATED SYSTEM FOR ACQUISITION OF VELOCITY DATA IN SMALL CHANNELS

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ABSTRACT

The primary objectives of this paper are to: 1) describe an automated technique developed to collect velocity and flow depth data for small streams in remote locations and 2) describe a method for developing a rating curve from measured velocity and flow depth data. The velocity tree system was designed and developed for use with an automated bubbler/sampler to provide measured velocities with flow depth for water quality samples. This system provides a safe, reliable, and time-efficient alternative to the common practice of traveling to a site and collecting velocity data with a hand-held velocity meter while standing in the stream. It also allows velocities to be measured for remote locations difficult to reach during short duration runoff events. Impeller clogging and blocking are disadvantages that may limit the amount of velocity data collected. To develop a rating curve, average velocities recorded in each flow depth interval were plotted versus impeller depth. From these plots, an exponential best-fit equation (velocity profile) was developed and solved for mean velocity. Discharge was calculated by multiplying mean velocity for each depth interval by flow area and used to produce the depth versus discharge relationship.

Key Words: Automated data acquisition, stream flow velocity

INTRODUCTION

Determinations of runoff volumes and rates are vital to water quality monitoring and modeling projects. Flow in natural channels is most commonly estimated from flow area and mean flow velocity determinations. Direct velocity measurements with tracers, floats, rotating and electromagnetic flow meters, and doppler technology have been used to estimate mean velocity (Haan et al., 1994; Leopold, 1994; ISCO, 1993). Flow control devices such as flumes and weirs are often used in research settings to measure flow, but use of these devices is often not feasible due to cost, location, and site characteristics (Chow, 1988; Brakensiek et al., 1979).

The common procedure used to determine flow rate in the field is to divide the stream width into sections and then measure velocity in each section at 0.2 and 0.8 times the flow depth from the water surface (USGS, 1984; Chow, 1988; Haan et al., 1994). The mean velocity for that section is the average of the two velocity measurements. The flow for that section is the product of mean velocity and cross sectional area of flow. Total stream flow is determined as the sum of the flows for each section. In small streams, where flow depths change rapidly or in streams too shallow to permit measurements at 0.2 and 0.8 of the depth, velocity is measured at 0.6 times the flow depth from the water surface and assumed to represent the mean flow velocity in that section (Brakensiek et al., 1979; Haan et al., 1994). This technique is then repeated for several events with multiple flow depths to produce an adequate number of depth versus discharge points needed to establish a rating curve. Therefore, depending on the frequency of storm events, acquisition of an adequate amount of data to produce the rating curve can take considerable time and effort, especially in distant locations.

In small watersheds, velocity measurements are often difficult to obtain for several reasons. The rapid response of flow level to excess precipitation makes it dangerous to wade into the stream and measure flow velocities and also makes it difficult for personnel to reach remote study locations before the end of short duration runoff events. Therefore, new automated techniques of determining flow velocities and depths are valuable tools for hydrologic and water quality studies.

The primary objectives of this paper are to: 1) describe an automated technique developed to collect velocity and flow depth data for small streams in remote locations and 2) describe a method to determine a rating curve from the measured velocity and flow depth data. The velocity tree system described allows runoff data to be collected safely, reliably, and efficiently from remote locations. It was used in conjunction with an automated bubbler/sampler to measure stage and relate measured velocity and flow depth data. With these data, a rating curve (plot of stage versus discharge) was developed for use in an ongoing water quality project. Without an accurate estimate of discharge, nutrient loadings to the stream could not be calculated.

METHODS

Site Description

The velocity tree system was developed on a small, perennial branch of Tannehill Creek in Austin, Texas. The contributing area includes portions of a large international airport and a municipal golf course and consists of a large amount of impervious areas as is common in urban areas. Mean annual precipitation in Austin is approximately 810 mm (31.9 in) (NOAA, 1993).

The stream (cross section shown in Figure 1) flows continually due to irrigation runoff and seepage. The stream channel is irregular with brushy vegetation on the banks and brushy vegetation and grasses in the floodplain.

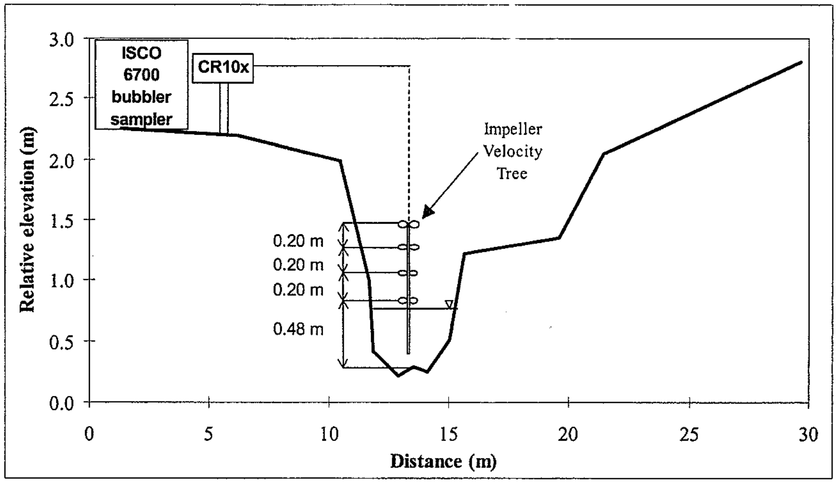

FIGURE 1. Stream Cross Section (Downstream View) with Velocity Tree System.

System Design, Installation, and Data Collection

The velocity tree system was designed to measure velocity data needed to establish a rating curve for a water quality project in Austin, Texas. The system was designed for use with an ISCO 6700 bubbler/sampler to provide necessary flow depth and water quality data for use in this project; however, it could be configured with any automated depth measuring instrument. The system (Figure 1) was designed to be durable and reliable in the field for several years with limited maintenance. We utilized four Swoffer® fiberoptic impeller assemblies (Figure 2) mounted on a vertical support oriented perpendicular to flow and wired to a Campbell CR10x datalogger. The sensor output is a square wave (4 pulses) for each impeller revolution. The data logger records the pulses and converts them to velocity by the calibration factor of 186 pulses per 3.05 m (10 ft) flow transect.

Velocity and flow depth data were collected continuously in 15-min intervals from October 1998 to March 1999. Maximum velocity readings were recorded for each 15-min interval. Flow depth readings were recorded at the end of each 15-min interval.

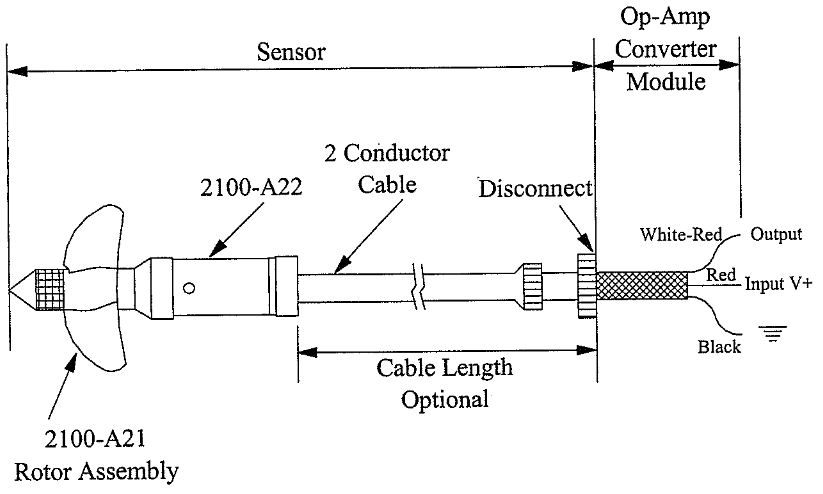

FIGURE 2. Sensor and Wiring Schematic for Velocity Tree Impellers (Adapted from Swoffer Technologies).

RESULTS AND DISCUSSION

Flow Depth and Velocity Data

Ten runoff events occurred from October 1998 to March 1999 with estimated peak flows ranging from 0.12 to 25 $m^3 s^{-1}$ (4.2 to 873 $ft^3 s^{-1}$), based on the rating curve developed. Mean velocity for the stream cross section (Table 1) ranged from 0.05 $m s^{-1}$ (0.17 $ft s^{-1}$) in the 0.53 to 0.61 m (1.75 to 2.00 ft) depth interval to 1.5 $m s^{-1}$ (4.91 $ft s^{-1}$) when depth exceeded 1.07 m (3.5 ft). The system provides a vertical velocity profile and thus allows mean velocity to be determined as opposed to being estimated from a point velocity measurement made by a rotating current meter, for example. Because the cross section is not a true control volume and due to other flow irregularities, any two measurements of velocity may vary for the same flow depth (Table 1); however, the deviations are small.

During each of the runoff events, transported debris (especially long grass strands) clogged at least one impeller resulting in erroneous data points. The debris, however, did not damage the

system in any of the storm events. Data points were judged invalid due to impeller clogging if extremely low velocities were recorded during times of significant flow, or if flow velocity did not increase up the flow profile.

TABLE 1. Average Flow Depth and Flow Velocity for Each Depth Interval.

Depth Interval (m)	n	Mean Measured Flow Depth (m)	1st Impeller Velocity ($m s^{-1}$)		2nd Impeller Velocity ($m s^{-1}$)		3rd Impeller Velocity ($m s^{-1}$)		4th Impeller Velocity ($m s^{-1}$)	
			Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
0.53 - 0.61	1	0.59	0.05	-	-	-	-	-	-	-
0.61 - 0.69	11	0.65	0.16	0.04	0.22	0.05	-	-	-	-
0.69 - 0.76	14	0.72	0.23	0.04	0.30	0.05	-	-	-	-
0.76 - 0.84	10	0.80	0.32	0.05	0.32	0.02	-	-	-	-
0.84 - 0.91	15	0.87	0.34	0.09	0.37	-	0.40	-	-	-
0.91 - 0.99	12	0.96	0.56	0.18	0.91	0.20	-	-	-	-
0.99 - 1.07	36	1.03	0.71	0.22	1.10	0.27	-	-	-	-
> 1.07	11	1.16	1.09	0.21	1.33	0.16	1.34	0.23	1.50	0.20

Rating Table Development and Comparison

From the velocity and flow depth data, a rating curve was developed by the following process. The flow depth from 0.53 to 1.07 m (1.75 to 3.5 ft) was divided into 0.076 m (0.25 ft) intervals. Flow depths above 1.07 m (3.5 ft) were included in one depth interval. For each interval, average velocities recorded in that depth interval by each impeller were plotted versus the depth of the impellers. From these plots, an exponential best fit curve (velocity profile) and equation were developed for each depth interval. The equation for each depth interval was then solved for mean velocity (assuming mean velocity occurred at 0.6 times the depth measured from the water surface). The cross sectional flow area at the average depth for each depth interval was then determined from the channel cross section survey data. With estimates of mean velocity and cross sectional flow areas, flow rate was determined for each depth interval and used to produce the rating curve (Figure 3).

At flow depths above 0.9 m (3 ft), flow spreads out onto the floodplain and is slowed by floodplain vegetation (Figure 1). Because of increased flow area and decreased velocity of floodplain flow, mean velocity determinations by the velocity tree (located in the center of the channel) overestimate the actual mean velocity considering the entire cross section. This conclusion is based on a comparison with Manning's equation at flow depths above 0.9 m (3 ft) (Figure 3). A weighted Manning's 'n' (determined by 'n' values for the floodplain, side slope, and channel) was used to obtain the depth versus discharge relationship and seasonality was not accounted for. The velocity tree system's inability to accurately determine mean flow velocity for the entire channel under floodplain flow conditions is a disadvantage of the system as installed at this site. An additional tree located in the floodplain to measure floodplain flow velocity would alleviate this problem.

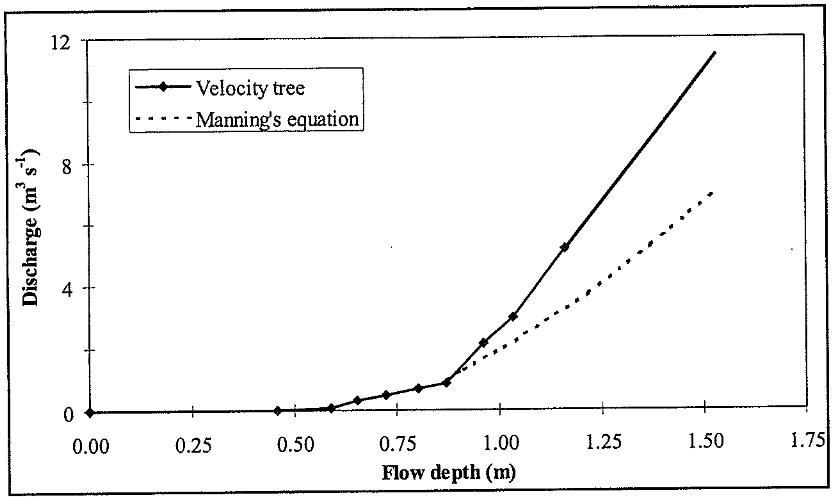

FIGURE 3. Rating Curve for Branch of Tannehill Creek Study Site.

The average velocity estimated by the velocity tree was evaluated against three other techniques. Floats were used to measure flow velocity during the March 8, 1999 event with a maximum depth of 0.66 m (2.17 ft) representing a peak flow of 0.28 $m^3 s^{-1}$ (10.0 $ft^3 s^{-1}$). The float velocity and water depth were recorded for two flow depths. It was assumed that mean velocity is approximately 80% of float velocity (Leopold, 1994; Haan et al., 1994). This velocity was compared to the average velocity determined with the velocity tree (Figure 4).

Data measured by the velocity tree on the March 27, 1999, runoff event were also used as a comparison. Velocity and flow depth in the depth interval at peak flow from 0.61 to 0.69 m (2.00 - 2.25 ft) were used to produce a velocity profile by the same procedure as described above. From the velocity profile, the average flow velocity was determined and compared to the average velocity determined with the velocity tree (Figure 4).

A doppler area flow velocity meter was also installed for comparison purposes. The estimated velocities from the velocity tree correlated well with average velocities using the doppler technique (Figure 4). However, an advantage of the velocity tree method is that it can be purchased and installed for less than the cost of a doppler system.

These comparison points are for relatively small, frequent events. As shown in Figure 3, the system needs adjustment (such as a installation of additional velocity tree to measure floodplain flow velocity) to accurately measure flow rates for less frequent, higher magnitude events. However, these initial results show that the velocity tree system can be an effective tool for measuring continuous flow velocity in a vertical profile.

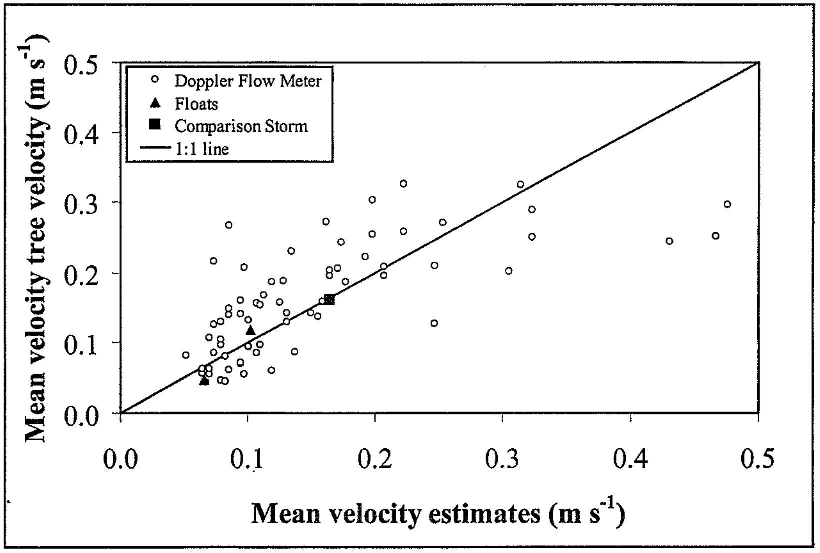

FIGURE 4. Comparison of Mean Estimated Velocities to Developed Velocity Tree Velocities.

CONCLUSIONS

The velocity tree system described is a safe, reliable, and time-efficient method of measuring velocities for small streams in distant locations. It is much safer than attempting to collect velocity data with a hand-held velocity meter while standing in the stream, since small urban streams are often "flashy" with rapid rises in flow depth. This automated technique also allows velocity to be measured for remote locations difficult to reach during short duration runoff events. The system saves time compared to the common practice of repeated trips to the field to gather adequate flow data to produce a reliable stage versus discharge relationship and provides a vertical velocity profile (as opposed to a single point measurement). The system can generally be created and installed cheaper than most other continuous time velocity measuring devices.

A major disadvantage of the velocity system is that impeller clogging may occur during the initial flush or at other times during the runoff event. Brush and trash tend to lodge onto the frame and could prevent proper operation. Also, floodplain flows over large areas decrease the accuracy of this system. This system is best suited for entrenched streams (flows are contained within the channel) with little floating debris, but improvements in design could improve its use in high debris, less entrenched channels.

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