USING ULTRASONIC FLOW METERS IN IRRIGATION APPLICATIONS

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INTRODUCTION

Irrigation is no different from any other crop production input; to be managed effectively and economically it must be measured accurately. Several devices exist to measure water flow in pipelines. A relatively new alternative is the ultrasonic flowmeter (USFM). The USFM is a non-invasive device that can be used to measure both flow rate and volume. Clamp-on transducers eliminate in-line installation, allowing one meter to be used at many locations (Figure 1). Exterior installation eliminates pressure losses and prevents leaking that can be associated with in-line meter installations.

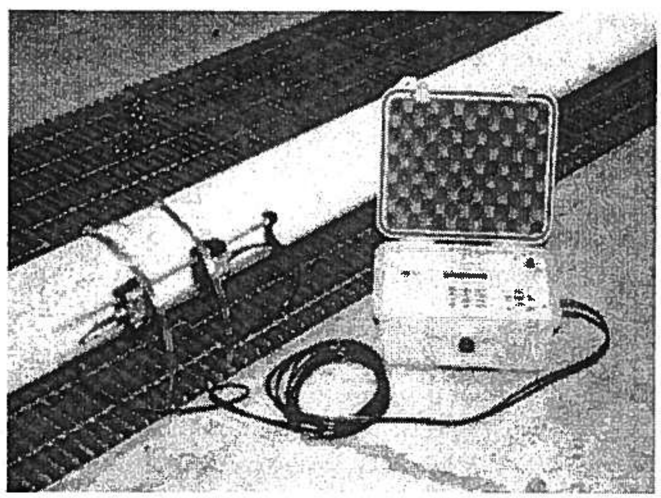

Figure 1. Transit-time ultrasonic flow meter.

The transmission, or transit-time, ultrasonic flowmeter operates on the principle of phase shift. Two transducers act alternately as transmitter and receiver as two paths of sonic beams travel back and forth across the pipe (Figure 2). One beam travels downstream while the other moves upstream. The motion of the fluid causes a frequency shift in both waves. This shift is related to the velocity of the fluid. Research has shown that, when installed properly, USFM accuracy ranges from +/- 1 to +/- 5 percent of full scale.

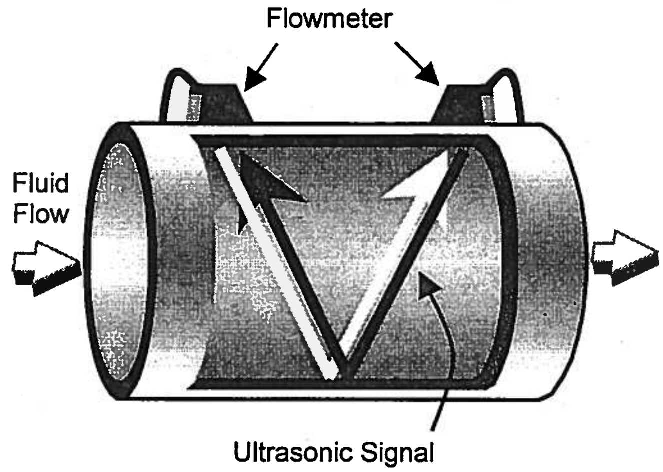

Figure 2. Transit-time ultrasonic flow meter measurement technique.

When measuring fluid in a pipeline, proper flow meter installation is one of the most important requirements for accurate flow measurement. This is true for any type of meter. As water passes through valves, pumps, reducers, tees, and elbows, it is agitated and sometimes sent into a swirling motion. It is difficult to accurately measure water that is agitated and swirling. To ensure that fluid flowing past the measuring location is "well conditioned" (*undisturbed*), meters should be installed with a sufficiently long section of straight, unobstructed pipe upstream from the meter location. Unobstructed upstream distances are often measured in terms of pipe diameters, Dp (Figure 3). For example, if one were measuring flow in an eight-inch pipe, 5 Dp (five pipe diameters) equals 40 inches. Table 1 shows a range of pipe sizes and the corresponding lengths for several values of Dp.

Most common meter location recommendations call for a *minimum of five to ten* straight Dp free of obstructions upstream from the meter and *at least one* straight pipe diameter free of obstructions downstream from the meter. If these requirements cannot be met, the piping conditions are "*non-ideal*" for flow measurement. A common problem found in irrigation-well meter installations is that the upstream unobstructed, straight pipe length recommendation cannot be met and metering is often done in a non-ideal piping configuration.

The popularity of ultrasonic flowmeters is due in large part to their portability and ease of use, they can be installed almost anywhere. Nonetheless, the need to adhere to proper installation guidelines remains. The purpose of this NebGuide is to report on recent research that will help ultrasonic flow meter users adjust inaccurate flow rate measurements that, because of preexisting conditions, are collected under non-ideal piping configurations.

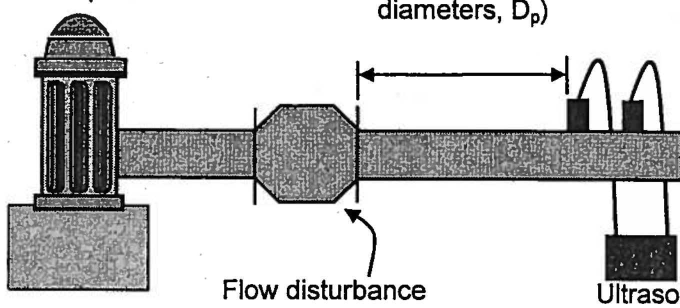

Figure 3. Schematic illustrating a typical irrigation system piping configuration.

Table 1. Dp (pipe diameters) lengths for the range of pipe sizes commonly found in irrigation systems.

	Pipe diameter (in.)			
	4	6	8	10
Pipe Diameters (Dp)	Distance (in.)			
2	8	12	16	20
4	16	24	32	40
6	24	36	48	60
8	32	48	64	80
10	40	60	80	100
15	60	90	120	150
20	80	120	160	200
30	120	180		
40	160			
50	200			

*Distances greater than 200 inches intentionally omitted

ULTRASONIC FLOW METER PERFORMANCE RESEARCH

For this research three flow disturbing devices were used, a 90° elbow, a spring-loaded swing check valve, and a butterfly valve. These devices were arranged to produce five different flow-disturbing configurations (Table 2). Table 3 shows the tested combinations of the pipe material, diameter, and flow disturbance. The 6-inch steel and 6-inch PVC pipe were used to evaluate the extremes of pipe roughness normally found in irrigation systems. For comparison purposes, four flow rates typically found in irrigation systems (220, 440, 660, and 880 gpm) were evaluated. A Polysonics Model ISTT-P portable transit-time USFM was used for this experiment. Flow rate measurements were taken at 2, 4.5, 10, 22, and 50 Dp downstream from the flow disturbance.

Table 2. Test configurations.

Abbreviation	Configuration, Flow disturbing device
SEL	Single Elbow
2EL	2 Elbows in different planes*
CHK	Swing Check Valve
BV5	Butterfly Valve, vertical axis 50% open
BH5	Butterfly Valve, horizontal axis 50% open

* Used to simulate the transition from an underground supply line to the upright of a pivot riser.

Table 3. Tested combinations of flow disturbance devices, pipe sizes, and pipe materials.

		Tested pipe sizes and devices				
Material	Diameter (in.)	SEL	2EL	CHK	BH5	BV5
PVC	6	x	x	x	x	x
PVC	8	x	--	--	--	--
Steel	6	x	x	x	x	x
Aluminum	6	x	--	--	--	--

As a part of this research, two components of accuracy were evaluated – bias and precision. Figure 4 illustrates the concepts of bias and precision. Bias is that portion of the overall accuracy of a given measurement that is the result of some systematic error. An example of bias would occur if you installed tires on your car that are too small. Since the speedometer is based on the rate of tire revolution, the smaller tires will cause the speedometer to systematically register higher than it would otherwise. Locating a meter too close to a flow disturbance can cause a systematic error.

Precision is that portion of the overall accuracy that is the result of random errors that are out of the user's control. As users of the ultrasonic meter, we can do little to correct for random errors, it is simply a measurement uncertainty that must be acknowledged. Recall that previous research has shown that, when installed properly, (i.e. with no systematic installation bias) ultrasonic flow meter accuracy ranges from +/- 1 to +/- 5 percent of full scale.

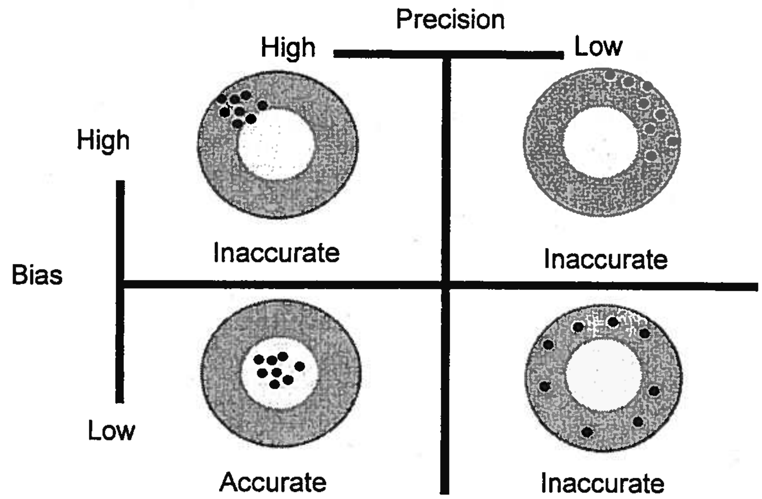

Figure 4. Illustration of the two components of accuracy, bias and precision.

<u>ULTRASONIC FLOW METER PERFORMANCE</u>

To characterize ultrasonic flow meter performance an accuracy or performance envelope was developed. The performance envelope incorporates both the bias and precision associated with the tested configurations of flow disturbance, pipe material and flow rate. The performance envelope documents USFM performance from 2 to 50 PD downstream from a given flow disturbance, Figure 5. By convention, because bias can be either negative (under prediction) or positive (over prediction), performance envelopes are drawn around the axis of perfect accuracy – zero percent inaccuracy. Figure 5 illustrates that when using the USFM at 2 Dp downstream from the type of flow disturbance evaluated here, the inaccuracy can be as much as +/- 36 percent.

Examining Figure 5 more closely, the bias at 2 Dp is a negative 15 percent. In other words, the ultrasonic flow meter systematically under predicted the actual flow rate by some 15 percent. The imprecision at 2 Dp was +/- 21 percent. That means that the range of measurements was +/- 21 percent of the average USFM measurements collected at 2 Dp. As one might expect as distance downstream from the flow disturbance increases, USFM performance improves. At 50 Dp the USFM exhibited essentially no directional bias and the overall accuracy had improved to less than +/-2 percent. Based on these results, its clear that meter location is critical to measurement accuracy. But what if meter locations are restricted to positions very near a flow disturbance? Using the bias and precision data just illustrated, a flow measurement correction approach was developed.

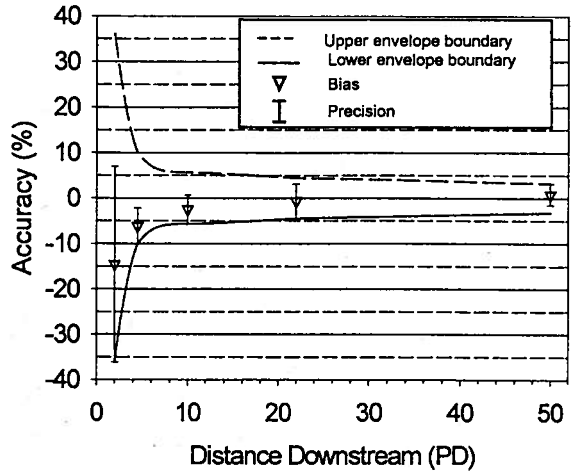

Figure 5. Ultrasonic flow meter performance envelope.

CORRECTING FLOW RATE MEASUREMENTS

To correct for the negative bias shown in Figure 5, a bias-correcting multiplier was developed. Figure 6 shows the multiplier relationship as it varies with distance downstream from a flow disturbance. The equation shown in Figure 6 can be used to predict a bias-correcting multiplier at any downstream measurement location between 2 and 50 Dp. Even after the bias of a particular flow measurement is corrected, a certain level of imprecision due to random error remains. That degree of uncertainty is characterized in Figure 7, which shows the corresponding accuracy for an ultrasonic flow meter reading after the bias-correcting multiplier has been applied. Developed from Figures 6 and 7, Table 4 contains multiplier and accuracy values for some specific Dp values. The following example shows how to use Table 4 to adjust inaccurate USFM measurements.

In this example, assume the USFM is mounted 6 Dp downstream from the flow disturbance, in this case a swing check valve. If this system were plumbed using 8-inch pipe, 6 Dp would be equal to 48 inches (Table 1). The distance between the spring check valve and meter is measured from the downstream flange of the check valve to the upstream USFM transducer. For this example assume that the USFM reads 837 gpm. If we look in Table 4 for Dp = 6, the multipler equals 1.05 and the accuracy equals +/- 3%.

Applying the bias-correcting multiplier to the USFM flow reading gives the *Adjusted Flow Rate.*

$$\text{AdjustedFlowRate} = 1.05 \text{x} 837 \text{gpm} = 879 \text{gpm}$$

Applying the accuracy value for Dp = 6 (+/- 3%) gives an adjusted measurement accuracy range of 850 to 907 gpm. The design flow rate for the irrigation system measured in the example was 880 gpm. This example and two others are shown in Table 5.

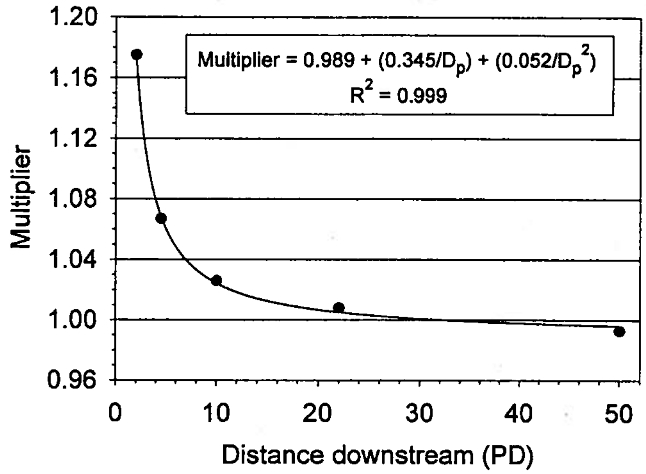

Figure 6. Bias-correcting multiplier.

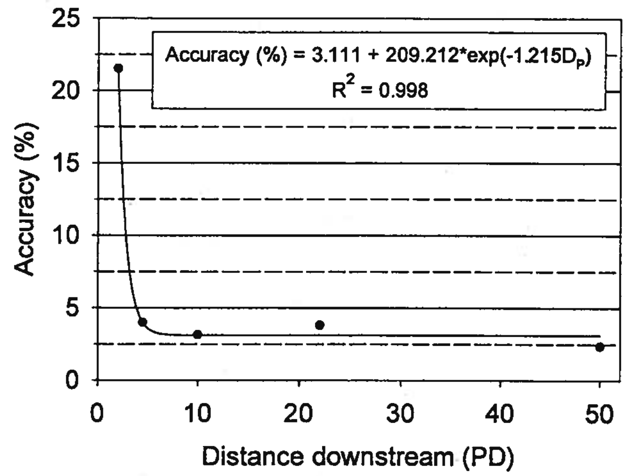

Figure 7. USFM accuracy with bias removed.

Table 4. Multiplier and accuracy values at selected pipe diameters (Dp)

Distance Downstream from Flow Disturbance (D_p)	Multiplier (dimensionless)	Accuracy after adjustment (+/-, %)
2	1.15	20
3	1.10	9
4	1.07	5
5	1.06	4
6	1.05	3
7	1.04	3
8	1.03	3
9	1.03	3
10	1.02	3
15	1.01	3
20	1.01	3
30	1.00	3
40	1.00	3
50	1.00	3

Table 5. Example of ultrasonic flow measurement adjustment and accuracy.

Measured Flow Rate (gpm)	Location (PD)	Accuracy pre-adjustment (+/-, %)	Multiplier	Adjusted Flow Rate (gpm)	Accuracy post-adjustment (+/-, %)	Accuracy range of adjusted flow rate (gpm)
758	2.0	35	1.15	872	20	1046 – 697
795	3.5	19	1.08	859	7	919 – 799
837	***6.0***	***7***	***1.05***	***879***	***3***	***905 – 852***

CONCLUSIONS AND RECOMMENDATIONS

For the flow disturbances evaluated here (Table 2), the USFM consistently under-predicted the actual flow near the flow disturbance and became more accurate as the distance downstream from flow disturbance increased (Figure 5). Based upon these results, we recommend, if at all possible, the USFM should be installed with at least 10 Dp of straight, unobstructed pipe upstream from the measurement location. In circumstances where the USFM must be installed closer than 10 Dp, the bias-correction method presented here can be used to find a more accurate flow rate and assess the accuracy of that adjusted measurement. *The reader should note that the correction multipliers presented here apply only to those flow disturbing devices listed in Table 2.*

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WHY COMPUTE THE ANNUALIZED COSTS?

A number of management decisions are based on the annualized costs of owning and operating an irrigation system. Before developing land for irrigation the first decision should be whether the irrigation system will be economically feasible, (will the returns more than offset the costs?). After deciding to proceed with irrigation development, one is faced with many alternative design choices. Sometimes there are offsetting costs and benefits associated with choices; e.g. lower initial cost for one distribution system vs. another may result in higher labor costs and/or lower irrigation efficiency which may increase operating cost and partially or completely offset the initial savings. Aside from development and design considerations, on rented land, an estimate of ownership and operating costs is necessary when negotiating a fair rental arrangement between the landowner and tenant.

Economic Feasibility Studies

Following a dry year like 2000, there is increased interest in developing irrigation. The question is: Will the return in higher yields over the life of the system more than off-set the cost of ownership and operation plus the additional crop input expenses for irrigated vs. dryland production? The only way to truly answer this question is to do a thorough economic feasibility analysis.

Irrigation systems have many components, each of which has a different expected useful life, anticipated repair costs, and different estimates for labor for normal operation and maintenance. Component costs, service life, maintenance repair, and energy costs all can differ under the same operating conditions depending on the design choices made.

If one has a set of financial records and has been irrigating in the past, they may have a pretty fair estimate of the expected out-of-pocket costs for operation and maintenance for an irrigation system. Out-of-pocket expenses only account for a portion of the total costs, however. When conducting an economic feasibility