

Peeling the Onion of Meter Accuracy Two Steps to Evaluating Flow Meter Data

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ABSTRACT

It is a natural desire and has been past practice to evaluate a meter's accuracy by reviewing its output – a measured rate of flow (Q). Most users test a meter's Q reading merely by comparing it to the Q from other meters or primary devices, much the same way drivers compare speedometers by driving next to each other and comparing outputs. The readings in such comparisons will never agree exactly, just as two watches will not. Experience shows that a traditional Q-to-Q comparison seldom results in a clear understanding of source of any meter inaccuracy.

The technique presented in this paper offers an easy process for evaluation of meter accuracy without a second flow measurement device. The first step in evaluating accuracy of any instrument is to evaluate its measurable components, not its output. For a speedometer, measurable components are distance and time; for an open channel flow meter, they are depth and velocity. A determination of precision and bias is then made for each measurable component. This concept of evaluating a meter's precision and bias has been incorporated into the EPA Environmental Technology Verification (ETV) program in the flow meter verification protocol.

KEYWORDS

Meter Accuracy, Precision, Bias, Depth and Velocity Scattergraph

INTRODUCTION

The two steps for evaluating the accuracy of flow meter data are:

1. Evaluate the measurable components of the meter, depth and velocity, in a scattergraph. This format is useful because there is a known and predictable relationship between depth and velocity in a free flowing sewer.
2. Check for bias in measurable components by comparing against manual confirmation measurements.

DISCUSSION

Precision and Bias

There is a very good discussion of data quality (accuracy) in Section 1030 of the “Standard Methods for Examination of Water and Wastewater” and it provides the guidance for the methods proposed in this paper. As described in “Standard Methods”: *“The principle indicators of data quality are its Bias and Precision, which when combined, express its accuracy”*. Bias is a measure of systematic error and precision is a measure of the closeness with which multiple readings of a given sample agree with each other. Figure 1 is similar to the figure used in “Standard Methods” to illustrate the concept.

An instrument can exhibit any of the four conditions shown in Figure 1.

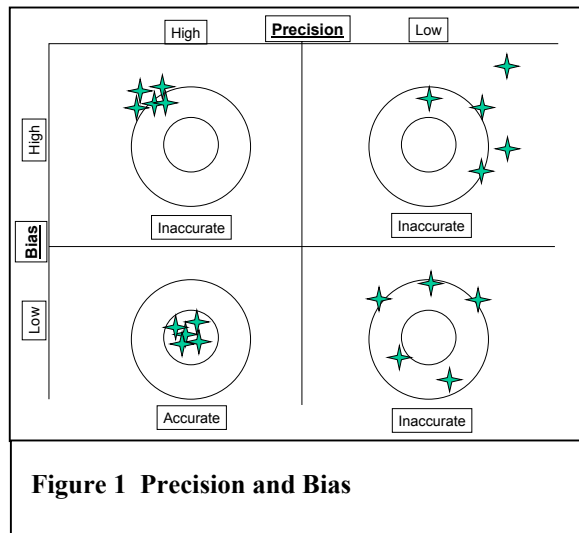
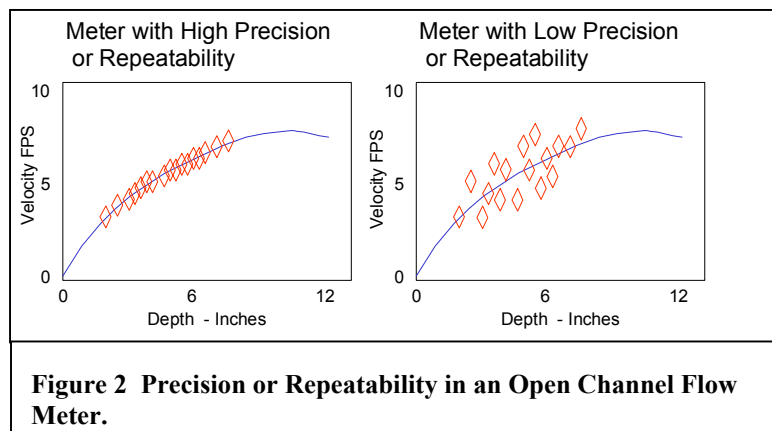


Figure 1 Precision and Bias

In free flow gravity sewers, the target is not a bull's eye, but a line (or pipe curve) that defines the depth and velocity relationship. In ideal hydraulic conditions, precision or repeatability of data is determined by how tightly the data conform to a pipe curve. Figure 2 illustrates the concept using a theoretical Manning



curve. The first pattern of data follows the pipe curve quite closely. The second pattern shows considerable deviation or scatter from the pipe curve. If the imprecise readings randomly deviate as illustrated here, the average flow volume reported over a period of time (say daily) could actually come close to measuring the daily total flow. “On average” this low precision meter would appear to be correct.

Bias is determined by how closely the depth and velocity data correspond to simultaneous manual readings. Figure 3 illustrates the concept of bias in flow meters by comparing meter readings of depth and velocity to manual measurements taken simultaneously. This exercise should occur periodically to assure that no bias has entered the measurement routine. It is also important to make manual measurements at the full range of depth (and velocity) to assure that bias is absent in all flow conditions.

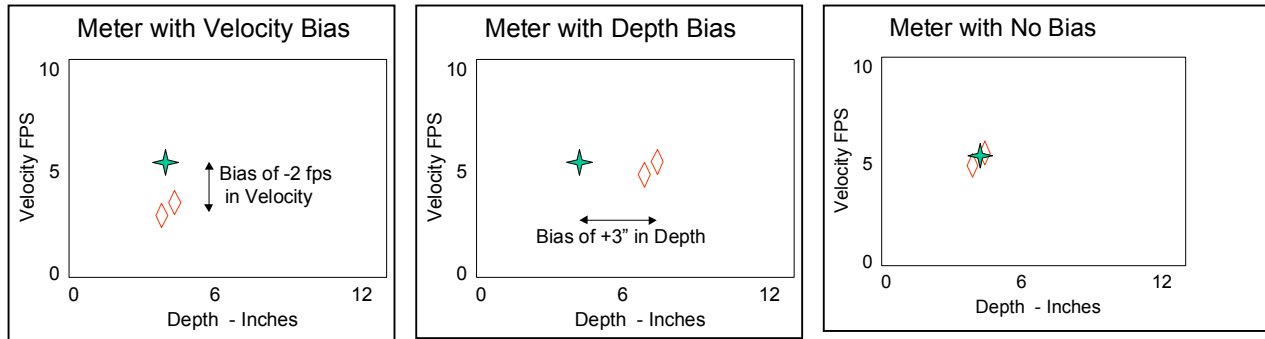


Figure 3 Bias exists when the meter readings (diamonds) differ from a simultaneous manual measurement (star). Bias in both depth and velocity would result in a diagonal offset.

Scattergraphs in Practice

Since 1995 ADS has been developing a method using depth-velocity scattergraphs for quickly determining if a meter is collecting accurate data. The method uses three sets of data plotted together on a scattergraph, 1.) Depth and velocity readings from the meter, 2.) Manual depth and velocity confirmations collected with a ruler and portable velocity meter and 3.) A Manning pipe curve. Figure 4 shows how these

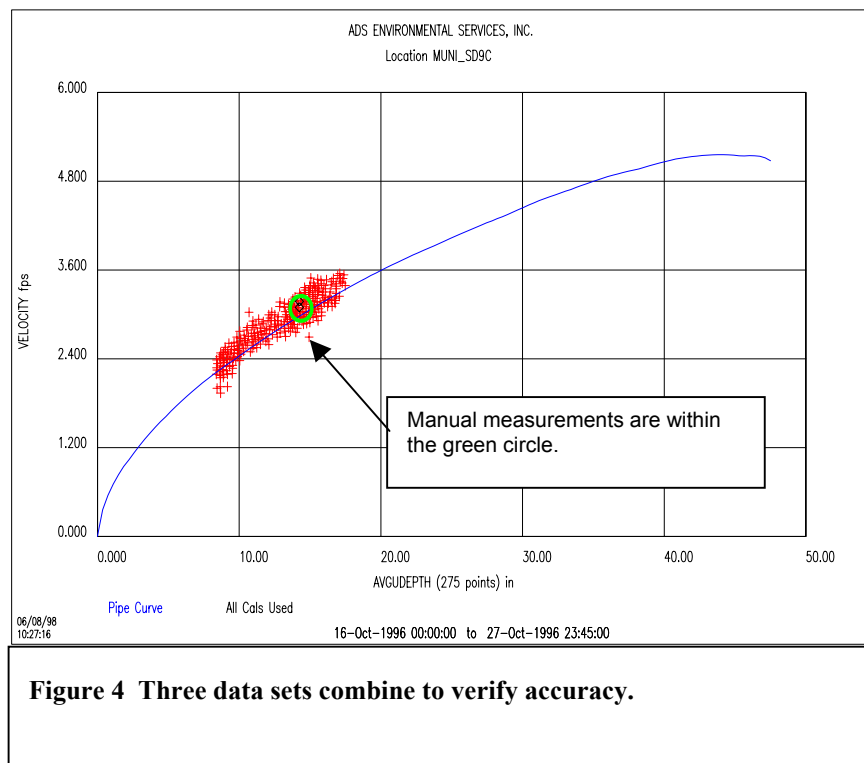
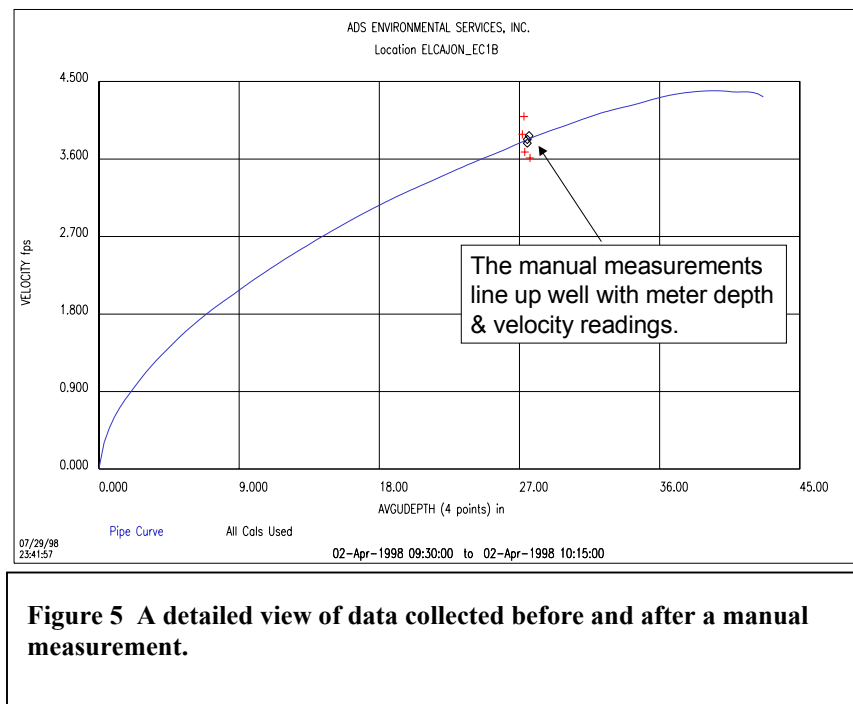


Figure 4 Three data sets combine to verify accuracy.

data should appear in a good free flow site with a properly performing meter. All three data sets should be aligned with each other.

It can be easily seen if data points align well with the Manning pipe curve, but it is not clear how closely the manual measurements coincide with the meter data. This is especially true if there are many data points. It is often instructive to look more closely at individual data points and the corresponding manual confirmation. Figure 5 is an example of a manual measurement plotted with four data points collected by a flow meter before and after the manual confirmation. Taking a manual confirmation at exactly the same moment as a meter reading could distort sewer hydraulics and the meter reading.



Analyzing a scattergraph is a **mandatory** first step in evaluating a flow meter's performance. The user can apply two tests in sequence to evaluate data in a scattergraph; looking for a repeatable pattern and comparing data to manual readings.

1. Repeatable pattern shaped like a pipe curve.

If both the meter's data and the manual confirmation data line up with the pipe curve, the user knows that the sewer is experiencing normal open channel flow with the velocity increasing with increased depth. If the meter data do not line up with a pipe curve, one of only two things is occurring. Either A) the sewer is not experiencing normal open channel flow or B) the meter is failing to make valid measurements. It is critical that the observer attempts to make this distinction before moving on to any other accuracy issues.

There are eight categories of unusual hydraulics that are easy to identify in scattergraphs and they are discussed in a separate document¹. It is important to recognize that in non-free-flow conditions the data may still be valid even though the data and the Manning pipe curve do not coincide. Not all meter software has the capability to display both a pipe curve and data simultaneously, however this evaluation can still be conducted by exporting data to a spreadsheet. If the patterns indicate that valid hydraulic conditions exist, then the user should move to step 2 below.

2. **Manual measurements confirm meter readings.** If the meter's depth & velocity readings are coincident or very close to the manual readings, the user knows that the measurable components are correct or bias free. Figure 5 shows an example of bias free data. It is important that the only those data points immediately before and immediately after the manual confirmation be used in this comparison. Apparent bias can occur in sewers with rapidly changing hydraulics such as an upstream pump station. In rapidly changing hydraulics the actual depth can change significantly between a manual measurement and the meter reading. Common sources of depth bias include pressure sensor drift, unstable hydraulics, large waves, noisy sites and fouled sensors.

Using This Technique in Practice

If flow meter data passes screening tests A & B, only then can the user consider the flow calculation itself. Of course if no manual measurements are conducted at the site, screening test B cannot be completed. Several things, including the use of an inappropriate equation or an incorrect pipe diameter can affect the accuracy of the subsequent flow calculation. Even the slightest downstream hump in a pipe can render the Manning and Colebrook-White highly inaccurate. A very common source of error is using the nominal pipe diameter shown on the drawings instead of using a field measurement. Especially in small sizes, the actual diameter often does not equal the nominal diameter.

Reviewing Hydrographs for Accuracy

Figure 6 show three hydrographs from three different meters measuring the same flow in adjoining manholes on a trunk line. The sewer is downstream of an industrial operation with an irregular diurnal pattern. The classic diurnal flow pattern that normally is used as a clue to a meter's reliability is absent here, so it is difficult to assess which meter is more accurate. The meters report different flow rates during a one-week test period.

Flow Rates Recorded by Three Meters in the Same Sewer		
	Total Weekly Flow (MG)	Average Daily Flow (mgd)
Meter A	18.2	2.43
Meter B	11.9	1.69
Meter C	13.4	1.92

The highest meter measured 53% more than the lowest and all three meters were new and were in place for approximately one month.

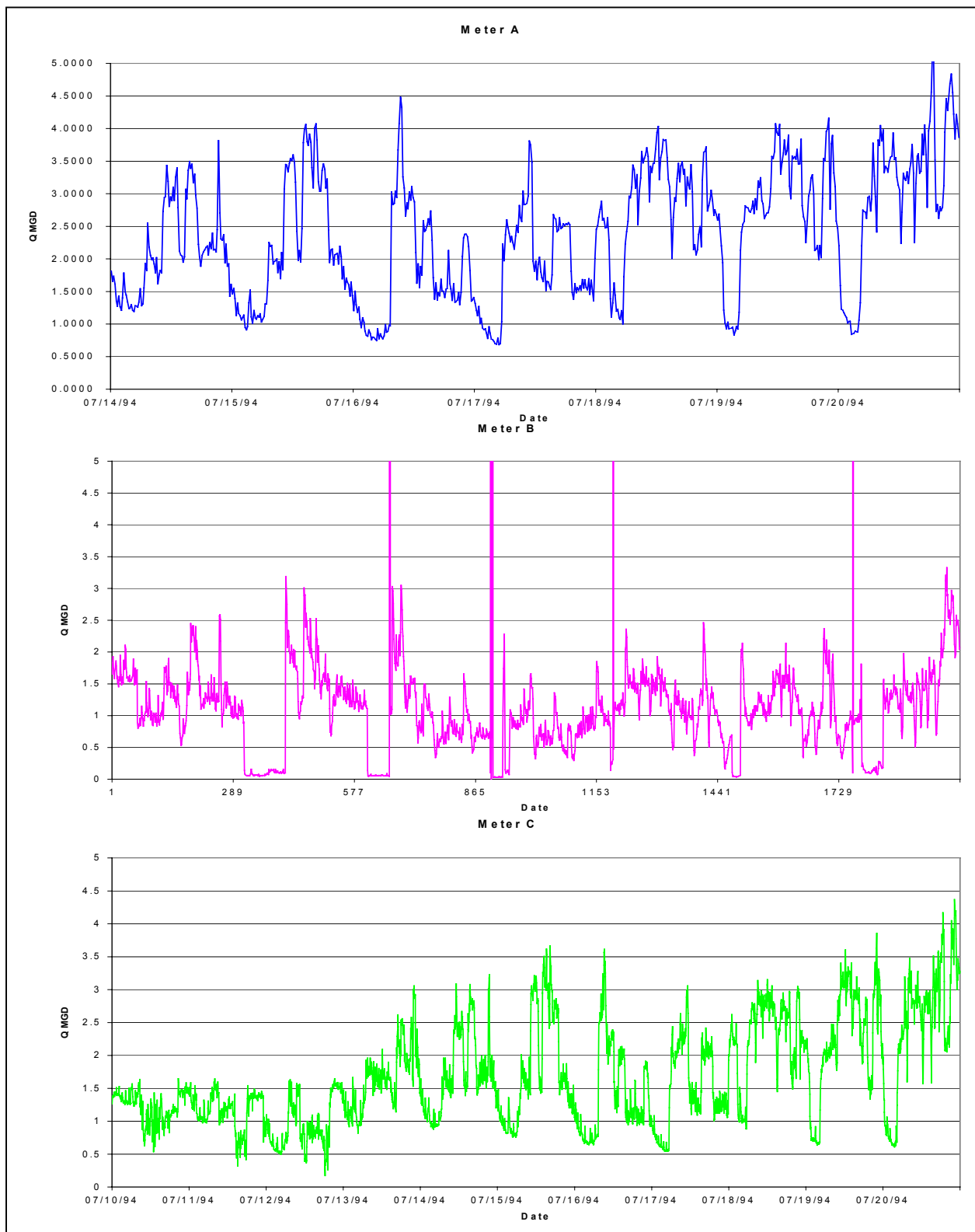


Figure 6 Hydrographs from three meters in adjoining manholes on a trunk line.

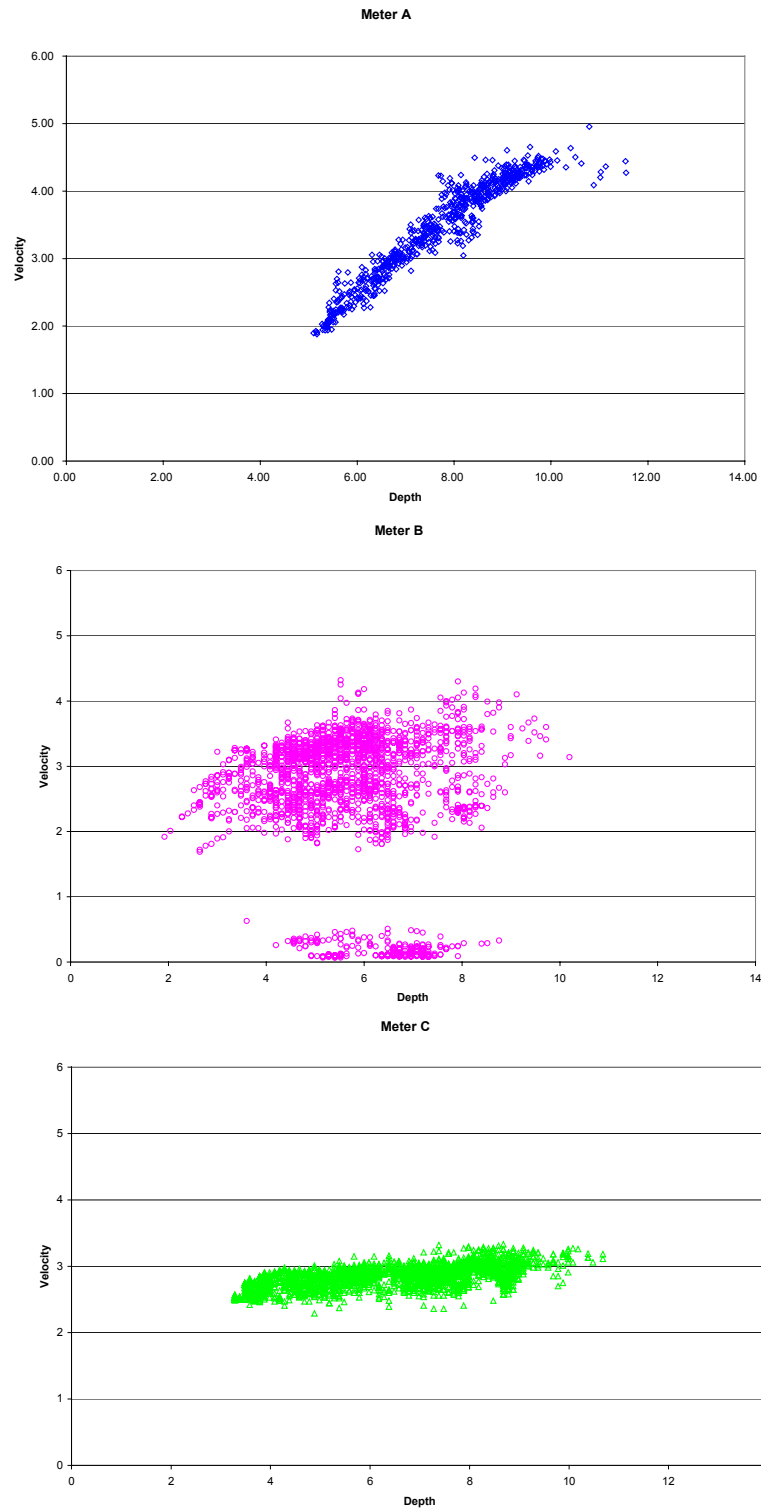


Figure 7 Scattergraphs of data from three meters in adjoining manholes on a trunk line.

Applying the Scattergraph Repeatability Test

There is no way to determine from hydrographs, which of these three meters is the most reliable or correct. By looking at the meter's depth and velocity data, we get the three scattergraphs shown in Figure 7. The meters are located on nearly identical slopes so similar depth-velocity relationships are expected. Applying the test of repeatability to these scattergraphs shows that Meters A and C each produce relatively tight patterns that form a possible pipe curve.

Meter B produced two patterns, neither of which is hydraulically possible. The width of the upper pattern shows that the meter's precision is low. It suffers from periodic velocity bias. This meter does not pass the first screening test and has no potential to be accurate.

Meter C produces a repeatable pattern, but velocity does not increase with depth as expected. Such a scattergraph is formed when a depth-velocity meter is installed in the backwater of a flume, but no flume exists here and this sewer was always in free flow condition. Note that Meters A & C each recorded depths of flow in the same 4 to 8 inch range, but the velocity ranges were remarkably different. Meter A velocities varied from 2 to 4.5 fps. while Meter B velocities were consistently around 3 fps. at all depths. Relative to the pipe curve defined by Meter A, Meter C experiences a high bias in velocity at low depths and a low velocity bias at high depths.

The conclusion is that only Meter A produces hydraulically valid data with acceptable precision. Only Meter A passes the first test and there should be follow up fieldwork to confirm that depth and velocity readings from Meter A are correct before it can be considered accurate.

Evaluating Long Term Data

The Water and Wastewater Instrument Testing Association (ITA) tested several flow meters for around six months in 1996 and 1997 and Depth-Q scattergraphs from three of the meters produced an instructive range of performance. Depth-Q scattergraphs display the calculated flow rate at each depth reading. The pattern should form a pattern similar to the pipe curve in Figure 4, but the curve is concave upward. The same evaluation of repeatability and precision can be conducted on Depth-Q scattergraphs, but bias is not readily evaluated.

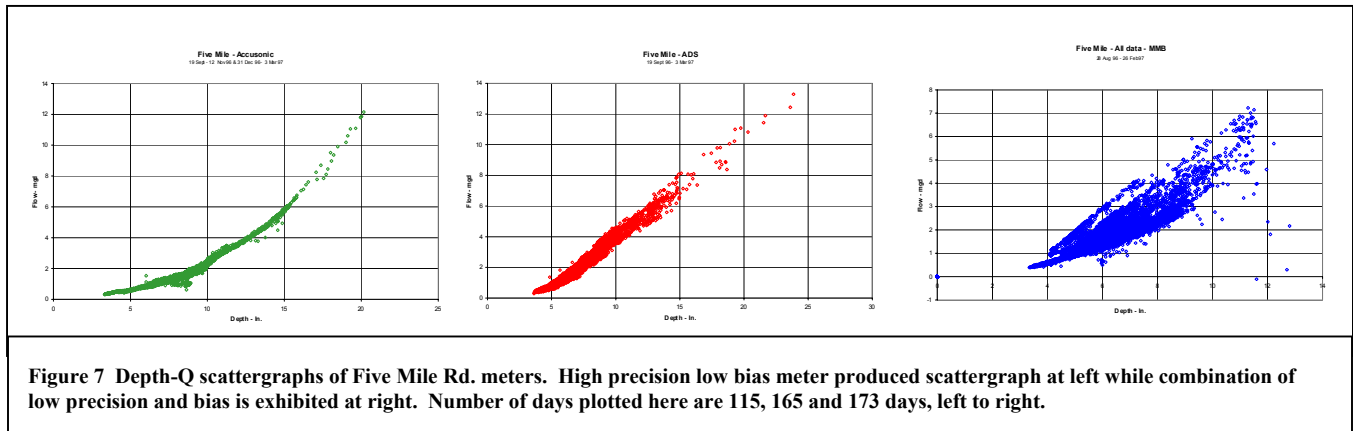


Figure 7 shows the three scattergraphs from approximately six months of data. A precision analysis ranks them from good to poor from left to right. The meter on the left exhibits very high precision and no apparent shift in pattern, while the meter on the right exhibits low precision and likely bias over the study period. It cannot be determined if the bias is in the depth or velocity sensors. Depth –Q scattergraphs are effective in revealing the performance of a meter throughout the full range of operating depths.

CONCLUSION

Conducting an evaluation of precision and bias in a scattergraph display is a fast and effective way to screen flow meter data for reasonableness and hydraulic validity. Time can be saved in any hydraulic study, such as an Infiltration Inflow study, by applying this simple screening test before conducting the analysis. Combined with manual confirmations of depth and velocity this method can determine meter accuracy without a second flow measurement device.

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