The Seductive Lure of Level-Only Meters for Measuring I&I

The Battle Between Theory and Reality

By Jay Boyd and Paul Mitchell, P.E.

Infiltration and Inflow (I&I) in the wastewater collection system draws a utility's attention. It's an ongoing threat for SSOs and has a substantial cost once it is received at the wastewater plant. As one senior plant operator put it, "I don't like paying to process rainwater".

The strategy for dealing with I&I can be simply described as *find it and fix it*. Both are time-consuming and costly. In this discussion, we will examine the "find it" portion which involves locating the source(s) and quantifying the amount to determine impact.

By far the most accepted technique to find I&I are flow studies where this process will locate and quantify the I&I impact. The preferred tools for these studies are area-velocity (A/V) monitors. To acquire data, these monitors measure water depth in a pipe and its velocity measurements to derive flow. While monitor manufacturers employ a range of specific technologies, A/V monitors generally share capabilities to measure flows with a sensor(s), communicate data from the remote location, capture and/or store data, and provide an output for user viewing and assessment.

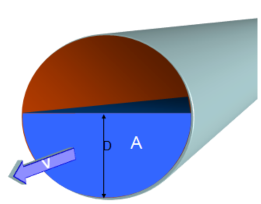
The cost of monitors, including installation, can be expensive for utilities with limited budgets and technical resources. Yet, these utilities are sometimes under pressure through regulatory agencies or have cost pressures due to excessive flows. As a result, some utilities look towards less expensive means for assessing I&I sources and have embraced the use of *level-only* monitors. These monitors measure depth only and use software-driven formulas to calculate flow. At a fraction of the cost of A/V monitors, they promise a quick and easy way to evaluate I&I entering the collection system. Under ideal conditions they may be capable of providing flow data. Yet, sanitary sewers present a substantial challenge for offering ideal conditions. To better understand this, we'll first take a look at flow basics and review the variables that influence the ability to provide "quick and easy" I&I evaluations.

<u>Some Well Established Flow Basics</u>

Understanding flows in collection systems for determining capacity or the effects of I&I is essential for operational performance and asset planning.

The well-known flow formula is Q = VA where: *Q* is flow, *V* is velocity, *A* (See Diagram 1) is the cross-sectional area of the pipe is derived and typically measured using Area-Velocity (A/V) monitors. Now well established, they provide accurate, repeatable measurements.

Diagram 1: Illustration of the two essential measures of flow. "A" is the cross-sectional area and "V" is velocity.



Those engaged in collection system flow measurement rely on A/V or *flow monitors* to conduct their work. Even small collection systems can have thousands of pipe segments and manholes. It would be more favorable to have numerous flow monitors distributed throughout the collection system, but it may be cost prohibitive. Thus, concurrent measurement of many sites can be budget limited.

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But Wait! Is There Another Way?

Over the past few years "level monitors" (level-only monitors) have offered the promise of providing collection system flow data but at a fraction of the cost of A/V monitors. These monitors measure the distance from the sensor to the water below and then calculate water level in the pipe for a given pipe diameter per Diagram 2, below.

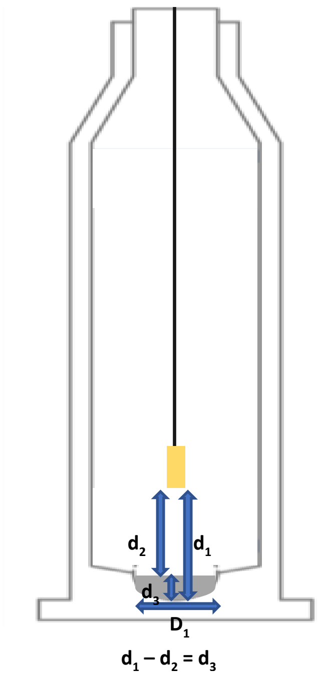

Diagram 2

d1 – d 2 = d3 (depth)
Where
d1 is the distance from the sensor to the bottom of the pipe (invert)
d2 is the distance from the sensor to the water level
D1 is pipe diameter

Level-only monitors do not measure velocity (*V*). So, if we are to solve the simple flow equation of Q = VA how can we account for velocity?
Using Manning's equation below it is theoretically possible to determine velocity (*v*) as shown:

$$v = \frac{1.486}{n} R^{2/3} S^{1/2}$$

Where (factors):

n is the Manning co-efficient (boundary resistance),
R is hydraulic radius (of the pipe),
S is slope (of the grade).

We must therefore know these three factors above to successfully arrive at velocity (*v*) . To do this we must determine:

- Pipe material for the Manning co-efficient, (*n*).
- Derive the hydraulic radius (*R*) from the level measures, pipe shape and pipe diameter
- Determine the slope of the grade

Once these factors are accounted for, software is typically used to derive flow (*Q*). Provided that level-only monitors and software can be used to derive flow there are some advantages to be realized as outlined below:

Cost. Level-only monitors typically cost 35% to 60% less than A/V monitors. Thus, users can either measure I&I for less cost or, alternately, the user can deploy more monitors for the same expense. The latter case increases the number of monitoring locations.

Installation. Generally, level-only monitors are easier and faster to install and uninstall. Consequently, they can be more easily moved to a new location if desired.

As the title of this paper suggests, level-only advantages seem compelling and even seductive at first glance, so we will now take a closer look.

<u>A Neat Equation Can Get Messy Quickly</u>

As expected, there are some significant challenges for using level-only monitors for calculating flow. The essential goal is to acquire *good quality* measurement data that is *accurate and repeatable*. Without this, poor quality, spurious data will lead to erroneous conclusions about flow or I&I sources or system capacity.

As stated previously, level-only monitors do not measure velocity (*v*), but instead derive it as shown above.

Looking at the velocity (*v*) formula, n, R and S are the variables (values) that must be determined to complete the equation. These values *must* be accurate otherwise a calculation will have error. To test if accuracy is possible we will take a look at each value.

Slope. Often, slope (*S*) can be obtained from the design drawings. We must then assume that the intended-construction slope noted in the drawing perfectly matches the actually-constructed slope (as-built). Experience clearly shows that this is a poor assumption as construction practices do not replicate design to high degrees of accuracy. In addition, segment to segment slopes (including the segment leading into the manhole) can be an order of magnitude different from the manhole to manhole *average* slope. Furthermore, the slope in the manhole itself is rarely the same as the assumed slope of piping.
Post construction, we must assume that nothing has influenced or changed the pipe slope. For example, we must assume that there is no settling or upheaval. In practice, this is another poor assumption. Therefore, from design to construction and from construction to the current state of the pipe we see two instances of potential error for knowing slope. At best, the slope value will be an estimate and even that can be an order of magnitude off.

Hydraulic Radius. When acquiring a radius (*R*) of a pipe, several assumptions are made.

- that the pipe geometry is round,
- that the diameter of the invert trough is dimensionally uniform,
- that the invert and the influent and effluent pipe diameters are uniform.

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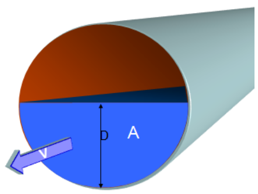
Invert geometry and uniformity are not well controlled in construction. To demonstrate these inconsistencies all it takes is a random inspection of a dozen or so manholes to bear-out that invert dimensions are not well controlled nor, do they have to be to be functional. Therefore, the poor control of geometry and dimensionality are sources of error.
Of special note, any manhole invert with a junction by design has differential radii and cannot be measured with level-only.



Manning's Coefficient. Manning's Coefficient of Roughness can be thought of as the resistance to flow on the pipe boundary pipe surfaces. The roughness co-efficient can be referenced using published tables based on pipe material. These tables provide the "*n*" value in the velocity equation. For example, a concrete pipe is listed as $n = 0.015$, a vitrified clay pipe is listed as $n = 0.013$, etc. While useful as a starting point, these values cannot account for actual pipe condition. The roughness tables provide a value range to account for this, but the reality is that judging pipe roughness coefficient is difficult at best. Therefore, the "*n*" value is an estimate. Potential error is again introduced.

Uniform Flow. Manning's equation always assumes that there is "smooth, uniform flow." In a sewer that's rarely true. Considering such conditions as backwater, drawdown, wavy/choppy, or transitional slope-change; the equation will be wrong. Transitional flows from such conditions, directional change, obstructions, pipe curves, and off-sets will violate the Manning's uniform flow assumptions. Backwater, may be the most egregious issue where level is rising but actual flow is not, in fact, changing.

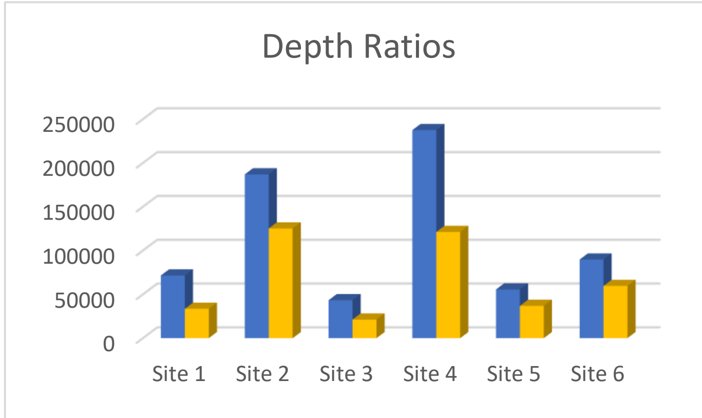
Sediment & Wetted Area. The final step in computing flow (Q), is to multiply estimated velocity (v) by wetted area (A) of flow. If sediment is present, this will render the assumed area erroneous. In some cases, this can add massive error to the computation. Often it is difficult or impossible to determine the presence of sediment from a topside view only. Even if an attempt is made to account for sediment in the flow cross sections, sediment is typically not uniformly distributed and causes excessive error regardless.

In summary, Manning's equation has the potential for providing acceptable results. As shown above, accuracy of results is dependent on a wide range of variables. Slope, hydraulic radius, wetted area, Manning's coefficient of roughness, and the assumption of smooth uniform flow all have error potential and some, significantly so. When these variables are combined into a single equation, error is multiplied significantly, and accuracy is severely compromised. Even an estimate would have to be called into question for its value of use.

<u>The Phantom Rise: False Positives</u>

Despite error from variables as described previously, it can be argued that level-only monitors can provide useful comparative information. Specifically, while the actual flow values may be inaccurate, level-only measurement can reveal differences for wet versus dry weather flows. Intuitively, one would expect that wet weather will produce higher levels at a given site than in dry weather as illustrated in Graph 1.

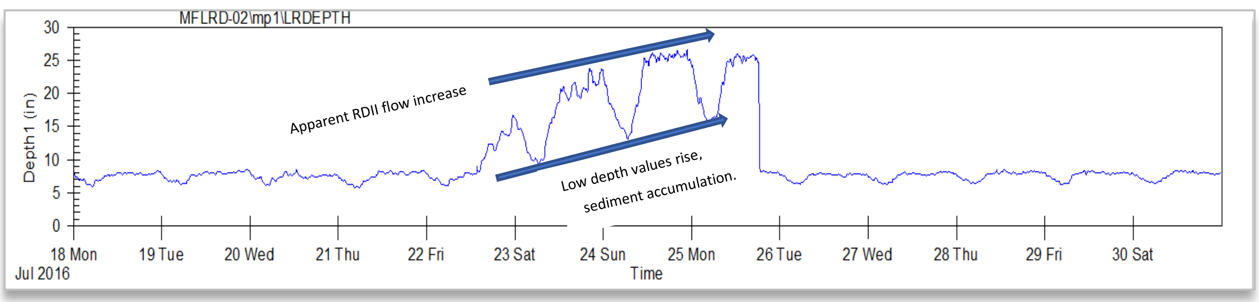
Yet, there are numerous factors that can influence level changes and *mask* the actual flow conditions when using level-only monitors.



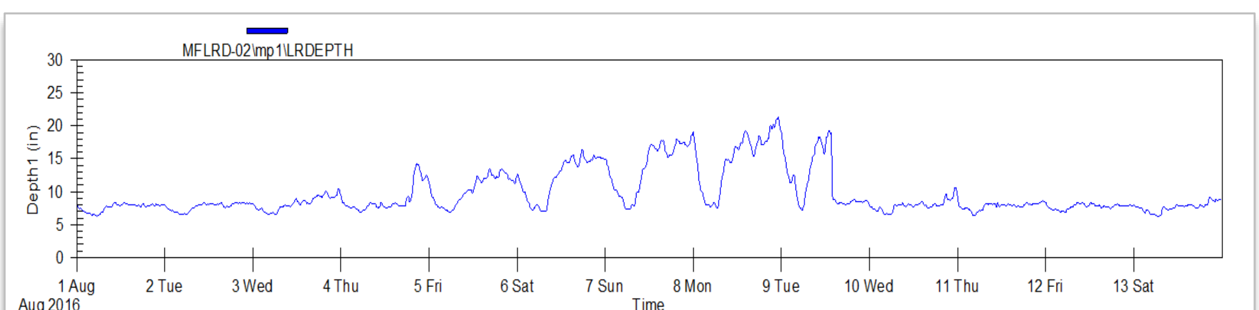
Graph 1

During a rain event flow (*Q*) would appear to increase substantially based on a rising level values. This appears to be the case as shown in the Graph 2 hydrograph where water levels rise concurrent with a rain event. Yet, level change (depth) in this instance was a result of a developing downstream blockage where dry weather sediment build-up caused a back-up. It was not due to rain derived I&I (RDII). In another example, the Graph 3 hydrograph shows what appears to be increased flow due to rain. Here again, a downstream fats, oils and grease (FOG) blockage was developing at the pipe crown. Measured levels (depth) in the pipe increased due to the blockage. In both cases these blockages and corresponding level rise would be interpreted as RDII. If we depended on level-only measurement this could have led to a conclusion that the area was a source of I&I leading to expensive action, possibly rehabilitation or replacement. Instead, a good cleaning of blockages would show that these locations only contributed minor to increases of I&I during rainfall.

Graph 2- sediment "phantom"



Graph 3- FOG "phantom"



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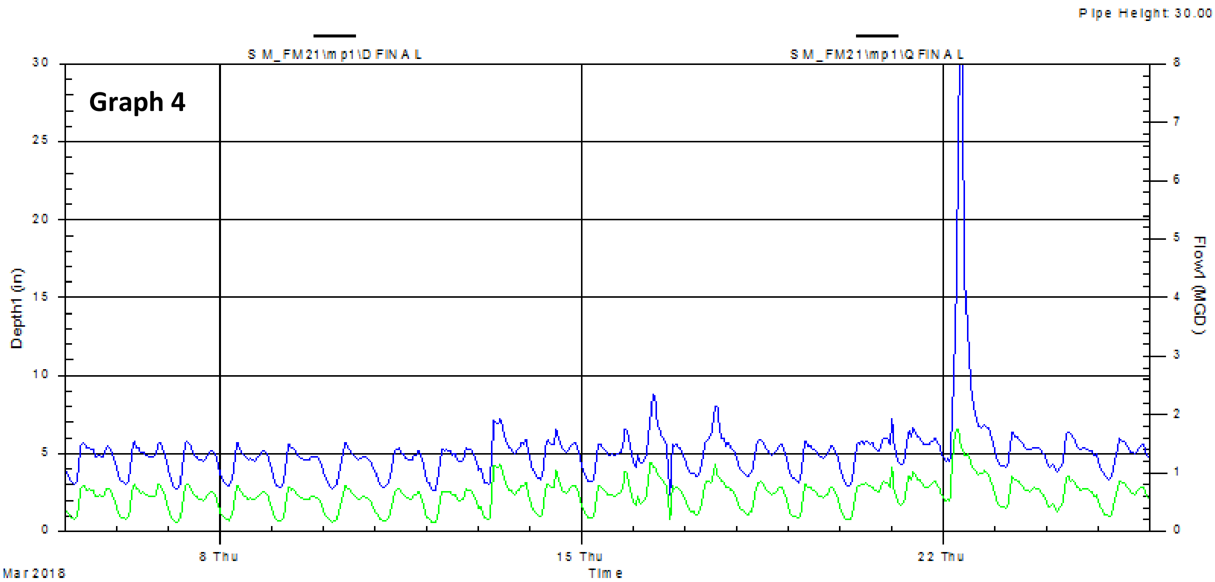
In Graph 4, below, we see a large 8X jump in level (blue) indicative that flow has significantly increased. Yet, the A/V meter data shows a 1.4X increase of flow. Why the discrepancy? This is a backwater condition. It looks like a I&I issue, but it is not.



<u>The Hidden Truth: False Negatives</u>

In a recent study in the Washington State, level-only monitors were compared to A/V monitors assessing their ability to identify and quantify I&I. Co-located monitors provided level data and flow data change at several locations. Hydrographs revealed a distinct pattern where the A/V monitors measured substantial flow increases while the level-only monitors showed minor change indicating a false negative.

In Graph 5 the two hydrographs representing depth-only measurement and flow did not correlate. Instead, the depth-only measurements showed a lower (negative) depth change (blue) while flow (green) hydrograph value doubled. Therefore, if level-only monitors were used to determine I&I, the event would have been completely missed and the utility might conclude that this site had no issues. Hydraulics can be odd and complex at times in sewers as shown here.

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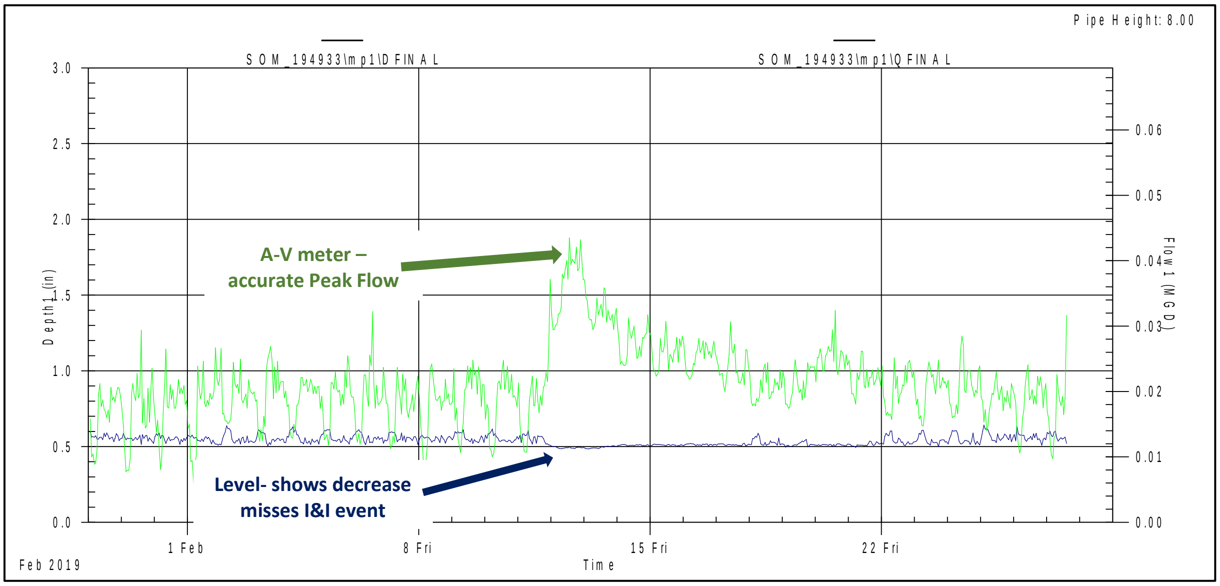
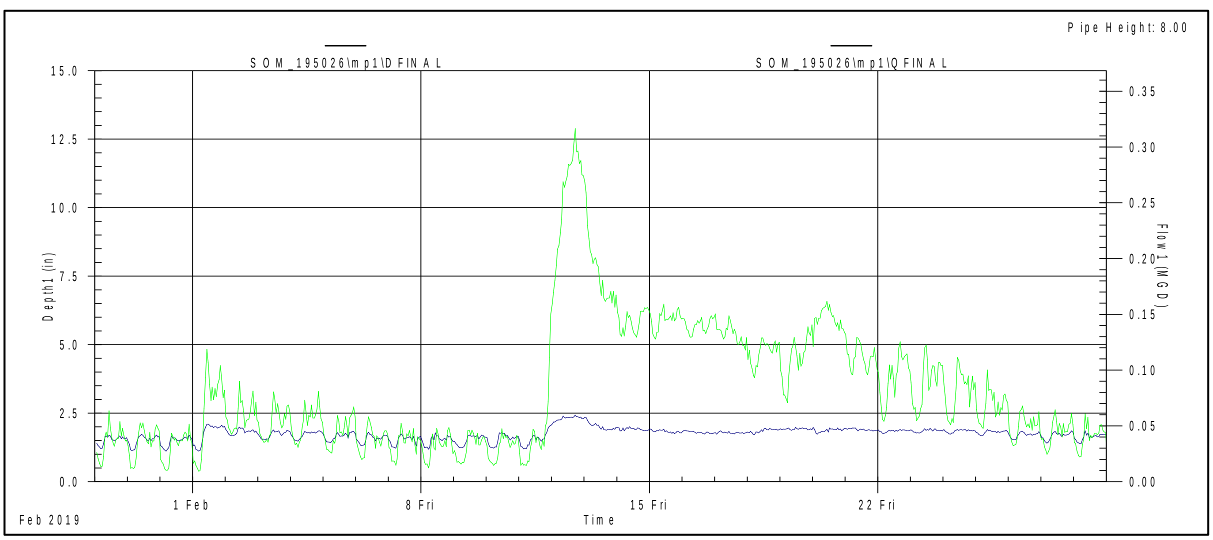


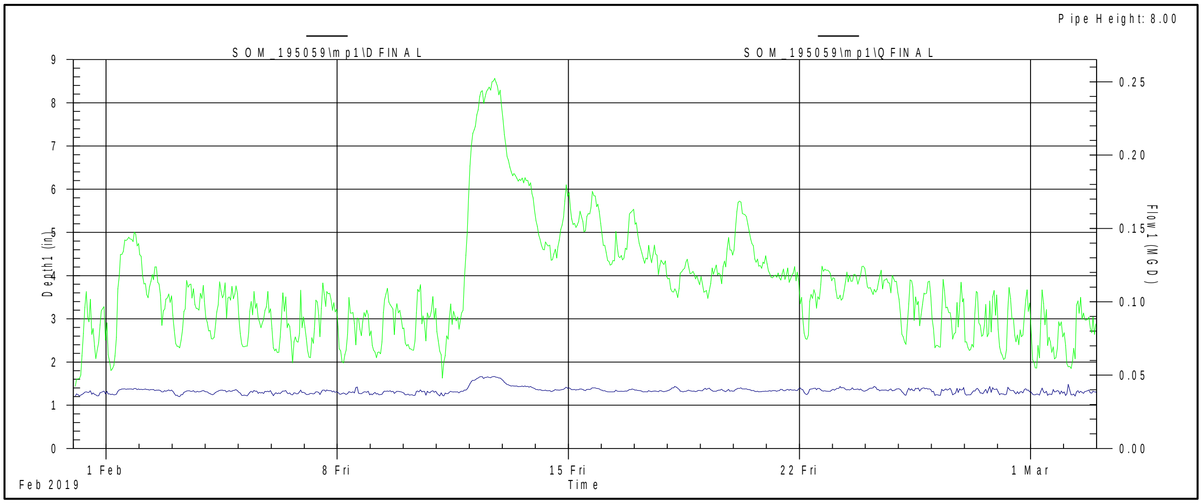
Graph 5: Depth (blue) decreases while flow increases (green).

Graph 6 is another example of poor level-flow correlation. In response to a 1.5" rainfall, the level-only monitor recorded a 1.0" level change. Using Manning's equation, we would calculate that this was a 2.8X increase in flow. Yet, the A/V monitor measured a 14X increase in flows. The level-only monitor registered as a minor level change and might be ignored by the utility.



Graph 6: minor change in level (blue) versus a significant change in flow (green)

A similar disparity is observed in Graph 7. The level measurement shows a modest 0.4” increase. The Manning’s calculated flow change would be 1.7X. Yet the A/V monitors measured more than a 3.6x increase. If only dependent on level-only monitors, the user would not perceive this site to be a significant issue with a Manning’s calculated increase.



Graph 7- level-only (blue) indicating moderate increase versus flow (green) show with 3.6x increase.

These examples illustrate how level-only monitors do not reflect actual conditions of flow. The reason is that in all cases there was a significant increase in velocity (*v*) which accounted for the corresponding increases in flow. The level-only monitors missed the velocity change altogether. Therefore, without direct velocity measurement of the A/V monitors, the flow change can be hidden from level-only monitors. Consequently, substantial I&I sources would not be detected, and these sites would be ignored for future corrective action.

Conclusions

Level-only monitors are useful for several collection system applications including sanitary sewer overflow (SSO) mitigation, optimizing cleaning schedules using real-time site feedback, reporting CSO activation, and even back-up alarming at wastewater pump stations.

Yet, it’s been demonstrated that level-only monitors attempting to measure flow and detect I&I by incorporating algorithms (any assumptive flow based on depth) for the flow calculation rely on multiple, poorly controlled variables. Thus, they are a significant source of error. As presented, level-only monitors can indicate false positives from blockages and backwater and false negatives in the case of undetected velocity changes.

It’s been argued that some error is acceptable and that you can get “close”. But how do we define “close”? If we study 10 sites and miss I&I on 50% of them, is that “close”? If we only miss I&I on 20% of the segments, is that acceptable? Rehabilitation costs can easily be in the six to seven figure range. That being the case, it is hard to imagine that even 20% error is acceptable when millions of capital dollars are at risk. Further, if an investment is made in the wrong sections due to error, there is no return on capital whatsoever. The low cost and seeming ease-of-use level-only monitors can be seductive but accompanying this is substantial potential for error and wasted resources.

By contrast, an investment in A/V monitors that measure compute actual flow rate will provide consistent, reliable data. In the final analysis, A/V monitors they will give users assurance and confidence in the results that, in turn, drive informed capital decisions and with substantial returns.