

Sanitary Sewer Overflows Leave Telltale Signs in Depth-Velocity Scattergraphs

Patrick L. Stevens and Heather M. Sands
ADS Environmental Services, Inc., Indianapolis, Indiana

Sanitary sewer overflows (SSOs) are elusive. They are difficult to witness or document because they usually occur during rain events, when people are indoors. Frequently they are located out of sight at the lowest manholes or structures along creeks and ravines. Toilet paper in the branches along the creek might be the only evidence that some SSOs leave behind. Casual observers and some collection system managers first assume that they need a greater capacity pipe. More often, most SSOs have a downstream bottleneck as a contributing cause, and in many cases greater capacity is not needed. SSOs and bottlenecks each leave telltale evidence in the data of nearby flowmeters. This paper discusses how SSOs and bottlenecks reveal themselves when the flowmeter data are displayed as a depth-velocity scattergraph.

The Hydraulic Grade Line

The hydraulic grade line (HGL) connects the surface of a liquid at various points. In open channel flow, HGL corresponds to the water surface, as shown in Figure 1. If flow exceeds the capacity of the pipe, the water level will rise and the pipe will operate in a surcharged mode. Under ideal conditions, the HGL is parallel to the slope of the pipe, as shown in Figure 2.

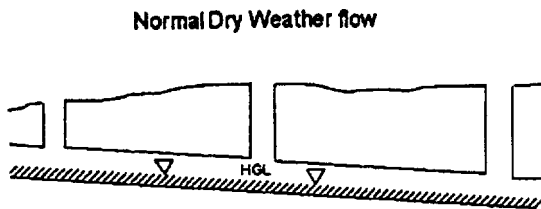


Figure 1. HGL corresponds to water surface.

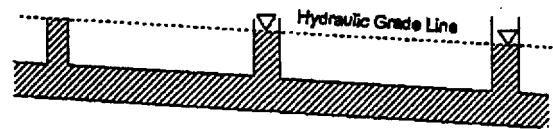
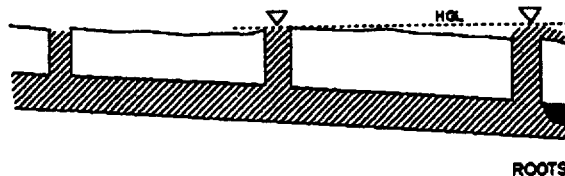


Figure 2. HGL is parallel to pipe.

If a downstream restriction prevents the pipe from carrying its full capacity, the pipe will fill during rain events and become surcharged while carrying only a fraction of its design capacity. If the bottleneck is major, such as from a collapsed pipe or excessive amounts of roots, the flow slows significantly and HGL becomes almost horizontal. Figure 3 shows roots reducing the pipe's capacity by approximately 50 percent and causing an SSO. Here HGL is measured from the elevation of the SSO and can become nearly horizontal.



SSO caused by a Bottleneck -
Severe Bottlenecks Flatten the HGL

Figure 3. HGL flattens during an SSO.

Scattergraphs

Manning's theory states that velocity in an open channel pipe increases as the depth of flow increases and that, for a given pipe, a certain depth should always correspond to a certain velocity. This relationship between depth and velocity is often displayed as the hydraulic elements curve shown in Figure 4. Open channel flowmeters on the market today calculate flow by the continuity method (cross-sectional area times velocity) and use depth and velocity sensors as their primary input. Plotting a flowmeter's data in a depth-velocity scattergraph offers a quick and easy way to check on the quality of the raw sensor readings. If the shape of the depth-velocity scattergraph resembles that in Figure 4, then the sensor readings are repeatable and valid. Scattergraphs are easily created using spreadsheet software. (All scattergraphs in this paper were created in Lotus 1-2-3, Version 4.0.)

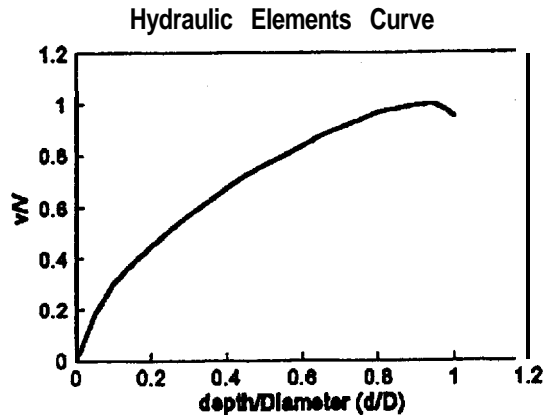


Figure 4. Manning's theory.

Figure 5 is a scattergraph that exhibits a classic cigar-shaped pattern, which indicates that the depth and velocity readings are valid. This scattergraph and most of the other scattergraphs in this paper are from data collected during infiltration and inflow (I/I) studies around the United States. All data were either collected by ADS Environmental Services or provided by municipalities, and most of the scattergraphs are from data collected over 60 days. No attempt was made to verify the accuracy of the data.

Depth and Velocity Sensors

Most of the depth data displayed in this paper are readings captured by ultrasonic and pressure transducer technologies. Most of the velocity data were captured by a digital Doppler velocity sensor. In routine situations, all three sensors are installed together. Figure 6 shows the basic configuration of the ultrasonic depth sensor used to measure flow depths during routine conditions. The measurements are accurate and drift free, and are used for depths less than full pipe. Figure 7 shows the basic configuration for pressure transducer measurement, which records depth of surcharging. In this paper, all depth readings below full pipe are ultrasonic readings, and those above full pipe are from the pressure sensor.

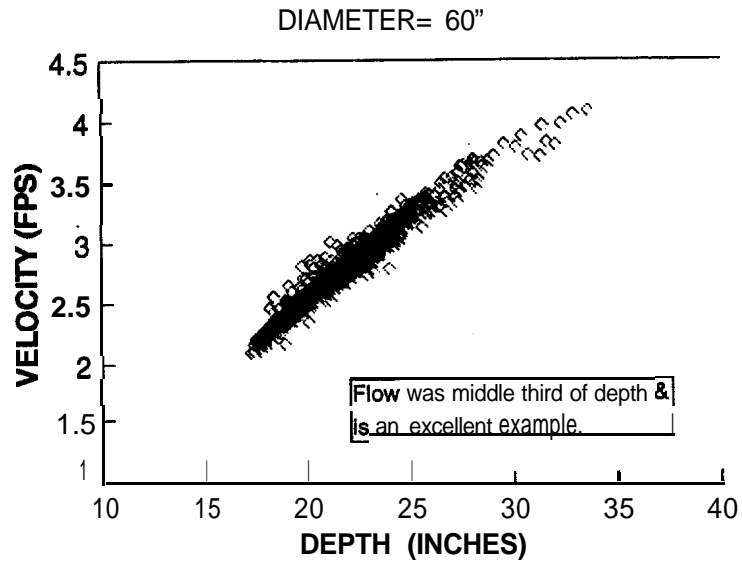


Figure 5. A classic cigar-shaped pattern.

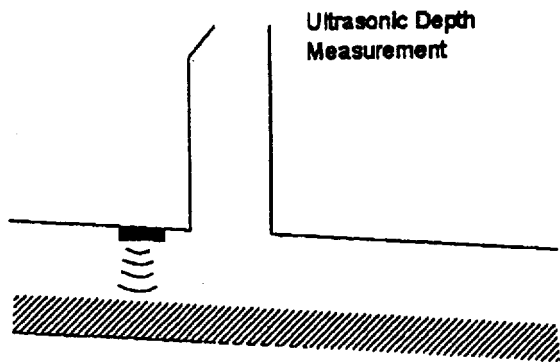


Figure 6. Ultrasonics used for normal flow.

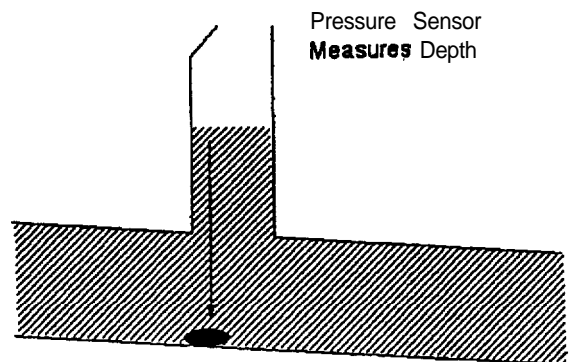


Figure 7. Transducer measures HGL.

The pressure sensor measures pressure in the adjoining manhole. Think of the pressure sensor as recording HGL above the flowmeter.

Velocity is measured by a digital Doppler sensor mounted on or near the bottom of the sewer. Its signal is transmitted upstream, as shown in Figure 8.

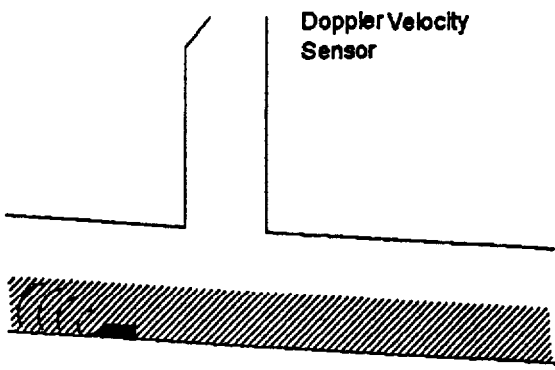


Figure 8. Digital Doppler looks upstream.

Classic Signature of a Bottleneck

Figure 9 is the classic scattergraph signature of a bottleneck downstream of the flowmeter. This scattergraph shows that during the minimum flow at this site, depth is around 4 inches while velocity is around 2 feet per second (fps). As the depth increases to around 10 inches, the velocity increases as expected to greater than 4 fps. As depth increases from 10 inches to full pipe (24 inches), velocities drop to around 2 fps. As depths increase above 24 inches, the sewer begins to surcharge, and additional pressure forces greater flow through the bottleneck. As depth increases to 60 inches, velocity increases to around 3 fps, the same as at 6 inches of depth.

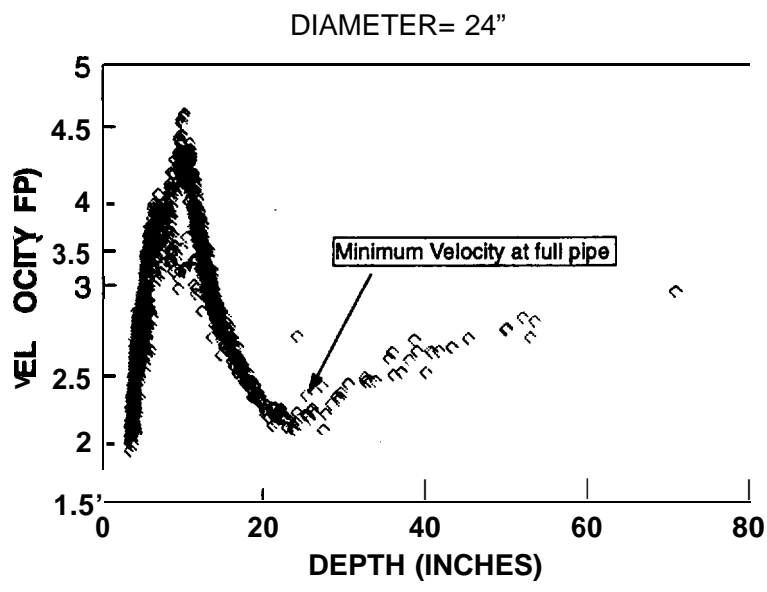


Figure 9. A classic bottleneck signature.

Signature of an SSO

An SSO occurs whenever the HGL rises to the lowest outlet in the sewer system, or when the SSO limits the height of the HGL. Therefore, if there is a pressure (or HGL) that is never exceeded, regardless of the number of surcharge events or the amount of rain, one must assume that an SSO is occurring. The classic scattergraph signature of an SSO can be seen in Figure 10. This 33-inch sewer experienced several wet weather events during the study, and there is a very distinct limit to the pressure depth or HGL. The low velocities reveal a flat sewer. Even during the SSO event, the velocities seldom exceeded 1.5 fps.

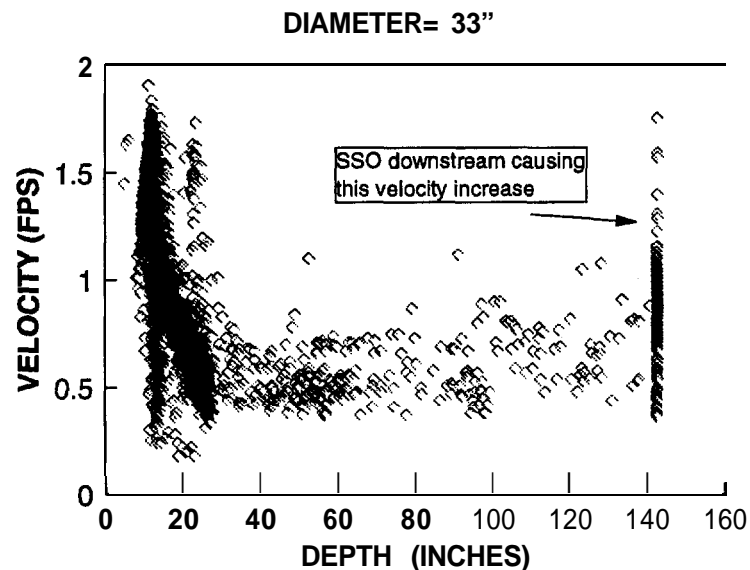


Figure 10. Vertical line at right is from an SSO.

Is the SSO Upstream or Downstream of the Flowmeter?

The shape of the scattergraph during the SSO event helps determine whether the SSO is upstream or downstream of the flowmeter. If the overflow occurs below the meter, as shown in Figure 11, activation of the overflow increases the volume of water passing by the meter, and an increase in velocity will be detected. Figure 12 is the scattergraph of a site with the SSO downstream. The telltale characteristic is that the velocity increases once the SSO is activated. Activation of the SSO allows more flow to leave the system. Because the pipe is already full, greater flow rate means greater velocity. The overflow at this site was within two or three manholes downstream.

SSO and Bottleneck Downstream of Flowmeter

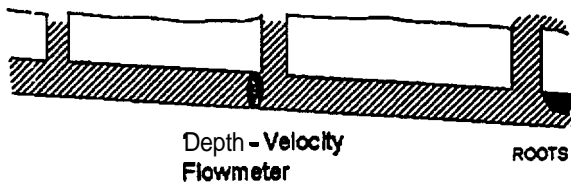


Figure 11. An SSO increases velocity at the meter.

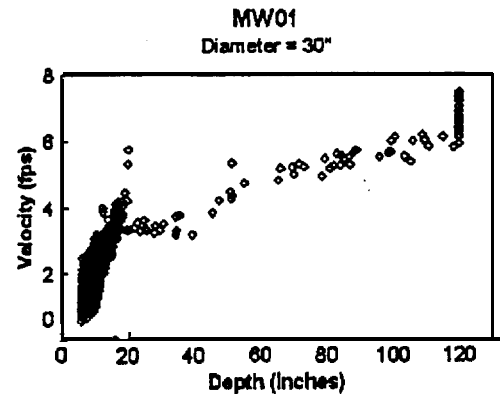


Figure 12. SSO activation downstream increases velocity at the flowmeter.

A word of caution is in order here. It is possible that the apparent limit to pressure (HGL) is actually the upper limit of the sensor. Even if the upper limit of the sensor is exceeded, a significant velocity increase would indicate that an SSO is active. It is also possible for a flooded basement to dampen depth increases sufficiently to create an apparent SSO signature in a scattergraph. Although EV08 (shown in Figure 10) appears to have reached the upper sensor limit, the SSO is documented by the velocity increase and **was** verified by field **crews**.

What should we expect if the SSO is upstream of the flow monitor, as shown in Figure 13? The volume of water passing through the flowmeter should remain steady during the activation of the SSO. Figures 14 and 15 are both sites that appear to have an SSO activated upstream of the flowmeter. The telltale characteristic here is that the velocity remains low during the SSO activation. Here again caution is in order. If the pressure sensor limit is exceeded and velocity remains low, it is invalid to assume that an SSO has occurred.

SSO Upstream of Flowmeter

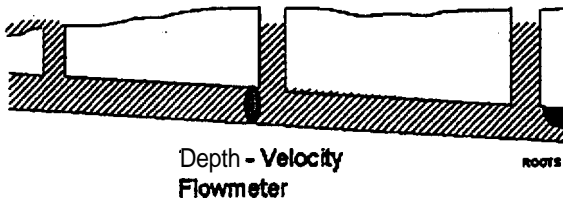


Figure 13. SSO volume escapes undetected.

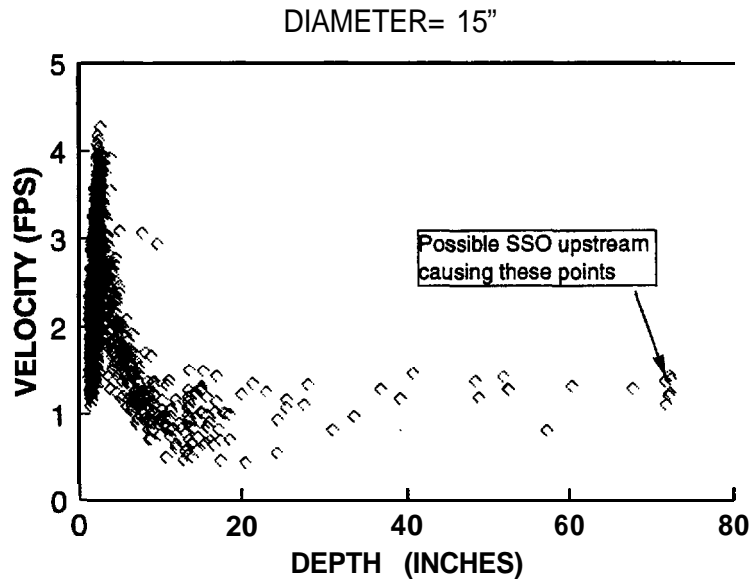


Figure 14. A likely SSO upstream.

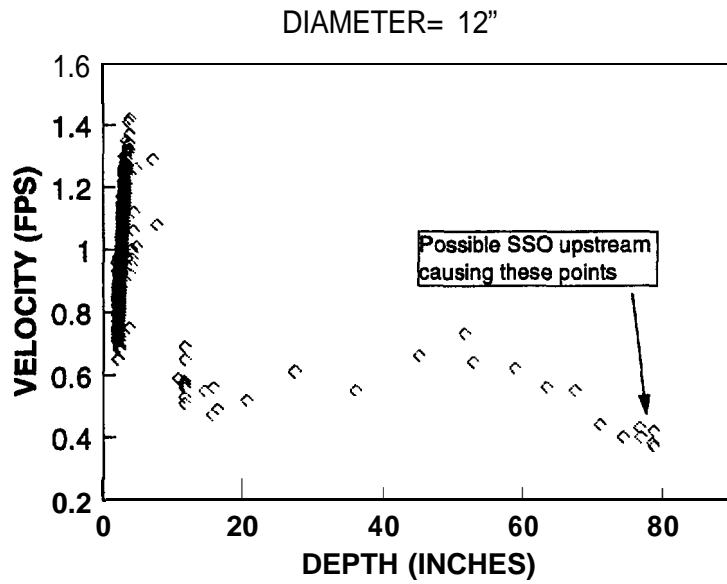


Figure 15. A likely SSO upstream.

These two sites are from the same study, and only one system-stressing rain event occurred during the study. Both sites exhibit the bottlenecked scattergraph patterns, and both sites maintain the same low velocity even after the SSOs activate at around 72 and 79 inches of depth. Even though each

scattergraph shows multiple readings at the upper depth, these sites should be monitored for a longer period to be certain that SSOs are present.

How Close Must the Flowmeter Be to the SSO?

In theory, any maximum pressure depth repeated over multiple storms indicates that the flow monitor is within the HGL influenced by the SSO. The flatter the HGL, the greater the influence. Consider a housing subdivision served by a 12-inch pipe that is almost completely blocked by roots or debris. Such a bottleneck would likely cause a surcharge with very little additional I/I, and the HGL would be nearly flat over the entire subdivision. A flow monitor anywhere within the subdivision would detect an SSO.

Do All Flow-Measuring Technologies Work the Same?

Technologies used to measure depth in open channel sewers today include ultrasonic and pressure transducers. Velocity technologies include electromagnetic, analog Doppler, and digital Doppler. Each exhibit characteristic signatures in scattergraphs.

The three scattergraphs in Figure 16 are from three flowmeters installed in adjacent manholes on a 30-inch line that experiences rapid fluctuation in flow rate. These data were provided by the municipality that conducted the 60-day test. The scattergraphs display depth and flow and are similar in shape to depth-velocity scattergraphs.

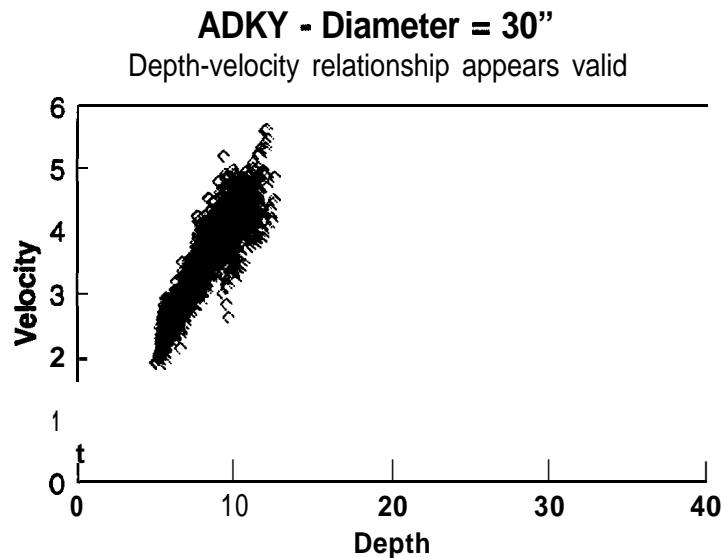
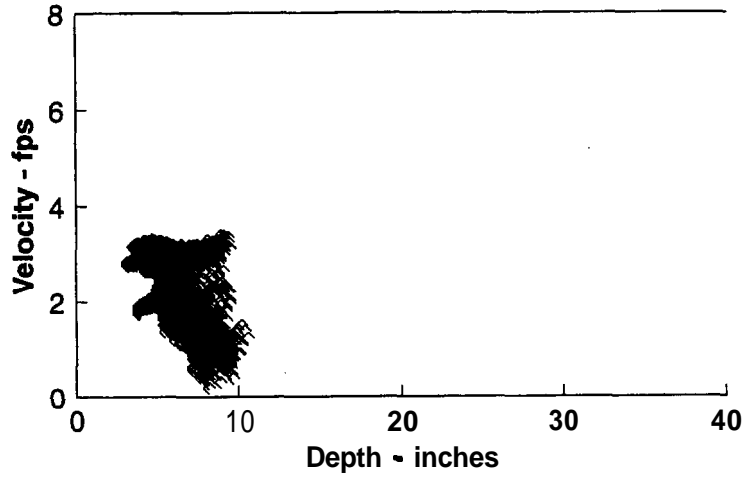


Figure 16. Scattergraphs from flowmeters installed in adjacent manholes at site AEBV.

MMKY - Diameter = 30"

Electromagnetic Velocity sensor gradually fouled.



ISKY - Diameter = 30"

Velocity Sensor has fouled or failed some of the time.
Depth-Velocity relationship not well formed.

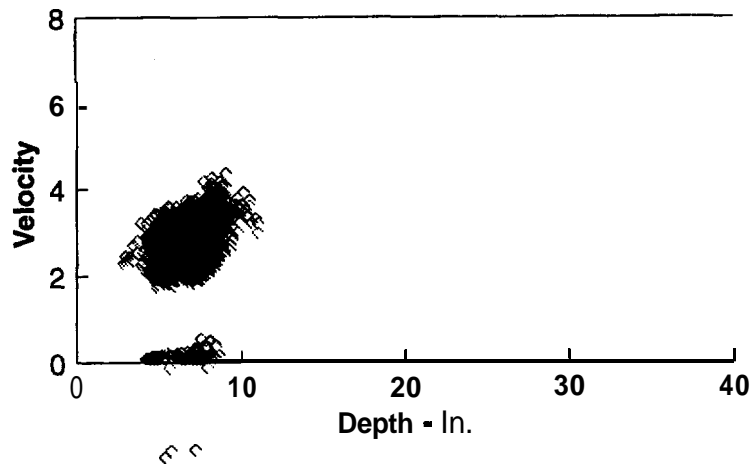


Figure 16. Scattergraphs from flowmeters installed in adjacent manholes at site AEBV (continued).