Collection Systems 2005
Sustaining Aging Infrastructure: System, Workforce and Funding

FINAL MANUSCRIPT

GETTING MORE FROM FLOW MONITORING - INTERPRETING SEWER FLOW DATA TO YIELD THE MAXIMUM BENEFIT

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ABSTRACT

Recent years have brought increasing pressure from Federal and State Regulators for more comprehensive management of collection systems in an effort to significantly reduce releases of untreated sewage to the environment. This has created a need to understand what the flows in the collections systems are doing at all times and during each season. In turn, this has created an increase in reliance on flow monitoring to understand actual system performance and increase reliability in predicting future wet weather performance and bottlenecks. Numerous flow-metering technologies are available, each with their own set of advantages and disadvantages.

When due care is taken to implement flow monitoring studies, numerous benefits are realized including: 1) Determining all the flow components including Average Dry Daily Flow, wastewater production, base Inflow & Infiltration (I/I); 2) Quantifying areas of excessive I/I and verification of post rehabilitation I/I reduction; 3) Use of the flow data to generate powerful scattergraphs that "tell the complete story" about system capacity at each monitored location; 4) Improving O&M through defensible wastewater billing, real-time surcharge detection and alarming; and 5) Reducing O&M and capital projects costs through the quantification of backwater caused by flow throttling.

KEY WORDS

Flow Monitoring, Manning Equation, Scattergraph, Sewer Capacity, CSO, SSO

INTRODUCTION

Formal Capacity Management Operation & Maintenance (CMOM) requirements for proper sewer system management were introduced at the Federal level in 2001. Since then, increasing pressure from Federal, State and local Regulatory Boards and Agencies in conjunction with fiscal requirements regarding proper Asset Management have caused heightened degree of scrutiny regarding the proper management of collection systems. (USEPA, 2004) More specifically, indiscriminate SSOs are no longer acceptable. Agencies must show that they have a good understanding of the flows and rainfall its collection systems can handle, where its limitations are and why they occur. In coastal regions of the western U.S., agencies are being required to document such system knowledge through the preparation of formal Sanitary Sewer Management Plans (SSMPs) and Capacity Assurance Plans (CAPs). (SWRCB, 2004)

Flow monitoring increasingly is being relied upon to understand actual system performance during all seasons, to predict wet weather performance and to spot bottlenecks and O&M problems. Most agencies have obtained flow information using flow monitors (using Agency staff or 3rd party flow monitoring contractors), with varying degrees of success. Several factors affect the success of a flow-monitoring program including selection of locations for flow meter installation, selection of the proper metering equipment, and thorough evaluation and understanding of the data provided from such flow studies.

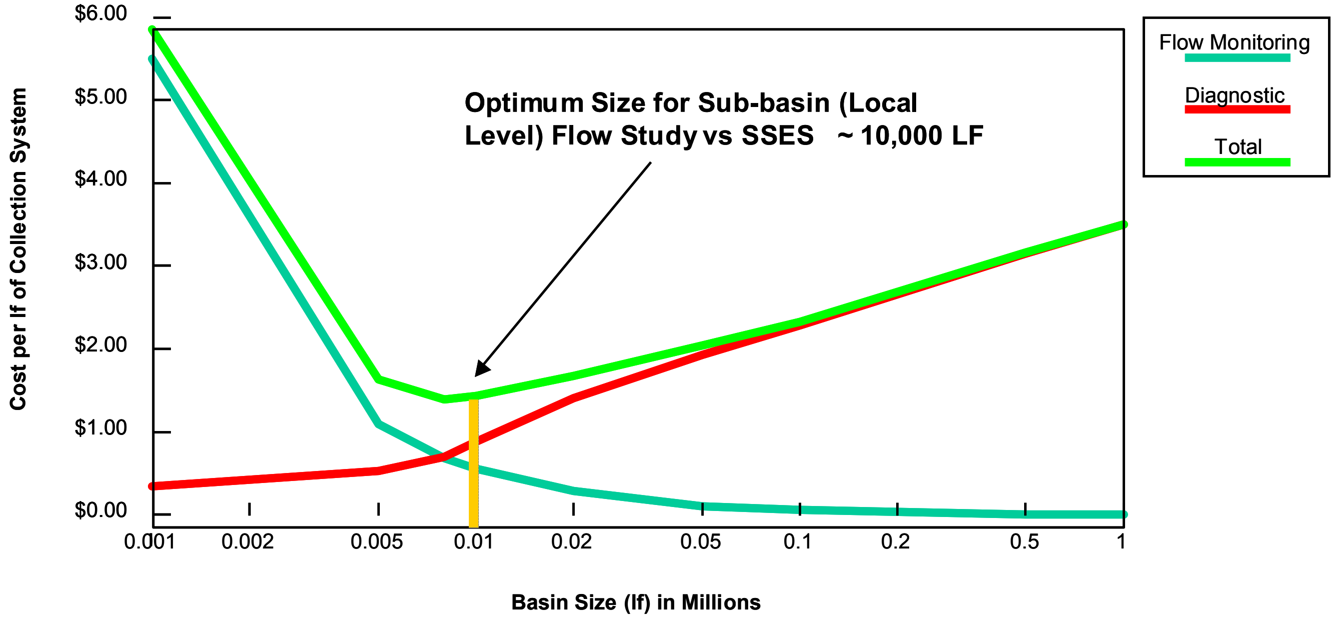
ESTABLISHING FLOW BASINS

Sewer drainage flow basins are generally defined as discrete areas of collection systems in which wastewater flows are gathered from several sewer main pipes into a common outflow pipe. These basins are the fundamental unit of performance measurement within an entire sewer system, whether for capacity, Infiltration/ Inflow (I/I) studies or to conduct mathematical modeling of the system to assist with proper master planning of community growth. The concept of wet weather basin performance monitoring was introduced three decades ago as a part of the U.S. EPA Sewer Construction Grant Program. (USEPA, 1978 & 1981)

Size Does Matter

The size of individual sewer basins is very important when establishing a collection system performance monitoring program. For the purpose of I/I performance measurement, very large basins (e.g. 50,000+ lineal feet (lf) of piping in each) will often hide areas with significant I/I defects by effectively diluting their response within the large basins. (Stevens 1993) Very small basins (2,000 lf) may generate flow depths that are below the optimum performance of open channel flow meters for much of the day. Furthermore, such small basins would require a large number of flow meters within the evaluated collection system. There is an optimum basin size range for basin performance studies of about 10,000 to 15,000 lf of piping. This can be determined by evaluating the cost of metering for multiple basin sizes (i.e. number of flow meters) vs. the benefit of eliminating basins from further study and rehabilitation. Figure 1 is a cost vs. benefit chart that displays the optimum basin size range by evaluating flow monitoring costs against sewer assessment costs for a typical system size of 1,000,000 lf.

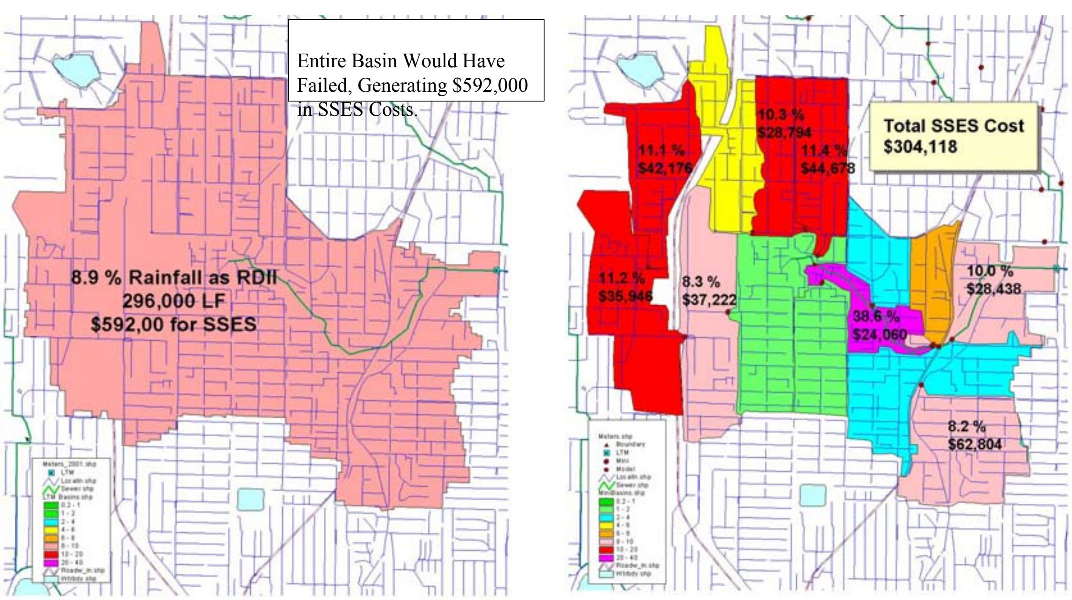
Figure 1 – Chart Depicting Optimum Basin Sizing



The benefit side of the analysis assumes one important governing factor: that defects are not evenly spatially distributed throughout a sewer system (an assumption that ADS has found to be sustained in all of its I/I studies to date).

This cost-benefit evaluation is further illustrated by reviewing the results of an actual I/I study conducted in the Pacific Northwest. In this collection system study, a large modeling basin (~300,000 lf of pipe) indicated marginal I/I performance. The agency determined that physical assessment costs to isolate system defects and storm cross connections would cost approximately $600,000. The use of fourteen additional meters (smaller basins) revealed that half of the system experienced low levels of I/I and could be eliminated from further evaluation. The savings of $300,000 was four times the cost of the additional flow metering. Figure 2 is a map of the basins associated with this study.

Figure 2 – Case Study Showing the Benefit of Small Basin Size



A basin size of around 10,000 lf corresponds to a common size of subdivisions. Subdivisions are probably the smallest component of common performance because they have similar construction methods, use the same pipe and backfill materials and have a common age.

Accuracy is King

There are two primary considerations for selecting open channel flow meters. First, the equipment selected will ideally have a track record of proven performance in both laboratory and actual field environments. EPA recognized the need for a central clearing-house of proven technologies associated with the protection of human health and the environment. In 1995, EPA in conjunction with NSF® International created the Environmental Technology Verification (ETV) Water Quality Protection Center. (USEPA, 2000) A part of this ETV program involves the verification of accuracy claims made by the various manufacturers of wet weather equipment, including flow monitors. Users should consider equipment that has been subjected to the rigors of such independent third-party verification testing.

The second important consideration pertaining to accuracy is the proper selection of the pipe segment/ manhole in which to install the equipment. All equipment available today is of the Area-Velocity type and relies on the Continuity Equation whereby the separate measurement of flow depth and velocity of the flow cross-section determines the flow rate.

$$\mathbf{q = v \cdot A}$$

where: q = flow rate, ft^3/s
v = flow velocity, ft/s
A = flow cross sectional area, ft^2

In a typical round sewer cross-section, the accurate measurement of depth becomes the most critical to the computation of cross sectional flow area in the bottom third of the pipe. Reliable velocity measurement requires well-established flow vectors that are normal to the flow cross section (or uniformly longitudinal to the pipe itself). The various field conditions that may affect these optimum hydraulic conditions are listed in Table 1.

Table 1 - Hydraulic Applicability Grading Chart for Site Inspections
(8" to 18" Pipes - estimated % flow error)

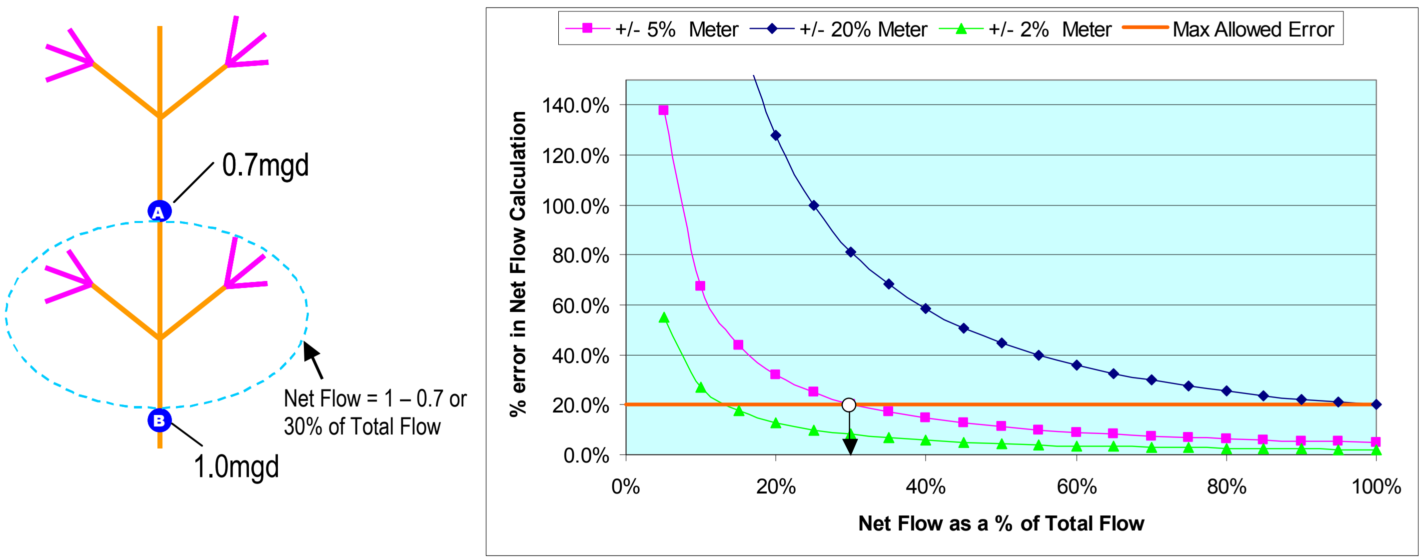
Hydraulic Parameter	Grade (A = good, B = fair, C = marginal)			
	A	B	C	NR - Not Recommended
Velocity 2.0 to 6.0=A, <2 fps=B, >6.0=C	2%	5%	10%	**Vel** <1 or >8 stagnant or negative **Vel** zones
Turbulence/ Waves Ripples: None=A, 0.5"=B, 1"=C	2%	10%	20%	Rolling Waves or Ripples/Boiling >1"
Uneven Flows (lateral level) Level=A, 0.5" slant=B, 1" slant=C	0%	5%	10%	>1" slant
Accelerating Flows (pump station) Surges: None-A, < 0.5 normal flow depth=B >1/2 normal flow depth=C	0%	10%	20%	>1/2 normal flow depth
Silt none=A, <0.5"=B, >.5"=C	0%	5%	10%	>2"
Depth 2.5"- 0.6Dia.=A, >0.6Dia.=B, <2.5"=C	5%	8%	15%	**Depth** <1"

Such errors would be considered additive in accordance with appropriate statistical methods. (Clesceri, 2004) In the above table, each accuracy impact or potential error should be added by taking the square root of the sum of the squares of estimated error from each category. For example, a site with a nominal velocity of 3 ft/s (Grade A ~2% error), some mild turbulence (Grade B, up to 0.5-inch waves ~10% error), that normally flows at a depth of about 40% of the pipe diameter (Grade A~5% error) would yield an estimated overall error of about 11%. A target value of 10% or less potential error should be sought for all flow meter locations where possible.

The Pain of Subtraction

In nearly all collection system flow studies, it is sometimes necessary to subtract an upstream meter from one or more downstream meters to isolate the net flow contribution from a basin. However, there are limitations to relying on such subtractions to yield net flows, because as upstream meter flows are subtracted from downstream meter flows, the potential flow computation errors are additive among all of the associated meters. This effect is compounded dramatically as the upstream flows being subtracted approach the total downstream flows. Figure 3 portrays the effect by showing potential net flow computation errors dramatically increasing when net flows are a small percentage of total flow.

Figure 3 – Chart Depicting Increased Error with Increased Upstream Meter Subtractions



In the best hydraulic conditions, a ±5% accurate meter (the best reasonably expected for open channel flow measurement) used to calculate net flows that are less than 30% of the total flow can introduce error greater than 20%.

Prioritizing Basins According to I/I Performance

I/I performance is best determined by measuring during several "system stressing" storms that produce measurable I/I throughout the entire collection system. System stressing events are typically more than one inch of rainfall in a 24-hour period. I/I is measured by first determining the typical average flow patterns associated with weekdays and weekends for each basin. These patterns are then compared against flow responses during the various storm events to determine the increase in flow above the normal dry weather pattern. Figure 4a is a hydrograph of wet weather flows overlain on the basin's normal dry flow pattern to yield a rain dependent I/I (RDII) hydrograph. The volume of RDII for this storm can be normalized by dividing by the associated rainfall and the basin's area (yielding % rainfall ingress). This process is outside the scope of this document, however more details can be found in the References listed herein. (Kurz, 2002) Figure 4b shows a chart of the % ingress from several basins ranked by severity.

This is the recipe for significant costs savings because the collection system owner can now concentrate efforts in areas of significant wet weather impacts.

Figure 4a – I/I Hydrograph

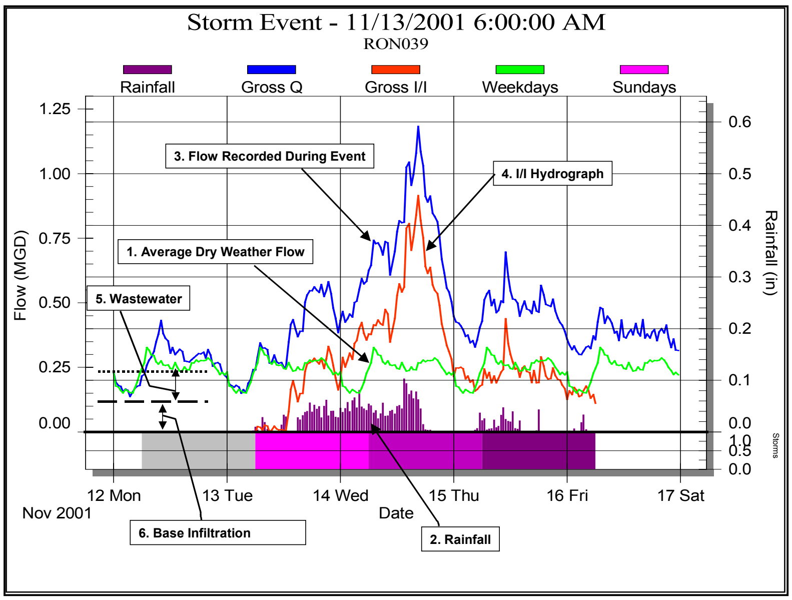
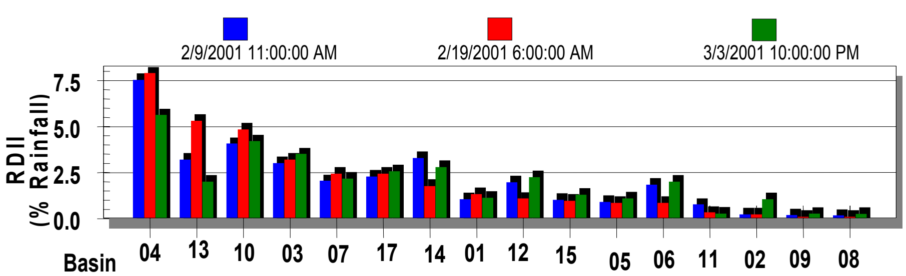


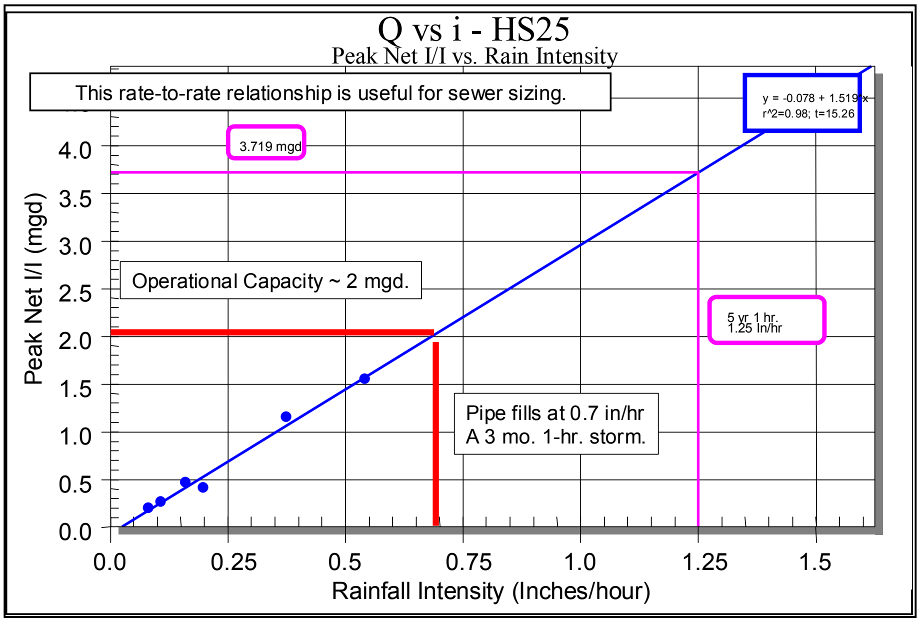
Figure 4b – Basin Performance Priority Chart



2/9/2001	7.52	3.20	4.05	3.00	2.03	2.27	3.27	1.04	1.97	1.00	0.90	1.84	0.75	0.22	0.19	0.15
2/19/2001	7.88	5.31	4.82	3.19	2.44	2.42	1.76	1.31	1.07	0.96	0.85	0.84	0.31	0.21	0.08	0.08
3/3/2001	5.61	2.00	4.20	3.49	2.16	2.55	2.79	1.13	2.23	1.28	1.09	1.99	0.27	1.04	0.26	0.24

Each basin's RDII response vs. rainfall can also be plotted on a Q vs. i chart, where Q is measured RDII in mgd and i is rainfall intensity (in/hr). Such a chart can be utilized to determine the largest rainfall event that a basin's outflow piping can handle based on its ultimate hydraulic capacity. Figure 5 is a plot of rainfall intensity vs. I/I rate from a Mid-West I/I study from a basin with a 2 mgd capacity outlet pipe. The regression line through the empirical rain response data indicates that RDII from a 0.7 in/hr (a 3-month, 1-hour storm) will fill the sewer. However, it is desired for this basin to be able to sustain a rainfall rate of at least 1.25 in/hr (a 5-year, 1-hour storm), which would result in flow of 3.7 mgd and a likely overflow. The city will need to either rehabilitate the sewer to reduce total I/I or add the basin to the CIP program for sewer expansion.

Figure 5 – Q vs. i Chart Depicting Rainfall Intensity vs. Basin Excess Flow

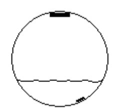
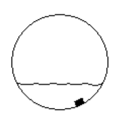
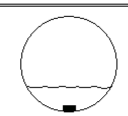
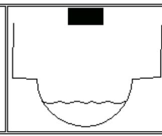
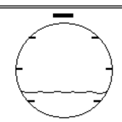


CHOOSING THE PROPER EQUIPMENT

As discussed previously, it is important to select flow-metering equipment that will provide accurate and reliable flow information. Flow monitors are available from numerous manufacturers, the five most prominent of which are listed in Table 2. This table divides flow meters into 5 different categories according to the manner in which each technology measures velocity. For completeness, Table 2 also lists a sixth category to include primary flow technologies such as weirs and flumes since these technologies are frequently still in use. The first three technologies use ultrasonic signals propagated against the flow to determine velocity by the Doppler shift principle. The fourth technology utilizes radar technology to estimate flow velocity based on determining the velocity of surface waves traveling through the associated manhole. The fifth technology utilizes the time of travel (or Transit Time) of a signal propagated across a flow stream. The “Method” section of the table depicts the placement of sensors to obtain depth and velocity information along with associated limitations. The “Applicability” section of the table summarizes the applicability of each flow technology to each of the indicated common flow conditions (e.g. backwater, full pipe, surcharge, and low flow). The “Specifications” section of the table summarizes some key features associated with each of the meters.

The savvy collection system operator will select the appropriate meter based on an understanding of the conditions at each site and end use of the meter data collected (e.g. wastewater billing, real-time alarming, longevity, portability, etc.).

Table 2 - Sewer Flow Monitor Applicability Chart

Flow Meter Type	Method (primary sensors)		Applicability to Non-Ideal Flows					Specifications/Requirements								
			Typical Pipe Size[1]	Backwater	Full Pipe	Surcharge	Low Flow (2" depth to <25% pipe dia.)	EPA ETV Verified[2]	AC Power	Battery	Site Calibratable	Remote Raw Data Collection	SCADA	No Sensors in Flow	Certified D,V,Q final data available	Petented in-monitor data validation (MLI)[3]
Peak Doppler (ADS)	**Q** - Continuity (AxV) **V**peak - use Vavg/ Vpeak low/ high flow (site calibration) **D**epth - downlook		8" - 104"	Y	Y	Y	Y[4]	Y	Y	Y 1 year	Y	Y	Y		Y	Y
Avg. Doppler (ISCO / Sigma)	**Q** - Continuity (AxV) **V**avg - bias to largest particle **D**epth - pressure		8" - 104"	Y	Y	Y	Y[4]			Y		Y	Y			
Gated Doppler (MGD)	**Q** - Continuity (AxV) **V**cells - Four paths, 2" layers **D**epth - uplook	 Sensor must be at pipe invert	24" - 144" (min depth 12")	Y	Y	Y[5]			Y	Y 22 weeks		Y	Y		Y	
Radar (MMcBirney)	**Q** - Continuity (AxV) **V**avg - at flow surface **D**epth - downlook		8" - 107" (max D range = 60") (min V > 0.75 ft/s)	Y[6]					Y	Y 10 weeks			Y	Y		
Transit Time (Accusonic)	**Q** - Continuity (AxV) **V**avg - multiple depths **D**epth - downlook		12" - 240"	Y	Y	Y		Y[2]	Y				Y		Y	
Primary Flume/ Weir	**Q** - from equation **D**epth - downlook		6" - 48" (very calm back water for weir) (calm slow approach for flume)				Y		Y	Y			Y			

1 - Range assuming average daily flow depth is 50% of pipe diameter and min. daily flow depth > 30% of pipe diameter.
2 - ADS models 3600 & 4000 tested. Accusonics TT meter used as ETV reference standard in field testing.
3 - Monitor Level Intelligence is a field proven statistical comparison to a D vs V pipe curve generated by the meter to validate or recollect each data point.
4 - Assumes non-transient, consistent hydraulic conditions at velocities from 1.5 ft/s to 5 ft/s.
5 - Provides flow rate only during surcharge, no depth information.
6 - Assumes velicity profile remains consistent and >0.75 ft/s.

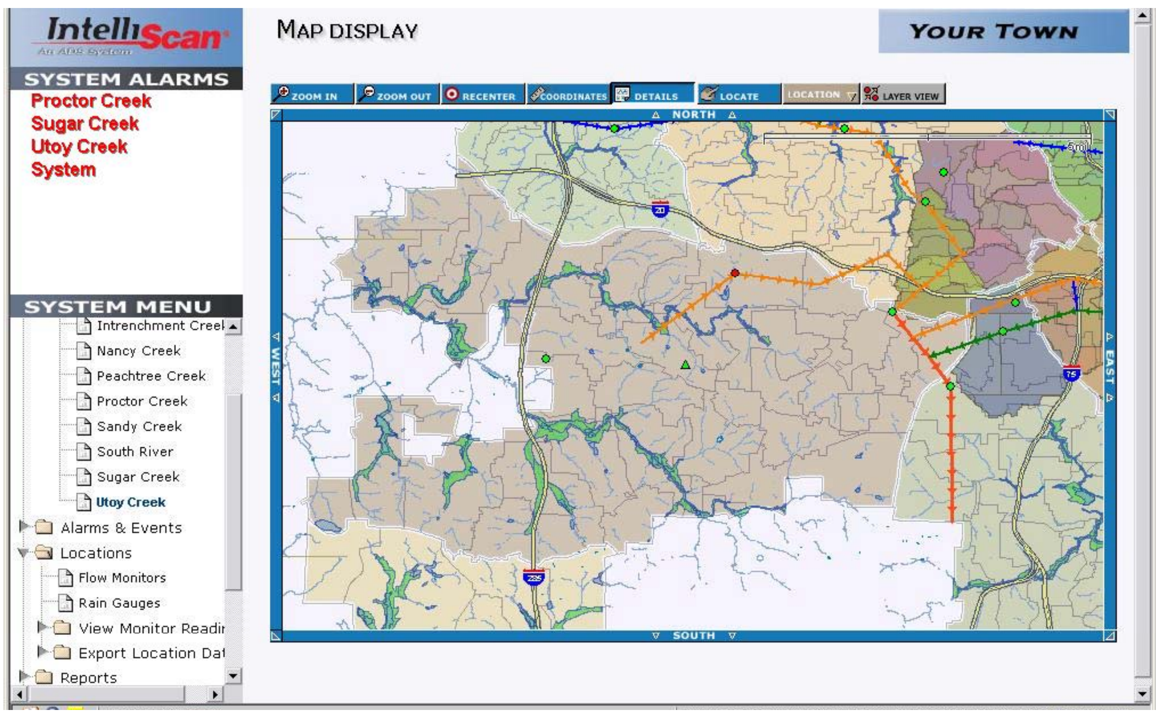
MAXIMIZING THE BENEFIT OF THE FLOW DATA

Given the proper selection of flow metering sites and equipment, there is significant additional information that can be gleaned from the collected data; much of which is currently unknown or untapped by most collection system operators.

Real-Time Flow Information

Just in the past five years, remote data communications technologies have enabled flow meters at distant locations in a collection system to provide real-time flow information to operators. In addition, this flow information can be fed to a database at a remotely located computer server that is providing continuous updated information to a dedicated and password-protected Website. (Griffin, 2003) These web-based collection system sentries are becoming important compliments to SCADA systems utilized by plant operators to effectively monitor performance of unit operations at wastewater treatment plants. Figure 6 is a screen capture of an actual remote Web-Based collection system sentry called IntelliScan™.

Figure 6 – Screen Capture of Actual Web-Based Collection System Reporting Tool



These systems can provide the "eyes and ears" in key locations within a collection system network and provide timely feedback of problems or pending problems. Figure 7 depicts a photograph of a sewer spill in the Southwest that prompted the installation of an IntelliScan™ system. The hydrograph in Figure 7 depicts an actual flow loss (and spill) detected by an operating IntelliScan™ system where the cause was discovered to be a mattress lodged upstream of the meter site. Minimizing the duration of such events can lead to mitigation of health risks and potential indirect substantial savings (e.g. reduction of cleanup costs and/ or regulatory fines and mandates).

Figure 7 – Screen Capture of IntelliScan™ Alarm Hydrograph with Photo of Spill Site

Scattergraphs and the Eight Most Common Sewer Hydraulics Cases

Flow Depth and velocity data collected by flow meters plotted in scattergraph format can yield extremely important insight into the performance of collection systems. These scattergraphs effectively "tell a story" about how the system is behaving at that location and how it may be diverging from its expected or design performance.

The scattergraph pattern of the velocity and depth-of-flow data points for a sewer operating in free-flow conditions over an extended period of time should conform to the depth-velocity relationship of the Manning Equation.

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

where: v = flow velocity, ft/s
n = roughness coefficient
R = hydraulic radius, ft
S = slope of the energy gradient

The Manning Equation defines a depth-velocity relationship (a pipe curve) that is the basis for evaluating flow meter data. (Enfinger, 2004) The Manning pipe curve can also be derived (then termed “Lanfear-Coll” curve) based on actual flow data (i.e. **v** and $\mathbf{R^{2/3}}$ data points are known) by combining the constant terms $(1.486/n)\cdot\mathbf{S^{1/2}}$ into one term called the hydraulic coefficient (C) and deriving C. Manning and/or Lanfear-Coll “pipe curves” are included in the scattergraphs that follow.

Free Flow Conditions (cases 1 and 2)

Scattergraphs from two typical sites are displayed in Figure 8a (case 1) and Figure 8b (case 2); each with the associated operational pipe curves plotted. The first case shows a typical open channel flow scenario in free flow conditions where the maximum observed depth throughout the monitored period never exceeded 50% of the 48-inch pipe diameter. The second case shows a typical open channel flow scenario during which the 18-inch diameter pipe regularly flows full under surcharged conditions, albeit under free flow conditions since the hydraulic grade line is still parallel to the pipe slope.

There are three notable observations that can be made from these scattergraphs: 1) The meter data follow a pipe curve throughout the non-surcharged part of the flow regimes; 2) The meter data are tightly grouped indicating they are highly repeatable or of high precision; and 3) The meter data closely match manual confirmations of depth and velocity during both the low and high flow periods indicating a high degree of accuracy.

Figure 8a – Open Channel Case Scattergraph with Confirmation Points & Flow Profile

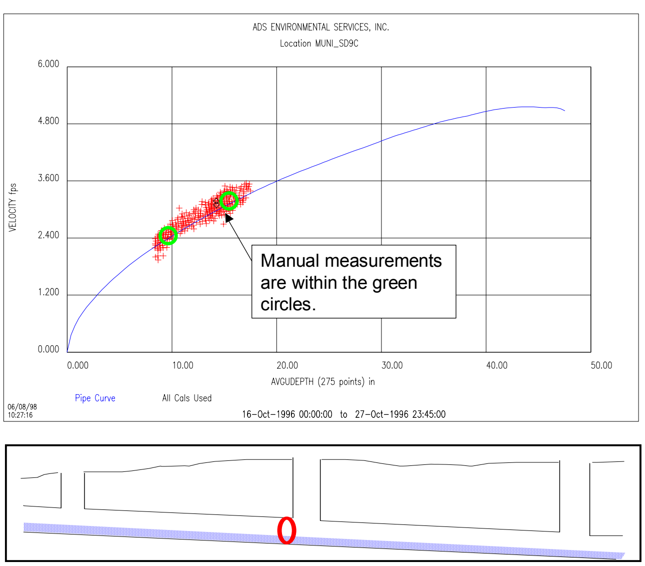
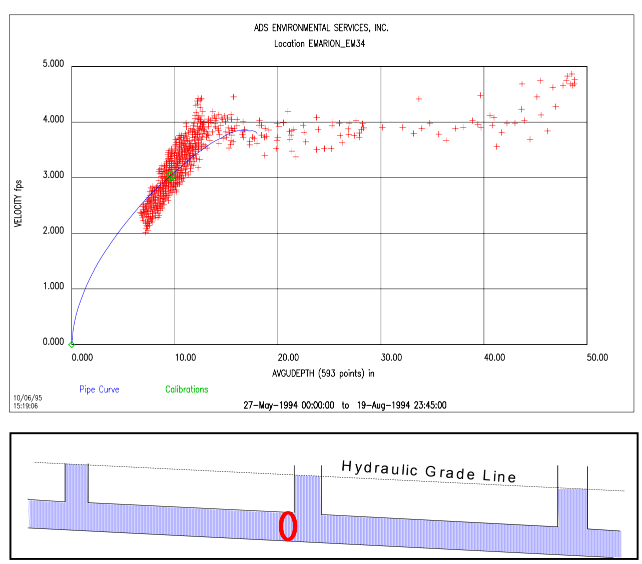


Figure 8b – Full Pipe/Surcharge Scattergraph with Confirmation Points & Flow Profile

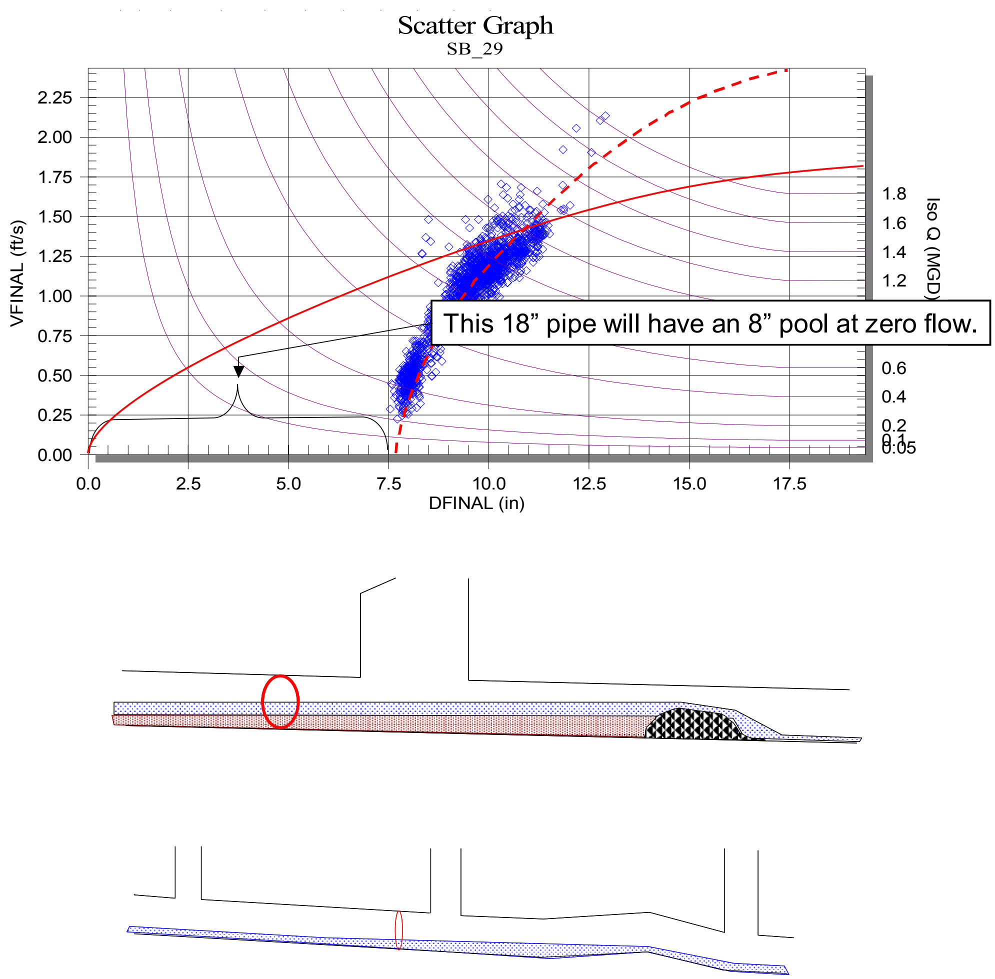


Open Channel Flow Conditions with Obstructions (cases 3 and 4)

There are several conditions in sewers that cause the depth-velocity relationship to diverge from the expected Manning pipe curve. A common condition producing a departure from expected pipe curve performance involves the presence of downstream pipe sags/ humps (i.e. adverse slope segments), obstructions, debris or silt.

Figure 9 depicts sewer profiles with steady-state debris and humps (case 3) and also shows a scattergraph of data from a flow study site on the West Coast revealing the presence of a significant obstruction or sag in the pipe downstream of the metered site. To aid in the interpretation of this site, the scattergraph below displays the additional feature of constant-flow or Iso-Q™ lines. This case revealed that a downstream obstruction was pooling wastewater at a minimum 8-inches deep as velocity approached zero over night. Applying a Manning's type relationship (i.e. a site data relationship that projects through the origin of the graph) is not reasonable in this condition. The data set appears to follow a pipe curve (dashed curve), but without additional knowledge about the source or type of blockage, projection of such a pipe curve to estimate the pipe's ultimate capacity would not be advised.

Figure 9 – Scattergraph Depicting Downstream Flow Blockage



Another common condition causing a departure from a Manning's pipe curve involves shifting or transient-state debris or silt (case 4). In such cases, the data cluster on the scattergraph will shift down and to the right along the Iso-Q™ lines over time, at a rate depending upon the accumulation of the offending debris and any related cleaning cycle. Figure 10 includes a depth and velocity hydrograph and the related scattergraph from a site wherein earth and construction debris was being deposited into a manhole downstream of the metered site without the knowledge of the sewer maintenance staff.

Starting around February of 2001, flow depths began a general rise with a corresponding decrease in flow velocity (with flow rate remaining reasonably consistent). This phenomenon can be readily seen as a "shift" of the data to the right on the scattergraph (below right) along the Iso-Q™ lines. Each different shade data cluster corresponds to different periods of data during the later portion of this hydrograph period. The lowest data cluster represents the period in June where the highest depths (most significant blockage) were observed. This scattergraph data shift caught the attention of a system operator, whereby a source investigation was launched by the end of June. Several tons of construction debris were cleaned out of the system through the month of July, at which time the data cluster returned to the normal position (adjacent to the pipe curve) on the scattergraph.

Figure 10a – Depth/Velocity Hydrograph Showing Debris Development

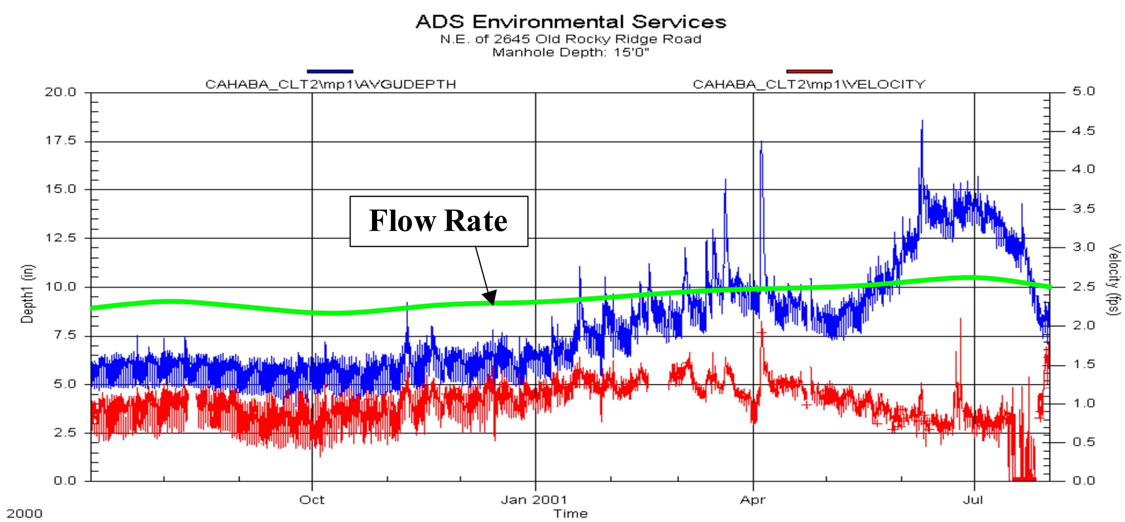
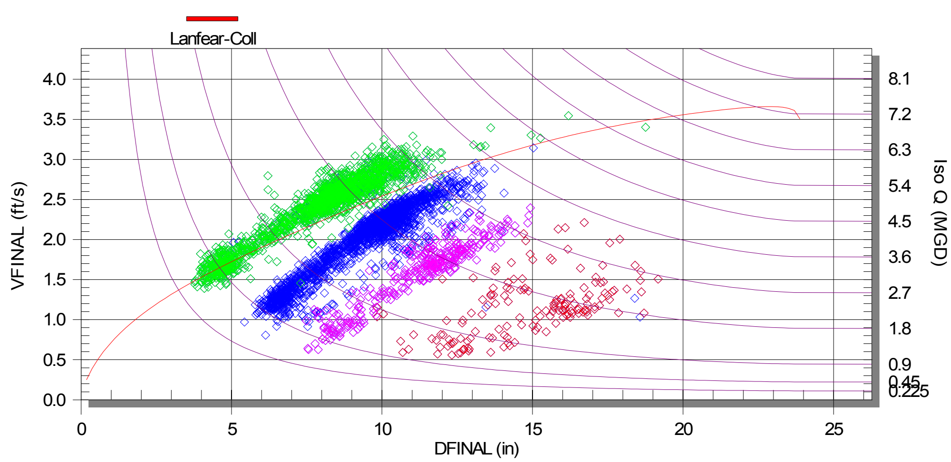


Figure 10b – Related Scattergraph Showing Debris Development

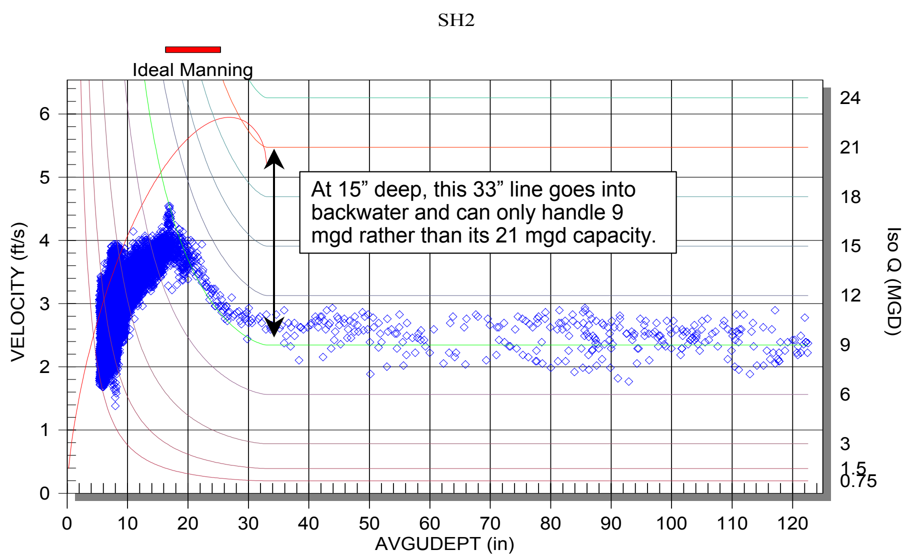


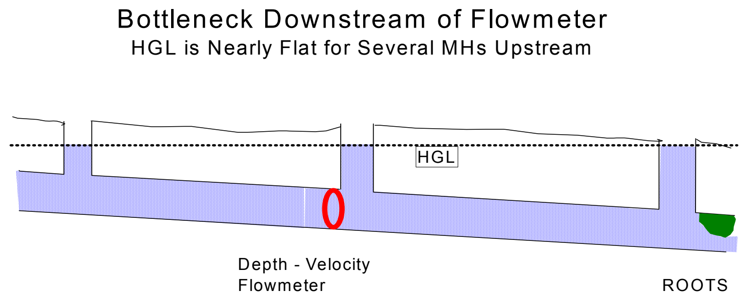
Backwater and Bottlenecks (case 5)

Backwater is defined as a condition in which free flow capacity in a downstream zone of a collection system has reached capacity and is acting as a bottleneck or restriction to any added flow rate. This causes the system to begin to store wastewater behind the system bottleneck; in turn, creating a Hydraulic Grade Line (HGL) upstream of the bottleneck that is shallower in slope than the pipe segment. Scattergraphs provide an excellent means by which to detect such a condition in sewers.

Figure 11 is an example scattergraph from a flow meter site in a 33-inch pipe where the flow enters backwater conditions upon reaching a flow depth of about 15-inches. Starting at around the 15-inch depth, the flow rate remained nearly constant at 9 mgd (i.e. the data follows the 9 mgd Iso-Q™ line) while the pipe continued to fill until full pipe conditions were reached, then further into surcharged conditions up to an HGL depth of about 125-inches. This line's operational capacity is 43% (9 mgd/ 21 mgd) of its theoretical capacity as a result of the downstream bottleneck. This can be alternately described as a 57% backwater condition.

Figure 11 – Scattergraph produced by Downstream Bottleneck





Sanitary Sewer Overflows (cases 6, 7)

The ultimate result of a bottlenecked sewer in many systems is an unplanned Sanitary Sewer Overflow (SSO) or an expected Combined Sewer Overflow (CSO). Clear evidence of such an occurrence can also be observed in scattergraphs.

In the case of separate sanitary systems, Figures 12a and 12b provides two such examples: The scattergraph in Figure 12a (case 6) is from a sewer with a downstream bottleneck causing a backwater condition starting at a depth of about 7-inches (0.9 mgd) progressing to full pipe at about a 1.2 mgd flow rate, then continuing into surcharge conditions up to about 50-inches depth at about 1.8 mgd. At this depth, a sudden drop in velocity is observed from about 2.3 ft/s down to about 1.6 (corresponding to 1.8 mgd down to 1.2 mgd on the Iso-Q™) indicating an upstream SSO has occurred. Close inspection of the rainfall data reveals that this SSO condition was achieved during a storm that would be classified as a >10-year, 24-hour storm.

The scattergraph in Figure 12b (case 7) depicts a similar backwater scenario upstream of a dual pump lift station. In this case, the pipe continued into surcharge flow conditions at the station's maximum capacity of about 16 mgd, up to a depth of about 148-inches; at which time a sudden increase in velocity and flow rate is observed, indicating an SSO has occurred downstream of the meter.

Sanitary system owners experiencing consistent conditions such as those characterized by Figures 11 and 12a/b may be tempted to consider costly upgrades or increases in pipe size. However, in many cases, simply removing a blockage (e.g. could be through a more regular cleaning or improved Fat/Oil/Grease control programs) or right-sizing a downstream structure such as an inverted siphon, lift station pump, or diversion structure may be all that is needed.

Conversely, flow monitoring can dispel concerns about capacity in areas of sanitary systems previously thought to be a problem based only on theoretical flow computations or modeling (usually associated with a Master Plan). Often times the savings associated with the knowledge gained through flow monitoring can amount to orders-of-magnitude of that which was spent to conduct the flow monitoring.

Figure 12a – Scattergraph with Downstream Bottleneck and Upstream SSO

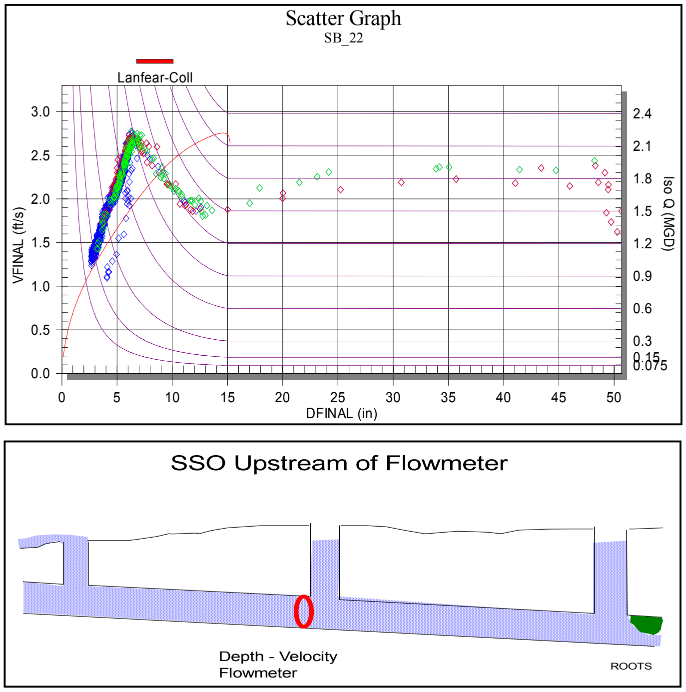
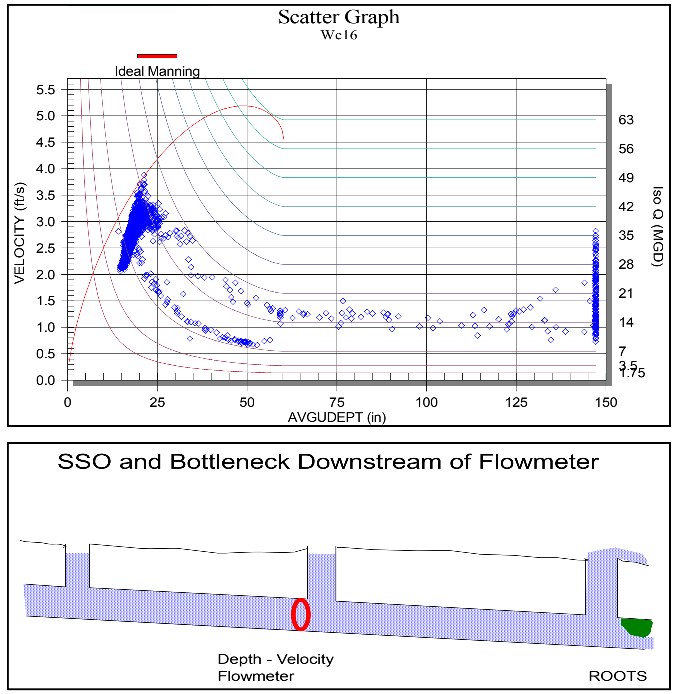


Figure 12b – Scattergraph with Downstream Bottleneck and Downstream SSO

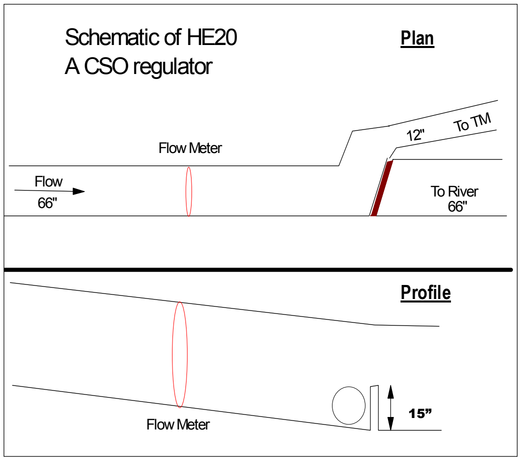


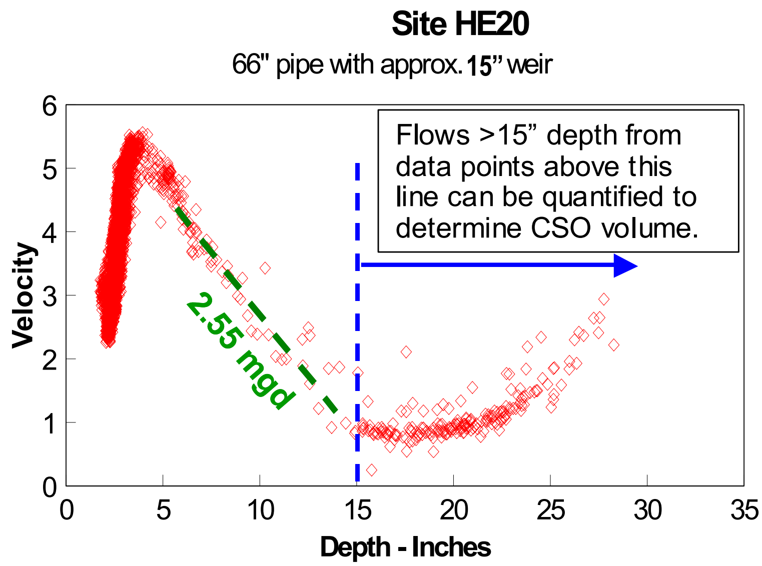
<u>Combined Sewer Overflows (case 8)</u>

In the case of combined sewer systems, Figure 13 provides an example of a scattergraph depicting a CSO occurrence during a rain event at a system CSO structure within a 66" diameter transport pipe. The left portion of Figure 13 depicts a plan and profile depiction of the CSO structure. The associated scattergraph to the right indicates a downstream bottleneck is causing a backwater condition starting at a depth of about 4-inches (~2.6 mgd), well before reaching the height of the 12" diameter sanitary outflow line. This backwater condition progresses to the approximate height of the end weir at 15"; at which time the flow rate picks up rapidly again.

The volume of water discharged from this CSO structure during rain events occurring during this 8-week study can be quantified by summing the flow rate data points over time that were posted above the 15" vertical line. In this case, the system engineer knows that if the full downstream capacity of about 6.5 mgd were available in the 12" outflow line, the frequency and volume of the CSO releases during the 8 week study period could have been reduced from 18 occurrences and 7.7 million total gallons to only about 8 occurrences and 4.4 million total gallons.

Figure 13 – Scattergraph Depicting Downstream Bottleneck and CSO





SUMMARY AND CONCLUSIONS

Recent years have brought increased scrutiny on collection system owners and operators to assure the current and future proper operation of these systems during all seasons and weather conditions without wastewater releases to the environment. This scrutiny has increased the reliance on flow monitors to deliver important true-to-life performance information about these systems.

Historically, common uses of flow monitors in collection systems include totalizing hourly flows from adjoining sewer agencies for monthly billing purposes, verifying flows and flow trends (usually for input into flow models) to update Master Plans, and conducting wet weather flow basin studies to spatially prioritize areas of the system for reduction of I/I. There are five different classifications of Area-Velocity type open channel flow meters available today. There are also a variety of different weirs and flumes available for the purpose of measuring strictly flow rate. Each of these types of equipment has advantages and disadvantages, depending upon various physical and hydraulic factors in the system to be monitored.

Given the proper selection of flow metering sites and equipment, there is significant additional information that can be gleaned from the collected depth and velocity data. This includes real-time data collection / evaluation via the Internet and a dedicated password-protected Web page, determining whether the system is consistently operating in free-flow conditions, determining the presence of backwater conditions, quantifying capacity available based on the backwater conditions, and determining the existence of SSOs either upstream or downstream of the metering location.

The extent of information available from a well-constructed flow-monitoring program consistently saves collection system operators many times the cost of the flow monitoring.

REFERENCES

USEPA (2004). Report to Congress: Effects and Control of CSOs and SSOs.

California State Water Resources Control Board (SWRCB - 2004), Resolution No. 2004-0080 to require collection system owners/operators to reduce SSOs through the implementation of Sanitary Sewer Management Plans (SSMP), SWRCB Meeting November 18, 2004.

USEPA., PRM No. 78-10 (March 17, 1978). Subject: Infiltration/Inflow Program Guidance, From: John T. Rhett, Deputy Administrator Water Program Operations, To: Region Administrators (I - X).

USEPA Facilities Planning (1981), Municipal Wastewater Treatment, FRD-20.

Stevens, P.L. (1993), “Basin Size is the Most Effective Variable an I/I Engineer can Control,” *Water Environment Federation Annual Conference, AC93-064-005*.

USEPA (2000) Environmental Technology Verification (ETV) program: www.epa.gov/etv

Clesceri, L.S. (2004) “Standard Methods for the Examination of Water and Wastewater”, 20th Edition. Joint publication of APHA, AWWA, WEF, April 13, 2004.

Kurz, G. Stevens, P.L., Ballard, G. (2002) “Assessing Hydraulic Problems – Tools for Targeting Sewer Renewal or Upgrades”, *Proceedings of the ASCE Pipelines Conference 2002*. ASCE: Reston, VA.

Griffin, J. and Stevens, P.L. (2003). “Measuring Flow That Isn’t There: Atlanta’s Strategy for Sewage Spill Detection”, *WEF Collection Systems Conference, 2003*.

Enfinger, K.L. and Kimbrough, H.R. (2004). “Scattergraph Principles and Practice” *Proceedings of the ASCE Pipelines Conference 2004*. ASCE: Reston, VA.