Removing One of the "I's" from Infiltration and Inflow

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The vast majority of water and sewer utilities in the United States are operated by municipal governments or local authorities. Local officials want to develop water and sanitary sewage systems that will meet the water and sewerage needs of the areas served by their utilities, ensure that existing and future utility systems are constructed, operated, and managed at a reasonable cost to the users without outside subsidies, and develop a system that is compatible with the area's future growth.

The initial goal of the Clean Water Act was to clean up the nation's rivers and streams through the removal of untreated industrial and domestic wastewaters, which means that the top priority of wastewater systems was to provide a level of service meeting state and federal regulatory requirements, as well as the demands and expectations of their customers. The initial focus was on treatment plants, but once they were constructed, the priority shifted slightly to combined systems, which had a propensity to overflow (sanitary sewer overflows, or SSOs) during rain events, due to hydraulic limitations of the piping systems in combined sewers that were mostly in the Northeast and Midwest.

Because the ratepayers bear the ultimate cost of service, utilities usually try to develop plans that will permit the utility to meet its priorities at an affordable and stable cost for the long term. These plans include long-term maintenance and repair of the piping systems; however, by their very nature (buried pipes and protected facilities that are out of the public view), water and sewer utility operations are not in the forefront in the minds of elected officials, local government management, or finance personnel. Water and sewer services are viewed as basic services, which are not as "glamorous" as more visible municipal services, such as industrial parks, community revitalization areas, public buildings, landscaping, public parks, or recreational opportunities that gain positive community headlines. Because of the technical nature of water and sewer systems, they are not well understood by local government officials. The lack of obvious problems or critical failures may lead local officials to believe the water and sewer infrastructure to be "ok" as it is (Bloetscher, 2011). As a result, these piping systems may be neglected over time.

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Figure 1. Coal tar epoxy on the outside of a manhole.

Regulatory focus under the Clean Water Act resulted in the development of the capacity, management, operation, and maintenance (CMOM) program. This program is intended to ensure that sewer collection systems, pumps, and wet wells are properly maintained in an effort to eliminate sanitary sewer overflows from plugged pipes or lack of pumping capacity in lift stations. With CMOM, pipe is inventoried and cleaning and repair work is tracked. Maintenance logs are also required for lift stations. Since keeping excess flows down benefits the utility financially, correction of leaks and infiltration should be priority projects. By reducing infiltration and inflows into the gravity wastewater system, the utility can reduce costs at wastewater treatment plants.

The gravity collection system consists of the gravity pipes, manholes, service lines, and cleanouts. Collection system piping throughout North America prior to 1980 was predominately vitrified clay, with polyvinyl chloride (PVC) being a major pipe material after that. Vitrified clay pipe has been used for well over one hundred years because the pipe is resistant to deterioration from virtually all chemicals that could be in the water, and from various soil conditions. It has a long service life when installed correctly and left undisturbed.

However, vitrified clay pipe is brittle, so settling from improper pipe bedding, unstable soil, surface vibrations, or freezing can cause the pipe to crack. Older vitrified clay pipe has short joints—as small as 2 ft prior to 1920, and 6 to 10 ft prior to 1960. Field joints were made prior to 1920, and even later. The joints were sealed with cement and

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cloth "diapers" wrapped around the joint. However, concrete is not waterproof and will crack with time. The combination results in piping with many joints, each of which has the potential to leak.

Temperature differences between the warm wastewater and cooler soils can cause the exterior pipe surface to be damp. The dampness encourages tree roots to migrate to, and wrap around, the pipe. Where cracks occur, roots will enter the pipe. Over the long term, the pipe will become broken and damaged from the roots, joint seals, and vibrations, and in colder climates, from freezing. When the pipe is submerged, like it is in most of Florida, the pipe will constantly leak; this is termed "infiltration." Infiltration increases the base flow and will often be indicated by low-strength wastewater during routine tests. However, it generally does not lead to peak flows.

As costs to treat and pump wastewater have risen, much of the focus has been on dealing with removal of infiltration; one step in this process is sealing manholes. Manholes are traditionally precast concrete or brick, with brick being the method of choice until the 1960s. Brick manholes suffer from the same problems as vitrified clay sewer lines: the grout is not waterproof so it can leak significant amounts of groundwater. Precast concrete manholes resolve part of this problem, but concrete is not impervious either. While elastomeric or bituminous seals are placed between successive manhole rings, the concrete is still exposed. Many utilities will require the exterior of the manholes to have a coal-tar or epoxy covering, which helps to keep water out (see Figure 1). Lining the interior is of some value, but not nearly as much as coating the outside prior to backfill.

The major focus to remove infiltration has been, and continues to be, oriented to lining gravity pipe, which includes a significant amount of televising to find leaks. Televising the sewer system and sealing and lining sections where leaks are noted is common; however, many miles of videotape show virtually nothing, but with significant money spent. Part of this is because "infiltration" and "inflow" are not the same, and storm events do not highlight infiltration nearly as much as inflow. The U. S. Environmental Protection Agency (EPA) has established infiltration criteria depending on the footage of collection sewer in an area as follows:

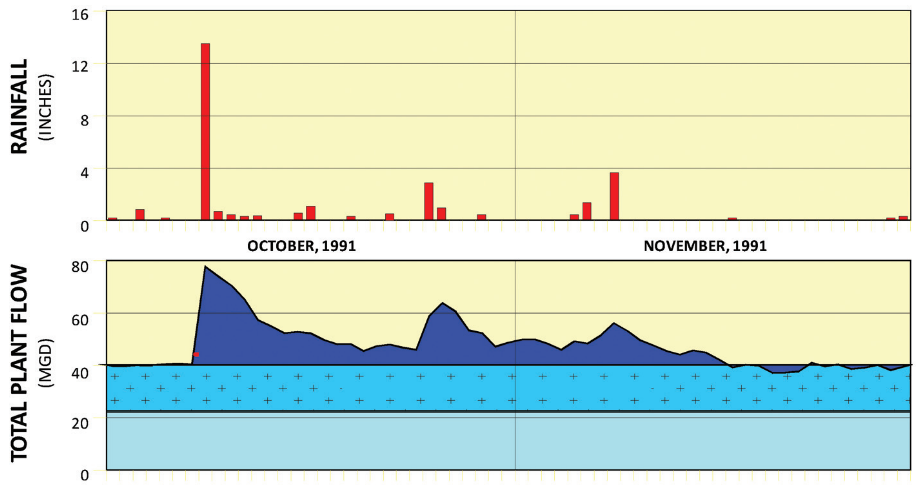

Figure 2. Indication of inflow to the sewer system. (Bloetscher, 2011)

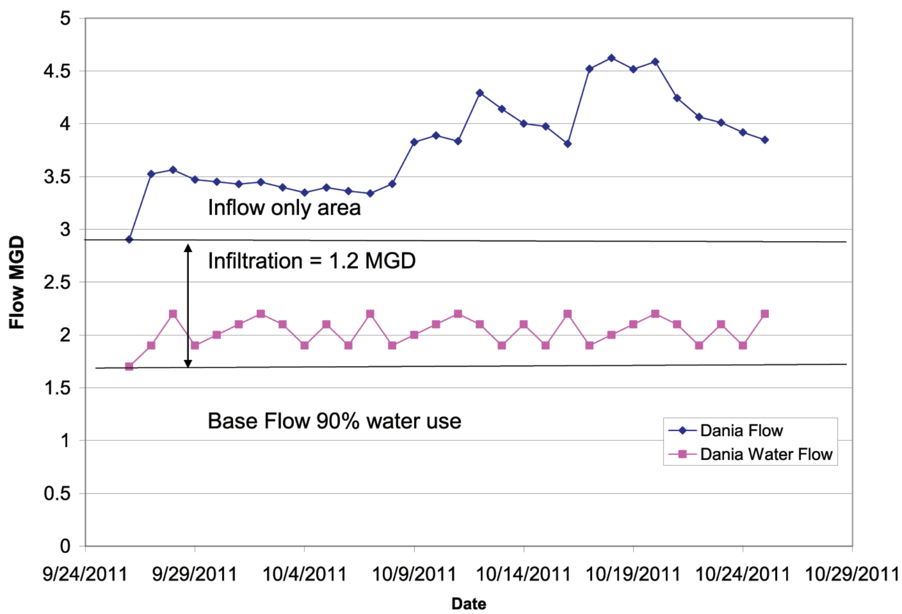

Figure 3. Identification of inflow, infiltration, and base flow in a sewer system flow hydrograph.

Table 1. EPA Infiltration Allowance
(Bloetscher, 2011)

Sewage Footage (ft.)	Allowance Range (gpd/in-mile)
> 100,000	2,000-3,000
50,000-100,000	3,000-5,000
1,000-50,000	5,000-8,000

The criteria in Table 1 are used as a primary indicator for the assessment and classification of collection system infiltration, but it should be noted that, for even large systems, the criteria may indicate 35 percent infiltration in the total wastewater flow, and it fails to separate inflow.

Separating Inflow and Infiltration

Where there are peaks in wastewater flows that match rainfall, inflow would appear to be a more likely candidate for the cause of the peaks than infiltration from pipes that are constantly under the water table. Storms highlight the need to reduce inflow into the collection system so as not to overwhelm the piping system hydraulically, causing plant damage or sewage overflows into streets because inflow results from a direct connection between the sewer system and the surface. The removal or accidental breaking of a cleanout, unsealed manhole covers, laterals on private property, connected gutters or storm ponds, damaged chimneys from paving roads, or cracking of the pipe may be a significant source of inflow to the system, which can be identified easily during storm events.

Figure 2 shows a typical graph of rainfall versus flow for a given utility. The peaking that correlates with the rainfall is *inflow*, not infiltration, since infiltration is part of the base flow that creeps upward with time. Infiltration looks much like the base flow. For the utility in Figure 3, the average daily water is just over 2.05 mil gal per day (mgd), but the wastewater flow is over 3.8 mgd, indicating nearly 1.2 mgd of infiltration. When plant operators and engineers see peaks in flows after rain events, this is not indicative of groundwater infiltration; it is indicative of active connections from the surface to the piping system, which is inflow. The good news is that simple, low-tech methods can be used to detect inflow, which should be the precursor to any infiltration investigation.

Figure 4. Installation procedure. (photos: USSI Inc.)

Resolving the Inflow Problem

Ongoing testing of the influent and monitoring of the lift stations by a utility provides a measure to determine whether inappropriate amounts of inflow are going to the wastewater plant. This testing can take a variety of forms, such as a review of lift station run times, followed by analyses of the influent wastewater quality. Low-strength wastewater is an indication of both infiltration and inflow problems, and low-strength wastewater during dry periods is infiltration; during wet events, it could be both.

Resoling Inflow

Resolving the inflow problems is straightforward, and from a utility standpoint, the more benefit that can be gained per dollar spent, the better. Lessening potential regulatory actions from overflows is also a risky issue to address. Both indicate that inflow should be the first priority, followed by traditional televising and lining projects.

Inflow can be resolved in an orderly fashion. The following outlines a basic program for inflow detection and correction for any utility system. The order of implementation is important, and pursuing all steps in order will resolve the majority of inflow issues, while permitting the utility to target the specific areas where infiltration is a problem. The program as outlined also minimizes unneeded videotaping of the collection system and permits more dollars to go toward fixing problems.

The first step is inspection of all sanitary sewer manholes for damage, leakage, or other problems, which, while seeming obvious, is often not the case. The manhole inspection should include documentation of condition, global positioning system (GPS) location, and some form of numbering if not currently available. Use of a geographic information system (GIS) database, with ties to photographic data, is a useful addition. Most manholes have limited condition issues, but where the bench or walls are in poor condition, they should be repaired with an impregnating resin. Deterioration may be an indication of wastewater quality concerns,

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requiring the addition of chemicals to reduce the impact of hydrogen sulfide.

Next is the repair and sealing of chimneys in all manholes to reduce inflow from the street during flooding events. The chimney includes the ring, cement extensions, lift rings, brick, or cement used to raise the manhole ring. Manhole covers are often disturbed during paving or as a result of traffic. Temperature, vibration, and traffic can break the seal between the steel ring and concrete. The crack between the ring and cover can leak a lot of water, as demonstrated by a Miami-Dade County test conducted several years ago (Miami-Dade 2010). The intent of the chimney seal is to prevent inflow from the area beneath the rim of the manhole, but above the cone. To properly seal the system, a flexible polymer based coating, installed in accordance with the following procedure, should be used (see Figure 4):

1. Remove all loose mortar, concrete brick, or other materials, as they will interfere with seal performance and adhesion.
2. High-pressure sandblast the chimney and ring to create a dry, clean surface, free from dust and moisture.
3. Apply a primer coat to the clean chimney material in accordance with manufacturer instructions.
4. Allow the primer to cure as specified by the manufacturer prior to application of lining material.
5. Apply the lining material on top of the primer in accordance with manufacturer instructions. The lining material should be flexible but resistant to account for surface loading, temperature, and vibrational changes that create most chimney damage.
6. The primer and lining should have a finished, dry thickness greater than 120 mL.

The following outlines a typical specification for the primer and seal:

Primer coat
- Specific gravity > 1.0
- >90 percent solids as measured by ASTM D2369
- Elongation 650 +/- 50 as measured by ASTM D412
- Adhesive strength > 700 psi on steel or concrete as measured by Eclometer 109
- Tensile strength = 3200 +/- 50 psi as measured by ASTM D412
- Tear resistance =325 +/- 10 psi as measured by ASTM D624
- Nonflammable as measured by ASTM D-93 in a Pensky-Martens closed cup
- Temperature range -65 to 200 F
- Minimal water absorption capacity (<0.5 percent)

Top Coat
- Specific gravity > 1.0
- >99 percent solids as measured by ASTM D2369
- As applied, solids greater than 70 percent
- Ultimate elongation equal to or greater than 850 percent +/- 50 as measured by ASTM D412
- Elongation as applied equal to or greater than 335 percent +/- 10 as measured by ASTM D412
- Adhesive strength > 700 psi on steel or concrete as measured by Eclometer 109
- Tensile strength = 2000 +/- 50 psi as measured by ASTM D412

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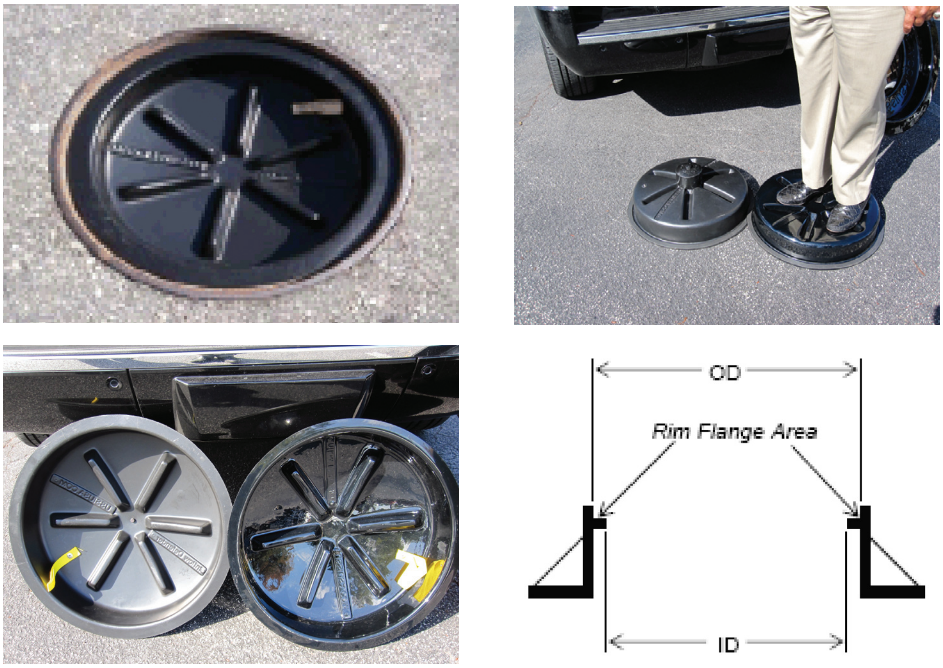
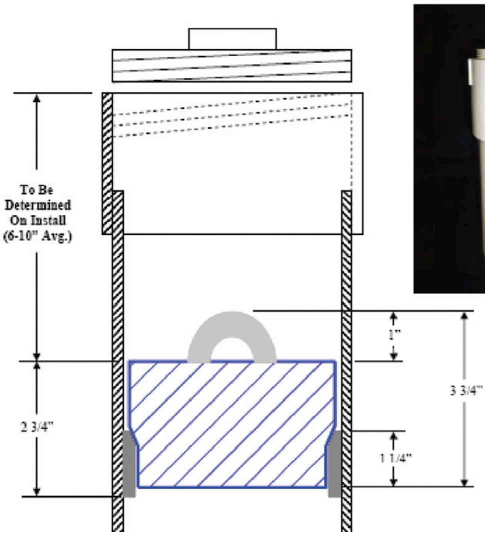


Figure 5. Inflow defender manhole rain dish showing installed dish, and both polycarbonate and polyethylene versions. Note the ribs and depth of dish that improves long-term strength. Note polycarbonate is required for newer, 30- or 48-in. manhole covers. Texas has mandated 30-in. holes for new manholes. Only stainless steel and polycarbonate are available in the larger sizes.

Figure 6. Smoke Test. (photo: USSI Inc.)



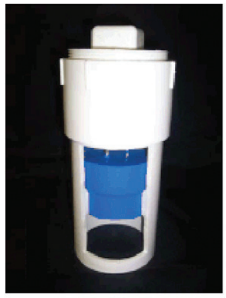


Figure 7. LDL Plug Design. *(photo: USSI Inc.)*

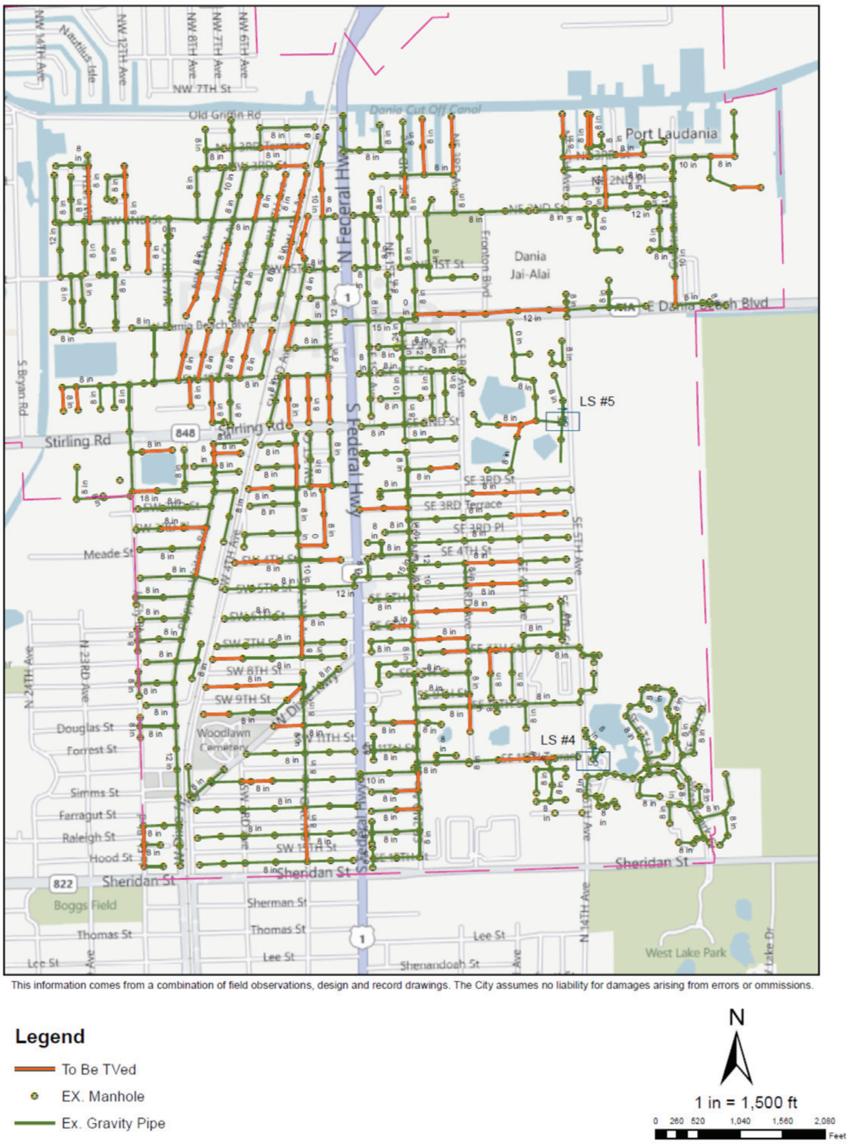


Figure 8. Areas where further infiltration investigation via televising is needed (only 15 percent of the system).

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- Tear resistance =300 +/- 10 psi as measured by ASTM D624
- Nonflammable as measured by ASTM D-93 in a Pensky-Martens closed cup
- Temperature range -65 to 200 F
- Minimal water absorption capacity (<0.5 percent)
- Shore A hardness equal to 75 +/- 5 as measured by ASTM 2240

The next step is to put dishes into the manholes. One might think that only manholes in low lying areas get water into them, but surprisingly, every manhole dish, even one that is properly installed, has water in it. Hence, it must be assumed that all manholes leak water between the rim and the cover.

Most collection system workers are familiar with dishes at the bottom of the manhole, where they are of limited use. This is because those dishes deform when filled with water or are constructed is a manner that allows them to be knocked in when the cover is flipped. The solution is a deeper dish with reinforcing ribs and a gasket. Figure 5 shows two examples (note the man standing in the upside-down dish). The dishes shown are made of a polycarbonate (shiny) and a polyethylene copolymer material that meet the requirements of Underwriters Laboratories (UL) Standard 94-HB and American Society for Testing and Materials (ASTM) specification Prime HDPE 250 to be suitable for atmospheres found in manholes. The polymer-based dishes eliminate the dissimilar metals issues with stainless steel dishes and are available at a lower cost. The key is the appropriate reinforcing to prevent dishes from dropping into the manhole. The gasket seal should be made of a closed-cell neoprene material with pressure sensitive adhesive on one side for adhering to the dish body, and be a minimum of ½ in. wide and 0.125 in. thick. As the standards for manholes gets larger (Texas rules are now 30 in.), only stainless steel and polycarbonate are available options.

To ensure the manhole dishes meet the system needs, a test can be run to evaluate dishes. Miami-Dade County tested dishes using the following procedure three times each, where the average drain time was used in the calculations of inflow rates (Miami Dade, 2010):

- Apply 2 ft of head pressure to the MH frame and cover.
- Document the time it takes the water to drain through the opening between the frame and the cover.

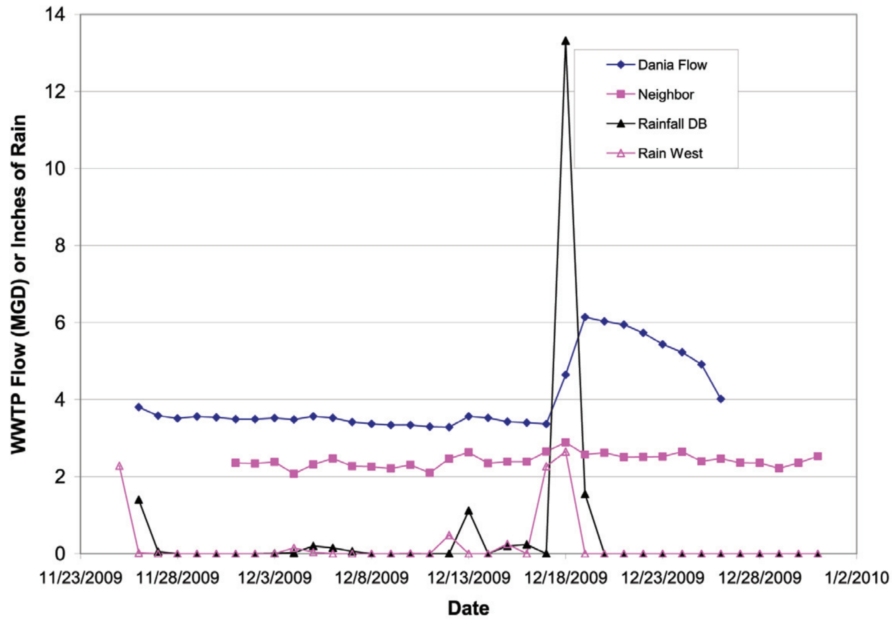

Figure 9. Comparison of flows in December of 2009 at Dania Beach and a neighboring system. Note the big spike after the rainfall that was not present on the system with limited rain (13 in. increased flows by over 2 mgd).

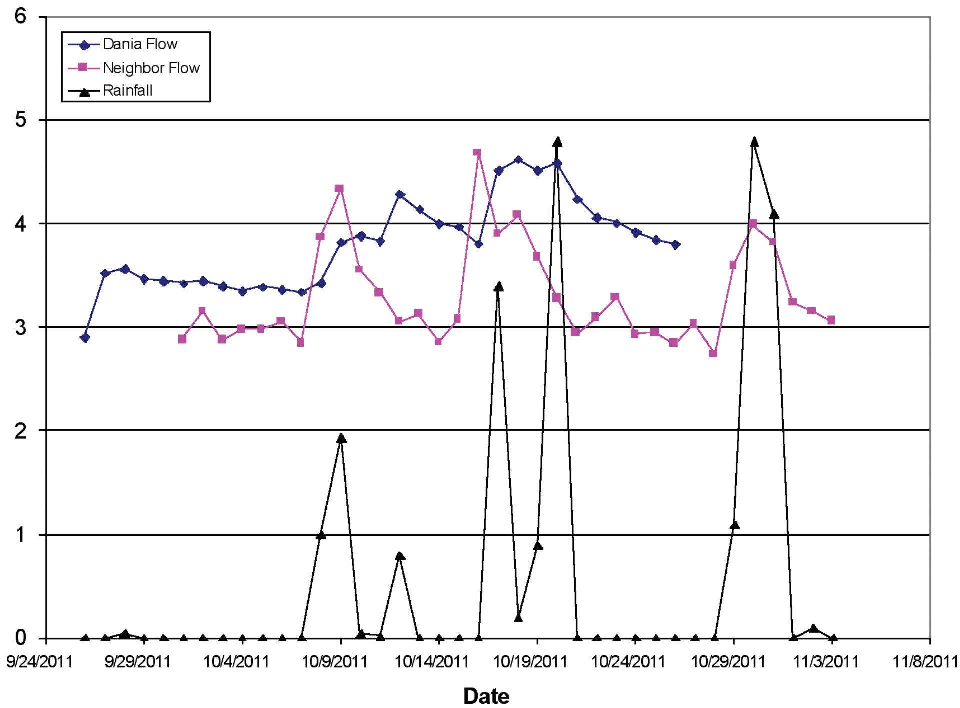

Figure 10. Comparison of flows in October of 2011 at Dania Beach and a neighboring system. Note the spikes on the same neighboring system versus the lack of large spikes in Dania Beach. The gradual upticks are likely groundwater levels creating infiltration.For Dania Beach, the 5-in. storm raised flows less than 0.5 mgd.

- The volume of the water in gal and the drain time is used to calculate an inflow rate.

The following scenarios were tested (no dish, standard dish, reinforced dish with gasket):

- No insert inflow rate: 5.45 gal per minute (gpm)
- Standard insert inflow rate: 0.72 gpm
- Inflow Defender Manhole Inflow Dish® (reinforced with gasket): 0.002 gpm

Miami-Dade County chose the latter dish for obvious reasons. Similar tests should be done in other locales.

Once the manholes are sealed, smoke testing can identify obvious surface connections (see Figure 6). The normal protocol for smoke testing will identify broken or missing cleanout caps, surface breaks on public and private property, connection of gutters to the sewer system, and stormwater connections. All should be documented via photograph, by associated address, and public or private location. The public openings at cleanouts can be corrected immediately using utility funds; the contractor can include this cost to make immediate repairs in the bid documents. However, if the cleanout is broken, it may indicate mower or vehicle damage that can occur again. If missing, the resident may be using the cleanout to drain the yard (more common than realized). In either case, the collection system needs to be protected. Utility Sealing Services Inc. (USSI) in Venice developed a solution, called the LDL plug, consisting of the following (see Figure 7):

- A molded, one-piece, synthetic urethane polymer material plug body designed to align and seal the cleanout.
- Inner seal of the plug shall consist of a PVC material fabricated with an internal tapered, beveled seat, with a thickness of 0.187 in. and overall height of 1.25 in.
- Embedded retrieval hasp and hardware should protrude at least 1 in. above the plug body, have a thickness of 0.187 in., and have hardware molded into the plug body using corrosion-resistant material to allow removal by utility crews from the surface.
- Plug has embedded steel to permit surface detection by a metal detector.

Installation in the vertical riser of the cleanout is undertaken as follows:

- Remove cleanout cap (broken or otherwise).
- Wipe all cleanouts to remove soil and moisture from the interior of cleanout stack as they would interfere with the plug.
- Scuff the interior of stack with emery cloth.
- Swab interior scuffed area with PVC cleaner.
- Swab exterior of inner seal ring of plug with PVC cleaner.

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- Apply PVC glue to interior walls of cleanout and exterior of inner seal ring of plug.
- Slide inner seal ring into appropriate point in cleanout, align with depth gauge installation tool, and twist to glue in place.

Notices should then be sent to property owners with documentation of the inflow connections to their properties. This is sometimes the most difficult part of the program due to political considerations, but it is necessary.

The final step is a low-flow investigation, which is intended to target the infiltration piece of the problem. Such an event will take several days and must be planned to determine the priority manhole to start with, and the sequencing. Based on a projected plan, the following protocol is based on where there is and isn't flow:

- Open the manholes.
- Inspect them for flow.
- Determine if the flow is significant. If flow exists, open consecutive manholes upstream to determine where flow is derived. Generally, a 2-in.-wide bead of water is a limit of "significant" infiltration.

Figure 8 is an example from Dania Beach. After 20 years of no investigation, only 15 percent of the pipe segments indicated infiltration leakage. This reduced the televising and lining portion of its lining program by over $1 million, which more than paid for the inflow reduction project.

Results

So, the question is: What is the cost, and how successful is this type of protocol? The City of Dania Beach pursued this program for its inflow correction to identify where infiltration efforts should be concentrated. The service area consisted of 800 manholes, and the total cost was $480,000, which included fixing 25 manholes, sealing all 800 manholes and dishes, repairing 200 public inflow openings, identifying 300 private connections, and conducting two smoke test events and one midnight run.

In the past, the City of Dania Beach incurred substantial peaks from "normal" rainfall events. Figure 10 shows the City of Dania Beach and a neighboring community in December 2009, when the rainfall on one day was over 13 in. (although it was only 2.5 in. the neighboring community). Significant flooding on the east side of Dania Beach lasted three weeks, in part because the sewer system was sealed on public property, but openings remained on private property. Figure 11 shows October 2011, when 13 in. of rain fell during the month, including 3.5- and 5-in. storms a week apart. While the data is given on a daily basis, it is clear that the Dania Beach system did not incur the sustained peaks of the past, although infiltration remains an issue (currently under contract).

The cost to treat wastewater averages $3.50/1000 gal. The City of Dania Beach has estimated it saved 200,000 gal per day (gpd) over the course of a year as a result of its inflow correction effort, while substantially reducing its peaks; this is a savings of over $250,000 per year. Payback is under two years.

In addition, Figure 10 shows the limited areas for televising to correct infiltration, the next phase of Dania Beach's program. Only 15 percent of the system had infiltration identified, and this is 20 years after the last "I and I" correction effort. Full television inspection would have revealed nothing in 85 percent of the system. An estimated 800,000 gpm of inflow existed in the yellow pipes, which will yield substantial additional savings. This effort has shown that investment in infiltration and inflow reduction by the utility should provide confidence that it will see reductions in inflow to the wastewater treatment plant, and reductions in its operating costs.

Most specifics can be discovered when daily flow information is compared in a given area before and after inflow repairs are completed. Cooper City, located in Broward County, decided to pursue a pilot inflow reduction program in spring 2012. Data for 2011 and 2010 were compared to determine how different the results were. Figure 11 shows a comparison of pump times and rainfall (x 1000 for ease of graphical comparison) for 2011 and summer 2012. The graphic does not show conclusive data, but breaking the information down is more illuminating. Figure 12 shows the same lift station with rainfall versus pump run time in 2011. This was done for three lift stations in the area, addressed with inflow correction for both 2011 and 2012.

More informative would be a graph of rainfall versus pump time for specific storm events; the concept is to determine if there is less run time post-inflow correction. The results will show, on a line sloped for a relationship, a greater slope, meaning more pump run time for a given rain event. The data were combined for the lift station basins (52 to 54) to find similar storm events each year; only these values were compared. Figures 13 to 15 show a comparison of specific rain events versus pump run time. In each case, the slope of the line through the 2011 values is substantially above the slope of the 2012 rain events. For lift station 52 and 53, the pump run times do not change significantly, regardless of rain totals, indicating

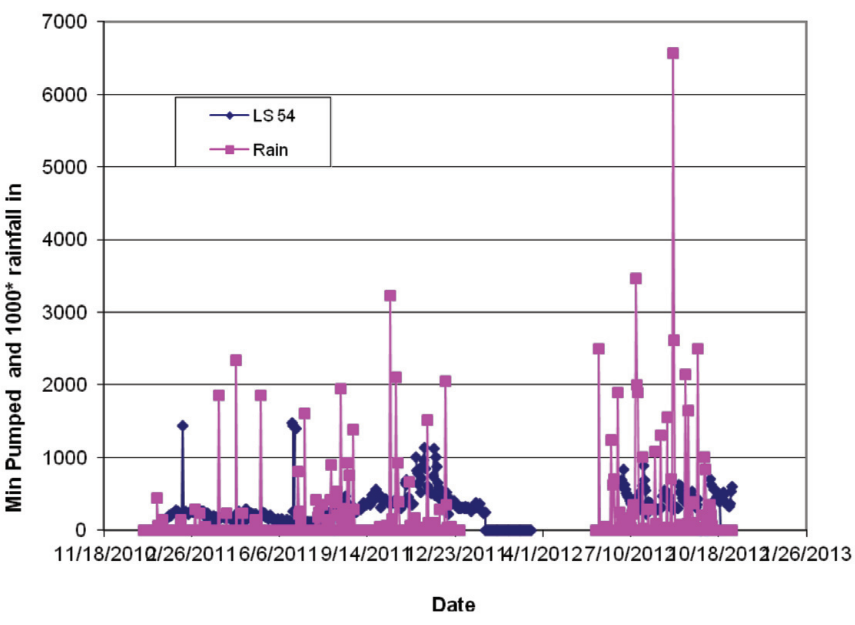

Figure 11. Comparison of Cooper City lift station area flows before and after the G7 program in one of four lift station basins (typical).

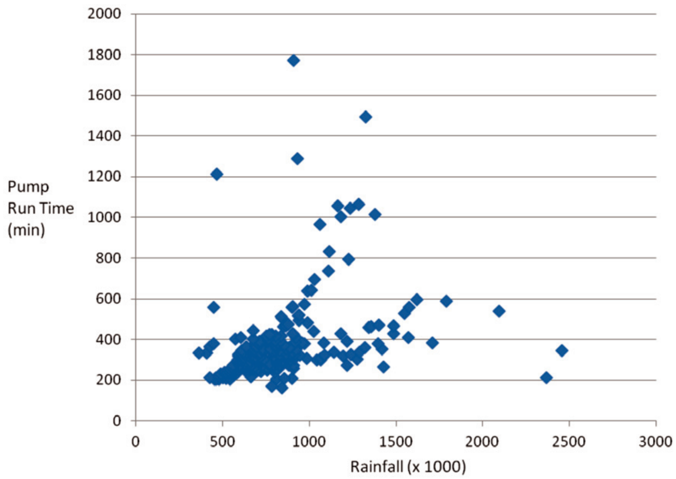

Figure 12. Rainfall (x 1000) versus pump run time. Correlation for run time and rainfall was 0.5.

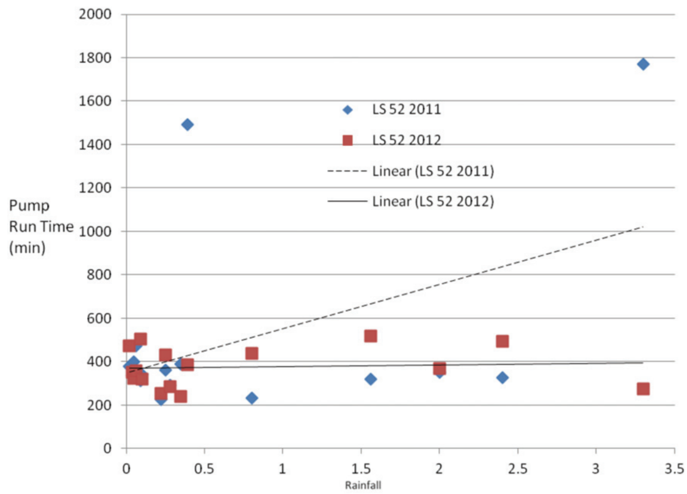

Figure 13. Comparison of rain events (in.) versus pump run times in 2011 and 2012 for Cooper City Lift Station 52. The slope of the lines show that the inflow correction substantially reduced inflow. The 2012 graph shows virtually no effect of rainfall on run times.

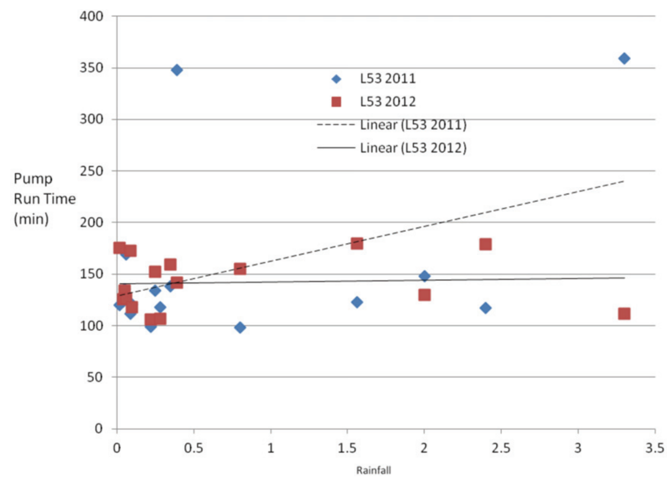

Figure 14. Comparison of rain events (in.) versus pump run times in 2011 and 2012 for Cooper City Lift Station 53. The slope of the lines show that the inflow correction substantially reduced inflow. The 2012 graph shows virtually no effect of rainfall on run times.

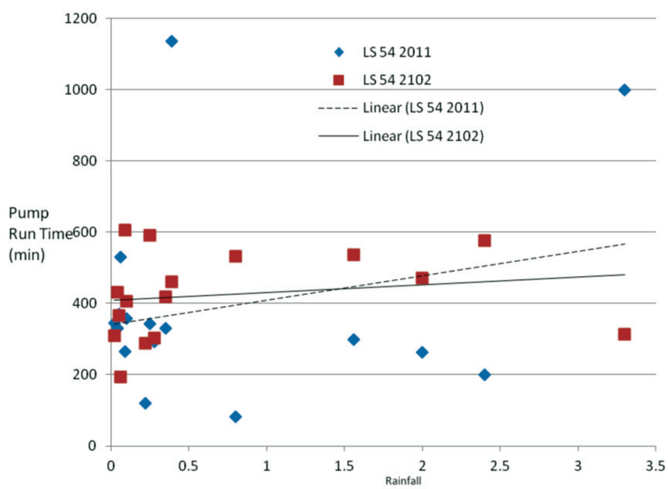

Figure 15. Comparison of rain events (in.) versus pump run times in 2011 and 2012 for Cooper City Lift Station 54. The slope of the lines show that the inflow correction reduced inflow.

that for this basin, most of the inflow has been removed (Figures 13 and 14). In the lift station 54 basin, the 2012 line is nearly flat, and there does not appear to have been as much inflow in this basin in 2011. Still a change in the slope is noted (Figure 15).

The results of the two case studies shows that inflow is separate from infiltration, the peaks in flows are inflow and can be removed relatively easily, the costs are reasonable, and the solutions relatively simple. Getting the right technology and specifications is important. Correcting inflow helps utilities target the specific lines where infiltration correction is needed, negating the televising and cleaning of miles of pipe where no damage is found. This saves the utility money as well. Overall, correcting inflow first will likely reduce the overall cost of infiltration and inflow correction, and bring a greater return on invested dollars in the form of reduced flows.

References

- Bloetscher, Frederick (2011), *Management for Water and Wastewater Operators*, America Water Works Association; Denver, Colo.