Defining the Cost Benefit of Inflow Removal Before Infiltration Exploration

Frederick Bloetscher, Ph.D., P.E., LEED-AP, DWRE
Florida Atlantic University and
Public Utility Management and Planning Services, Inc.

Trent van Allen, E.I. and Nadia Locke, P.E., E Sciences

Dominic F. Orlando, P.E. and Ronnie Navarro, P.E.,
City of Dania Beach, FL

Mike Bailey, P.E., Cooper City

Lloyd Wander, Greg Smith and Dion Valsak, USSI

Abstract

Substantial savings in operations can be achieved by reducing the amount of wastewater that must be pumped and treated. Utilities have long dealt with the infiltration and inflow (I and I) issues in their system by televising their pipes and identifying leak points, but this primarily addresses only the infiltration part of "I and I." Inflow, which creates hydraulic issues during rain events, leads to sanitary sewer overflows and can subject the utility to fines from regulatory agencies, and create publicity and legal issues when houses are damages from sewage backing up into houses and businesses. As a result, dealing with the inflow portion of I and I is needed. Inflow often can be identified and corrected easily, and removing the inflow portion from I and I, often leads to a more focused plan for infiltration correction program. The intent of this paper is to provide a guideline on dealing with inflow identification and removal, using a pair of utility examples, and showing the resulting benefits on the infiltration correction that resulted. A side benefit is a better understanding of what goes into the system.

Introduction

In the United States, 4% of the total power produced is used by water and wastewater systems (Lisk et al, 2012). In both cases, as much as 90 percent of that power is used for pumping. In wastewater collection systems, much of that cost is lift stations, especially in flat areas like Florida where utilities routinely maintain lots of lift stations. The vast majority of water and sewer utilities in the United States are operated by municipal governments or local authorities, and as result report to elected or appointed officials who disdain rate increases for routine items. Yet these same local officials want to develop water and sanitary sewage systems which will meet the water and sewerage needs of the areas served by the utility, yet ensure that existing and future utility systems are constructed, operated and managed at a reasonable cost to the users without outside subsidies, and to develop a system that is compatible with the area's future growth. That comes at a cost.

The initial goal of the Clean Water Act was oriented to clean up the nation's rivers and streams through the removal of untreated industrial and domestic wastewaters from the nation's waters. The initial focus was on treatment plants. Hence, a top priority was to provide a level of wastewater service that meets state and federal regulatory requirements. However, once the treatment plants were constructed, the priority shifted 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, which were mostly in the northeast and Midwest.

NASSCO's manhole committee noted that two 1 inch pickholes in a manhole cover can leak 45 gpm into the sewer system (NASSCO, 2015). Manholes without pick holes can leak 12 to 27 gpm with less than 2 inches of water on top. Miami-Dade County found even pickhole-less manholes leaked. Missing or removed cleanouts can provide additional flows. Combined, Wingard (2015) reported that inflow can contribute 90% of flows under storm events, and needlessly tie up capacity of pipes and treatment facilities. As an example, the City of Austin experienced a 354% increase in flows with a 10 inch rainstorm last year (Rizk, 2015). The result is SSOs, plant overflows or bypasses or flooded homes.

The City of Baltimore reports 450 basement floods a month on its 1300 mi gravity system (Santino, et al 2015). None of these results are acceptable alternatives and all subject the utility to financial risk from fines or lawsuits.

Getting funding for sewer collection maintenance is often difficult, and may stem from a lack of understanding of the components of inflow and infiltration, a failure to understand the risks and the fact that buried pipes are out of the public view. For staff, the concept of televising and lining gravity pipes appeals to the technological view of local officials, but this does nothing to find inflow, only infiltration. Televising the sewer system and sealing and lining sections where leaks are noted is common, but the reality is that many miles of videotape show nothing, so significant money is spent to find "nothing" despite the fact that even for large systems, the EPA criteria for determining "too much" infiltration and inflow may indicate 35% a total wastewater flow. The lack of "results" may cause local officials to perceive that the sewer infrastructure is "ok" as it is (Bloetscher, 2011), or that staff is wasting money. As a result, is not uncommon for staff that finds "virtually nothing" to face difficulty in getting "round 2" monies for the actual lining and service repairs. As a result, these piping systems may be neglected over time and the potential for inflow events to create financial risks increases.

In the lexicon of sewer collections, it must be clear that "infiltration" and "inflow" are not the same, and storm events do not highlight infiltration nearly as well as they do inflow. However, the regulatory focus under the Clean Water Act today is SSOs. SSO concern led EPA to establishing the cMOM program, which is intended to insure 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. Pipe cleaning and repair work is tracked, and maintenance logs are required for lift stations. Since keeping excess flows down benefits the utility financially, inflow correction programs should be a higher priority since they can help cMOM programs because in this regard as inspection data can be tracked and material in the manholes can be observed. By reducing inflow, the utility can reduce costs at wastewater treatment plants and financial risks to the utility can be reduced.

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 (see Figure 1). Figure 1 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 2, the utility the average daily water is just over 2.05 MGD, but the wastewater flow is over 3.3 MGD, indicating nearly 1.2 MGD of infiltration. When plant operators see peaks in flows after rain events, 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.

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. All are potential sources of inflow which can be identified easily with manhole inspections and smoke testing.

Methodology

To analyze the benefit of inflow removal, two south Florida sewer systems were studied. Both were relatively small, served defined areas, had readily available information on daily flows and pump station records, and had participated with inflow removal programs. One pursued infiltration correction subsequently.

Data for Dania Beach was gathered from 2005 to 2013. The original sewer pipes were installed in the 1960s. Cooper City data was available from 2011 to 2013. Their pipelines were installed in the late 1970s. Both utility directors recognized issues with excess flows in the utility system and were interested in resolving issues with inflow and infiltration at reasonable cost. Significant flows during rain events were noted before the efforts were undertaken. Rainfall records for the closest rain station were acquired from DBHydro from the South Florida Water Management District.

It was hypothesized that inflow into sanitary sewer lines is linearly related to rainfall (Merrill 2004), and infiltration is linearly related to groundwater elevation. Based on these assumptions inflow and infiltration could each be separated out from the wastewater flow, leaving only baseflow. Once the inflow and infiltration have been separated from the flows, pre and post flows could be compared to determine a percent reduction in both to develop a cost analysis.

The expectation was that result would be that the water discharged to the sewer system is a relatively constant percentage of the total potable water pumped. Baseflow would not be of significance in this study, and it was assumed that any increases or decreases of baseflow over the study time period were negligible.

Basic statistical means were used to develop correlations and extract the three components. It was assumed that rainfall and inflow were linearly related; a linear regression analysis was completed to extrapolate inflow values based on assumed rainfall values. A regression analysis was used because it focuses on dependent variables, and can provide understanding of how the dependent variable (inflow) changes when independent variable (rainfall) is varied. The regression analysis could also be used to predict future inflow values based on rainfall. Once the linear relationship between rainfall and inflow was determined, any rainfall could be entered into the regression analysis to determine the associated inflow value.

Once the inflow values were separated, the relationship between groundwater elevation values and flows were developed using the Pearson product-moment correlation coefficient. This time the dependent value was the baseflow+infiltration and independent variable was the groundwater elevation. Since it was assumed that fluctuations in baseflow were negligible, any changes between baseflow+infiltration were assumed to be a result of fluctuations in infiltration. 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 documented condition, GPS location, ties to photographic data and some form of numbering if not currently available. Manhole inspections can also document useful information like excessive grease build-ups, improper disposal of feminine hygiene products, wipes, and other trash (see Figures 3a-d). It should be noted that 17 percent of people regularly flush baby wipes down the toilet because manufacturers say they are flushable (Stratton-Childers, 2015). Unknown percentages flush diapers, towelettes and other products, Options to reduce this problem include trash cans, access to towels and wipes in restrooms, bidets and systems like the Heinie-Genie (Rabines, 2015), but none of these are convenient away from home. Education is the best and cheapest solution as the wipes do not deteriorate in the sewers. Instead they clog pumps, stick to grease and clog pipes. Most manholes have limited condition issues, but where the bench or walls are in poor conditions, that should be repaired with an impregnating resin. Deterioration may be an indication of wastewater quality concerns requiring the addition of chemicals to reduce the impact of hydrogen sulfide.

Next is repair/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 breaks 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 (MiamiDade, 2010). The intent of the chimney seal is to prevent inflow from the area beneath the rim of the manhole, but above the cone (see Figure 4). 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 that is properly installed has water in it. Hence assume that all manholes leak water between the rim and 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 in such 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 guy standing in the upside-down dish) - one polycarbonate (shiny) and a polyethylene copolymer material 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.

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 storm water 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. 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 we realize). In either case the collection system needs to be protected with a device like an LDL plug (see Figure 7).

The final step is a low flow investigation, which is intended to target the location of infiltration in the piping system. Typically the lowest best time for such an analysis occurs from 1 AM to 5 AM when people are sleeping and not using water. Ground water infiltration flows do not fluctuate greatly in sanitary sewer lines during wet-weather conditions. However there are seasonal variations due to changes in the water table. Typically the highest levels of ground water infiltration in South Florida occur in summer when the water table is at its highest (E Sciences 2013); this is different from most other parts of the country when the water table is at its highest in late winter and spring. Such an event will take several days and must be planned to determine priority manhole to start with and sequencing. Based on a projected plan, the following is the protocol based on identifying where there is and is not flow:

- Open the manholes
- Inspecting them for flow
- Determining if flow is significant. If investigation of basin will end and new basin will be started. If flow exists, open consecutive manholes upstream to determine where flow is derived from. Generally a 2 inch wide bead of water is a limit of “significant” infiltration (see Table 1).

The results can be tabulated (see Table 2 for an example) and plotted in GIS (see Figure 8).

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. A comparison of 2009 vs 2012 flows in Dania Beach shows that the system deteriorates, which must be taken into account for any analysis (see Figure 9). However, Figures 10-12 show how the inflow can be deducted from the total flows. Inflow and rainfall were correlated for each system. However once the inflow correction efforts outlined herein were all completed, the inflow amount diminished (see Figure 13) to a point where rainfall makes limited impact on system flows. Breaking down a series of lift stations in Cooper City indicated that most had no increased flow (see Figures 14-16). Overall the flows were reduced over 30% and 60% for Dania Beach and Cooper City respectively (see Table 3)

Infiltration

Internal pipe inspection does nothing to address inflow and searching for infiltration can be costly. Miles of pipe may have no defects, which means money is spent on non-productive activities. While infiltration is best handled with an internal sanitary sewer system inspection, which includes manhole inspection and sewer line and lateral inspection via camera, the midnight inspection helps identify where these leaks might be present. Closed-circuit television (CCTV) is the most common assessment tool conducted by municipalities to gauge the current condition of their collection system, determine the structural condition, the presence of roots, condition of joints, depth of debris in the line, and depth of flow (USEPA 2005). A 2004 research project, which surveyed large wastewater utility districts, found that 100% of the 31 survey respondents relied almost exclusively on CCTV as the primary means to inspect pipes (Thomson 2004), but the costs can be cut considerably during the inflow portion of the project. Such an inspection assists utilities in. Hence a short discussion will be included here.

Infiltration is the water entering a sewer system and service connections from groundwater leaking through defective pipes, pipe joints, damaged house lateral connections, or manhole walls (Feeney et al 2009). Infiltration most often is related to a high groundwater table that is observed during a wet season or in response to a severe storm. Damaged lateral connections are thought to be a major contributing factor to infiltration in sanitary sewers (Swaner and Thompson 1994). Figure 17 shows the Typical Base+Infiltration flows vs Groundwater elevation for Dania Beach Figure 18 shows that deterioration continues with time, and must be accounted for in any analysis. Figure 19 shows the correlation of Groundwater vs Flow – not time dependent. It should be noted that only those pipe identified during the midnight investigation were televised and addressed. Half of those pipes had breaks, the rest had service lateral breaks. Five point repairs were noted during the midnight investigation and repaired by city staff. Overall the flows decreased 3.4 MGD in 2005 to 2.4 MGD, despite a 0.2 MGD addition of concentrate from a new membrane facility, in 2014. Over 30% of the total flows were removed.

Summary of Results as they Relate to Cost

Based on the analysis of the two systems, significant decrease in inflow between the pre and post-construction flows was experienced. The construction activities resulted in a total net inflow decrease of 68.9%, but these are periodic flows, accounting to only 4 to 5 percent of total flows, but it substantially reduced risks of regulatory concerns and litigation to the utility. The pre and post construction activities for infiltration resulted in over 25% removal. However the inflow protocol resulted in cutting total infiltration program costs by over 50%.

Two things to note are:

- The percent decrease in infiltration still accounts for a larger total flow decrease than the inflow decrease because infiltration is such a larger portion of the yearly total flow (by a factor of 5 in Dania Beach)

- The infiltration percent decrease was marginalized due to the fact that baseflow was left in the calculations. Without an adequate way exclude to baseflow, flow measurements were left in baseflow + infiltration. Leaving the baseflow in the analysis does not affect the amount of the flow reduced from the infiltration reduction work but it would decrease the percent change. Even though the percent change is minimalized due to the additional flow within the calculation, it will not affect the cost analysis, which will be based on the amount of flow reduced and not the percent change.

The inflow calculations generated previously, based on the rainfall and flow, were used to calculate the cost savings from the inflow construction activities. Using the equation created to show the relationship between the 2006 flow and rainfall and the 2009 rainfall values, the amount of inflow that would have been generated if no construction activities were completed, 14.1%/yr was added to the 2006 inflow values based on the 2009 rainfall values to account for the amount of increase in the system which would have occurred if no inflow reduction activities would have occurred.

The baseflow + infiltration calculations generated previously, based on the groundwater elevation and flow minus inflow, were used to calculate the cost savings from the infiltration construction activities. Using the equation created to show the relationship between the 2012 flow minus inflow and groundwater elevation and the 2013 groundwater elevation values, the amount of infiltration that would have been generated if no construction activities were completed was 8.5%.

The cost for all services, for the entire service area consisted of 800 manholes is shown in Figure 5. Included fixes to 25 manholes, sealing all 800 manholes, 800 dishes, repairs to 200 public inflow openings, identifying 300 private connections, two smoke test events and one midnight run. The cost was $472,000. The savings was 18 MGY ($55,044/yr in treatment costs). However, when Dania Beach corrected the infiltration ($772,000 contract), they saved over $1.2 million on the televising and lining portion off their lining program by, which more than paid for the inflow reduction project. Overall the program saves almost $270,000 per year (see Table 4). Payback is under four years. This effort has shown that investment in inflow, helps reduce the investment in infiltration reduction by the utility, and should provide the utility with some confidence that it will see reductions in inflow to the wastewater treatment plant, and reductions in its operating costs by using this protocol.

Conclusions

The conclusions developed from this project are directly related to the method for determining the inflow and infiltration reduction, which were related to rainfall and groundwater elevation, respectively. The results of the analysis showed that inflow and infiltration were a major portion of plant flow, meaning that the utilities were spending money to build plants to treat stormwater and groundwater. When it is noted that the municipalities are spending approximately $3/1,000 gallons, they are spending a lot of money treating stormwater and groundwater. While inflow makes up a small percentage of the total annual flow, it is the portion of flow that creates the most exposure to regulatory fines and public health incidents. The amount of inflow can be measured by comparing the daily flow vs. rainfall for each utility. The graph can be used to calculate difference between years by comparing the slope of the trendline equations.

The results of the two case studies shows that inflow is separate from infiltration, that the peaks in flows are inflow and can be removed relatively easily, that 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 I and I correction, and bring a greater return on invested dollars in the form of reduced flows.

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Table 1 – Flow Volumes for Midnight Run

flow. 2 inch wide flow, 1/4 in deep at 2 ft/s =	0.77917	gpm
flow. 3 inch wide flow, 1/2 in deep at 2 ft/s =	2.3375	
flow. 4 inch wide flow, .75 in deep at 2 ft/s =	4.675	gpm
flow. 6 inch wide flow, 1.25 in deep at 2 ft/s =	28.05	gpm
flow. 8 inch wide flow, 4 in deep at 2 ft/s =	49.8667	gpm

Table 2 - Typical Midnight Run output.

MH 1-11	MH 1-12	3		2	
MH 1-15	MH 1-3	4		4	
MH 1-30	MH 1-40	3	3	0.5	
MH 1-30	MH 1-41	3		2.5	
MH 1-31	MH 1-32	2		0.35	
MH 1-4	MH 1-13	5		30	
MH 1-40	upstream	8		150	LS FM?
MH 1-41	MH 1-42	4	3	35	
MH 1-42	MH 1-43	3		3	
MH 1-5	MH 1-6	6	2	40	
MH 1-6	MH 1-7	5	2	30	
MH 161	lateral	2		0.35	

Table 3 - Comparison o f Inflow Amount Eliminated

Community	% Change (Pre Vs. Post)
Dania Beach (2006 vs. 2009)	-31.9%
Cooper City (2011 vs. 2013)	-62.8%

Table 4 Costs of Inflow and Inflow Correction

Assume 800 MH	Inflow	Infiltration
Sewage Reduced (gallons)	18,348,011	72,706,566
Amount Saved	($55,044)	($216,665)
Cost	$472,000	$772,000
Cost/1000 gallon	$22.72	$7.64
BUT…		
Avoided Cost	($1,200,000)	$0
Cost/1000 gallon	($42.68)	$7.64

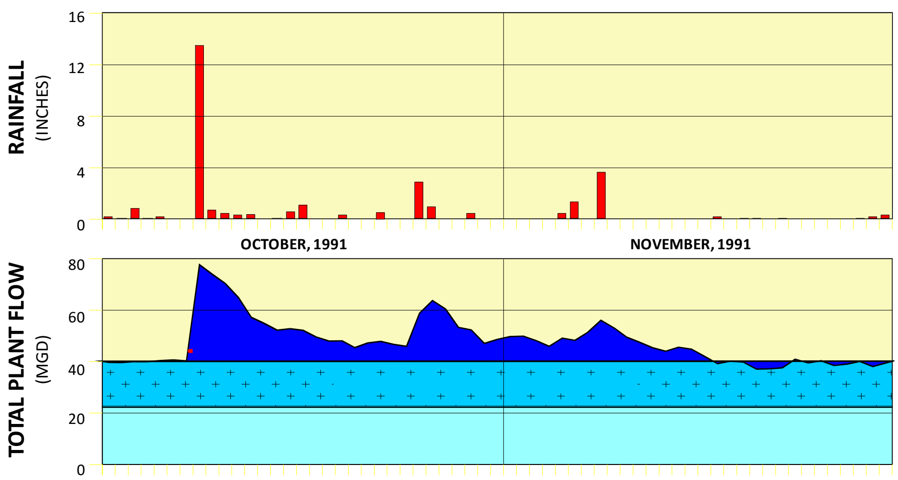

Figure 1 Indication of inflow to the sewer system (Bloetscher, 2011)

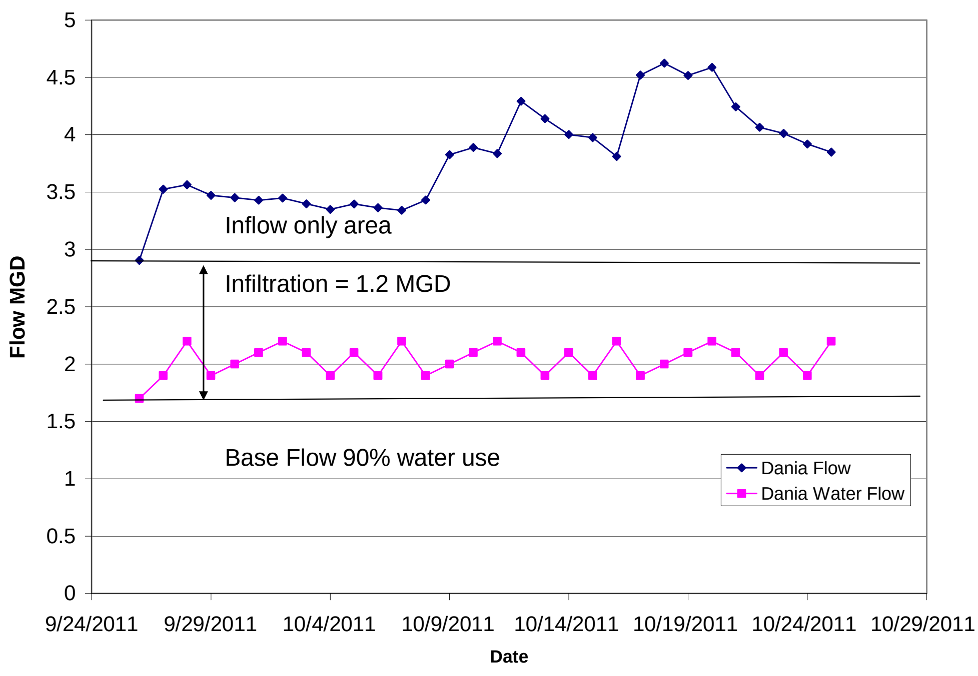

Figure 2 Identification of inflow, infiltration and base flow in a sewer system flow hydrograph

Figure 3a Grease in the manhole 3b. Improper disposal of material   3c Wipes   3d Old manhole dish

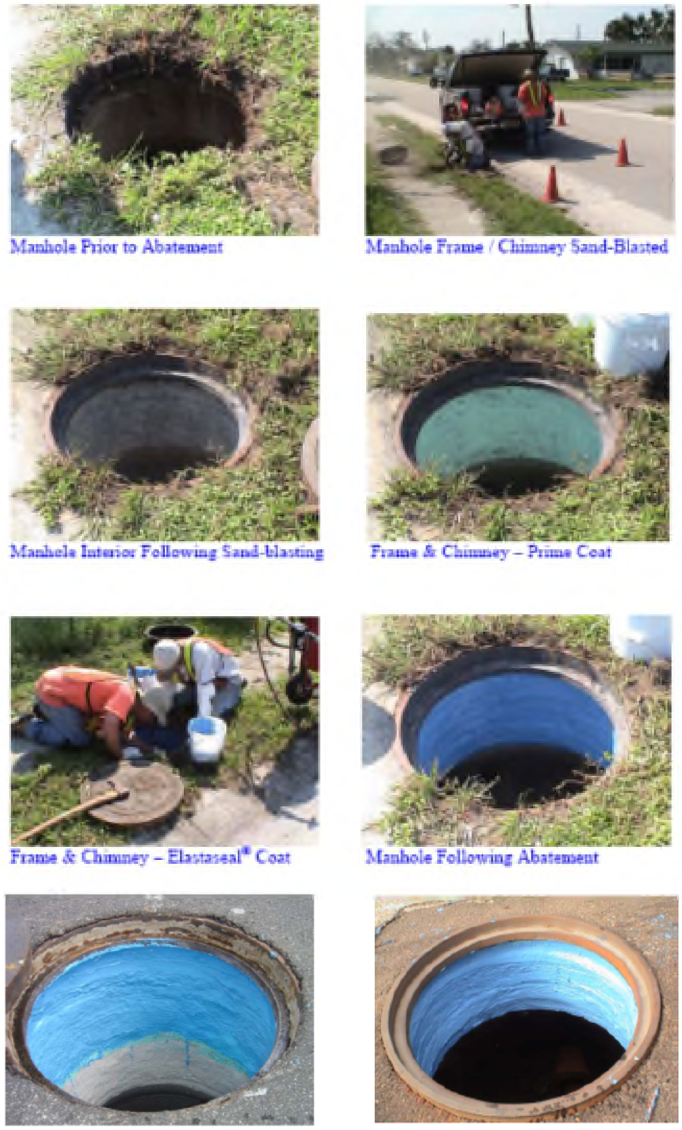

Figure 4 Installation Procedure (courtesy, USSI, Inc.;)

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 inch manhole (Courtesy, USSI, Inc.; Bloetscher, 2011)

Figure 6 Smoke Test Results

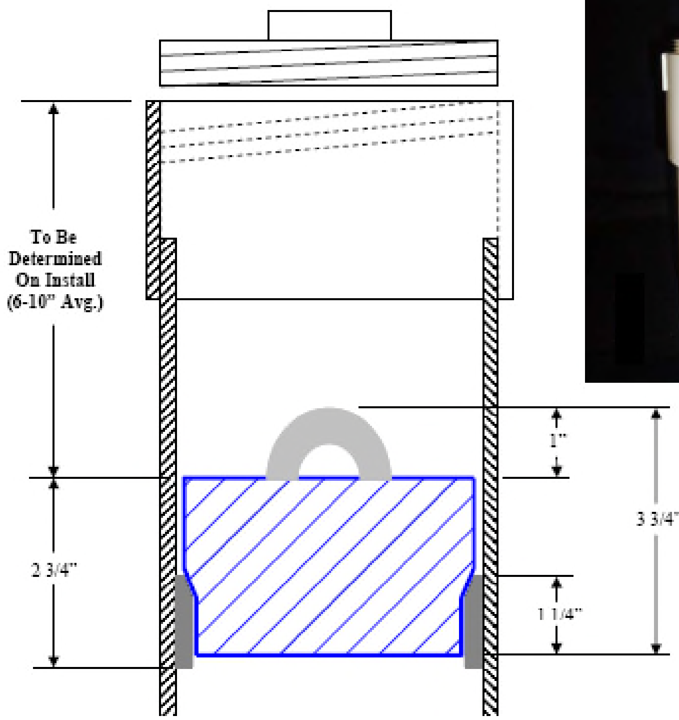

Figure 7: LDL Plug Design (courtesy, USSI, Inc.; Bloetscher, 2011)

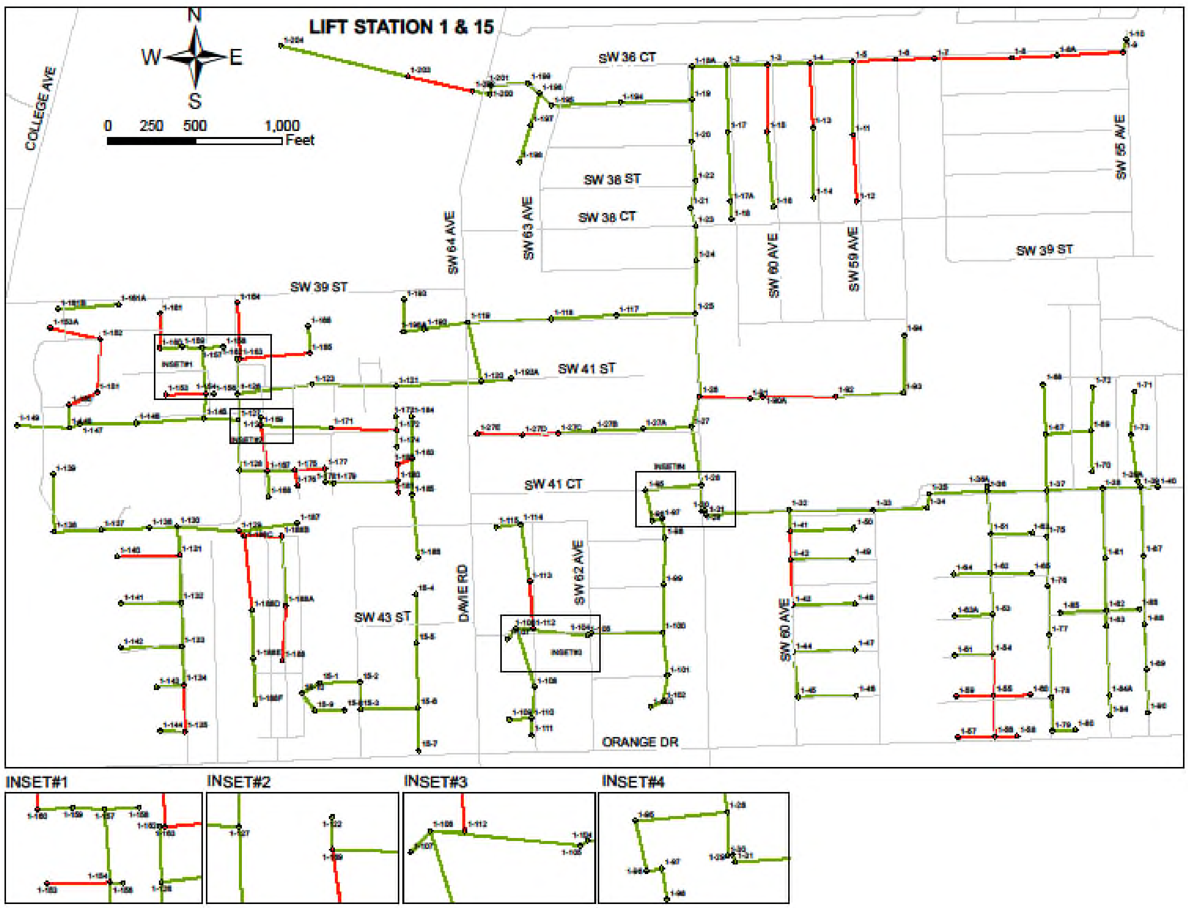

Figure 8 Typical GIS output for Midnight Investigation 15-20% of pipe contribute most of the infiltration.

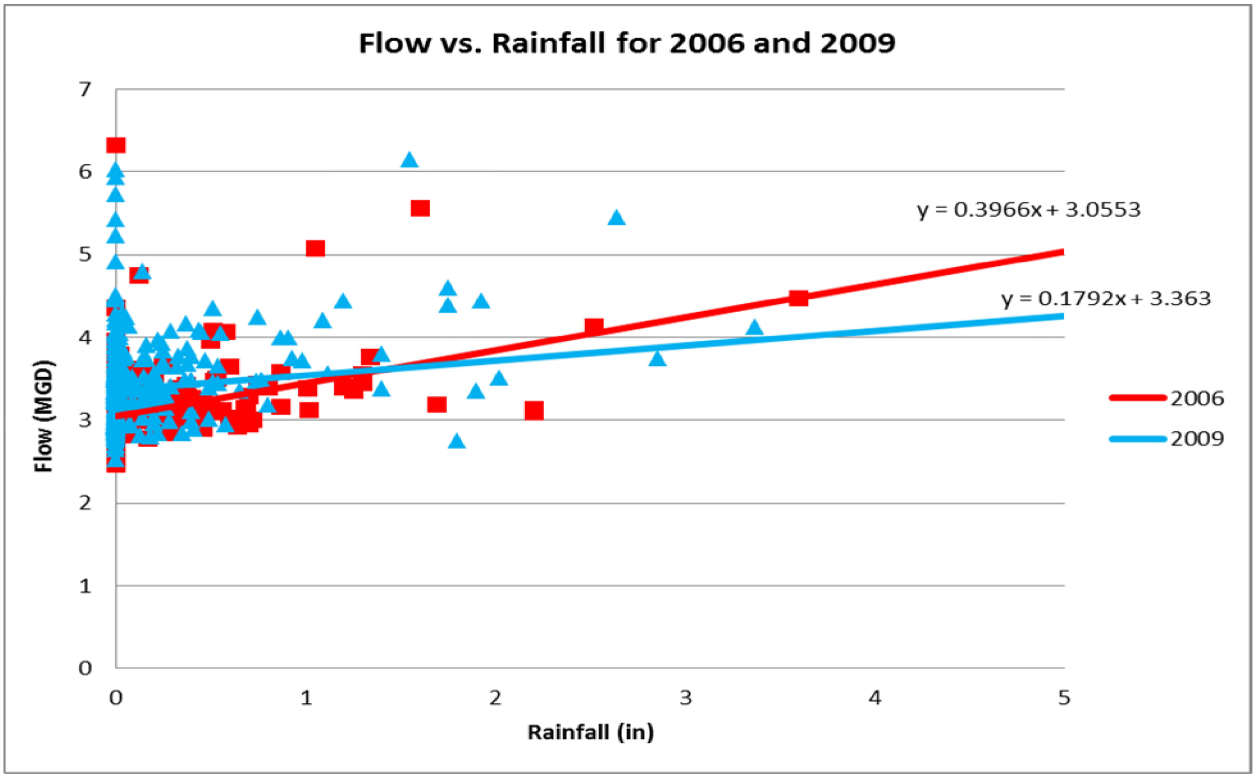

Figure 9 Comparison of 2009 vs 2012 Flows in Dania Beach – Note system deteriorates

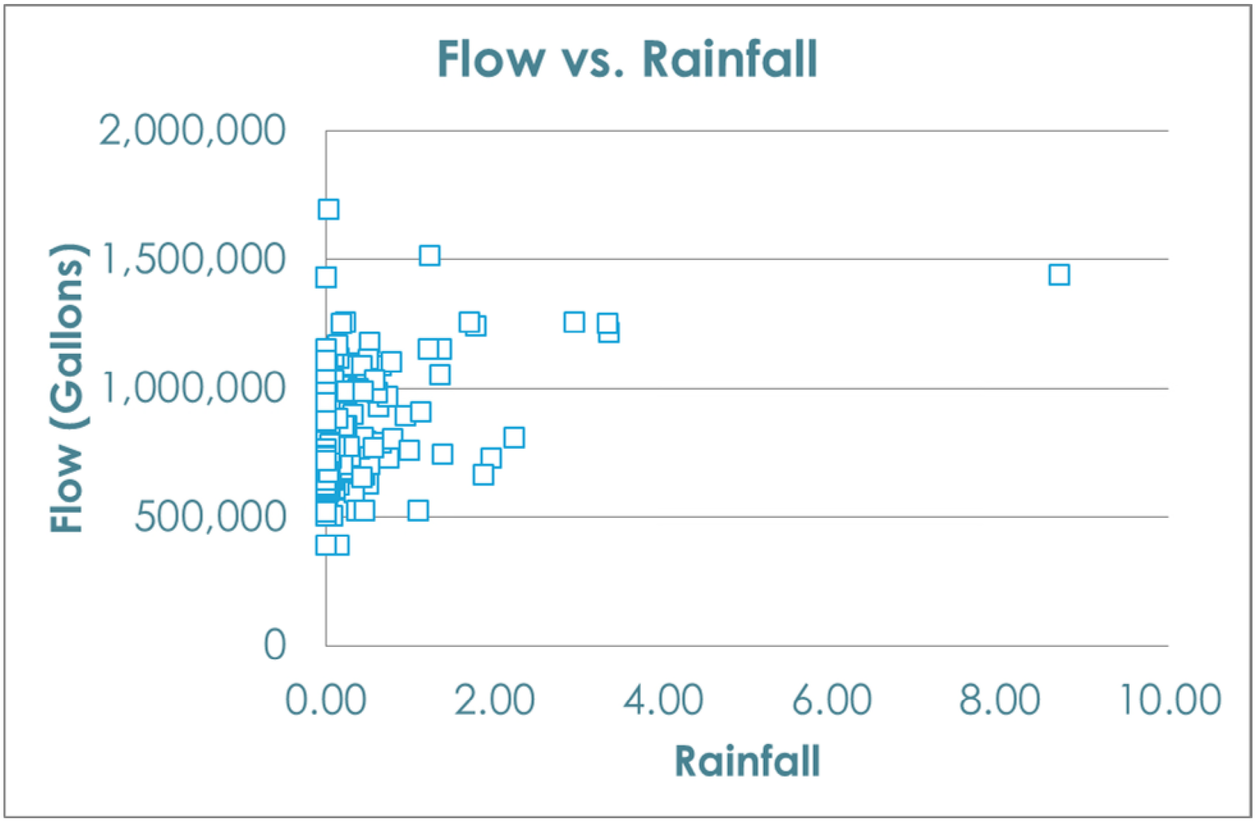

Figure 10 Comparison of rainfall storm total vs Flows in Cooper City (area with correction)

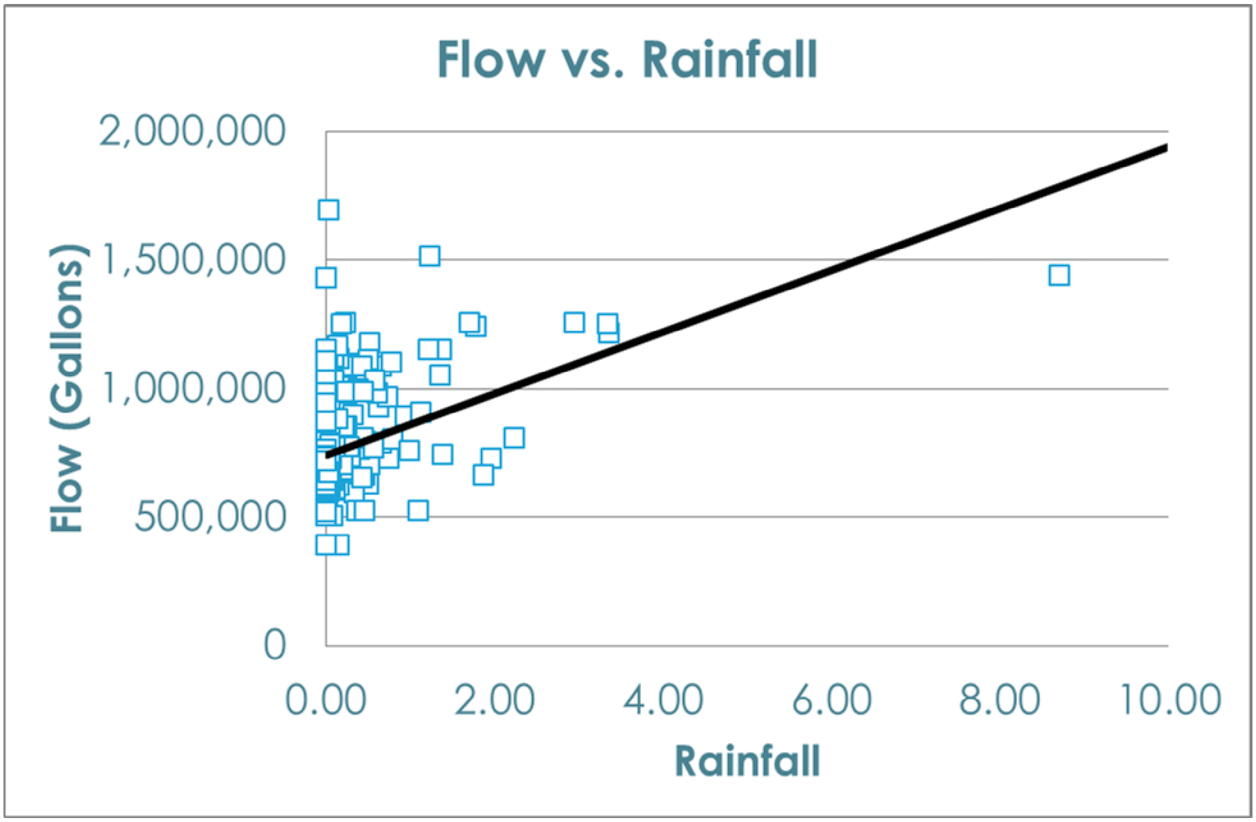

Figure 11 Comparison of rainfall storm total vs Flows in Cooper City (area with correction) identifying inflow correlation

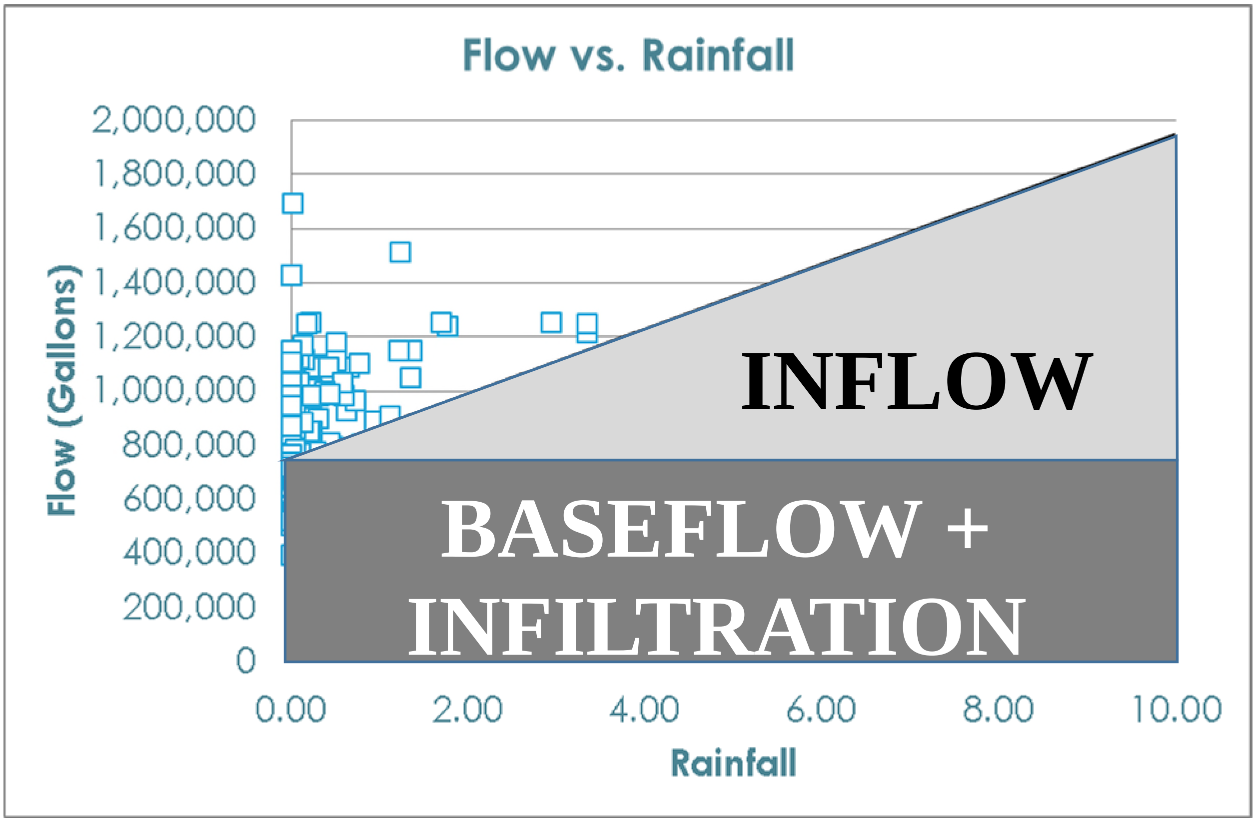

Figure 12 Comparison of inflow vs infiltration

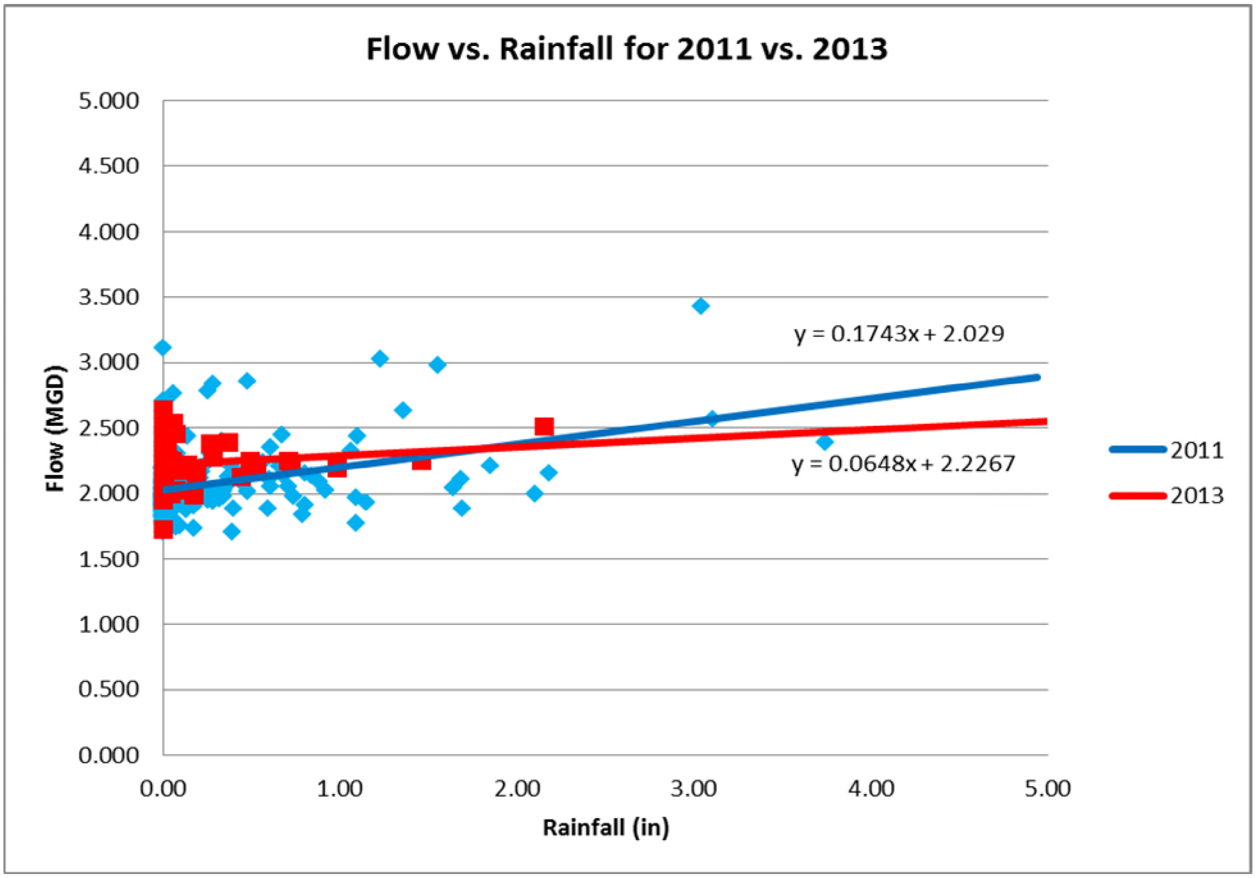

Figure 13. Comparison of rain events (inches) versus pump run times in 2011 and 2013 for Cooper City. The slope of the lines show that the inflow correction reduced inflow.

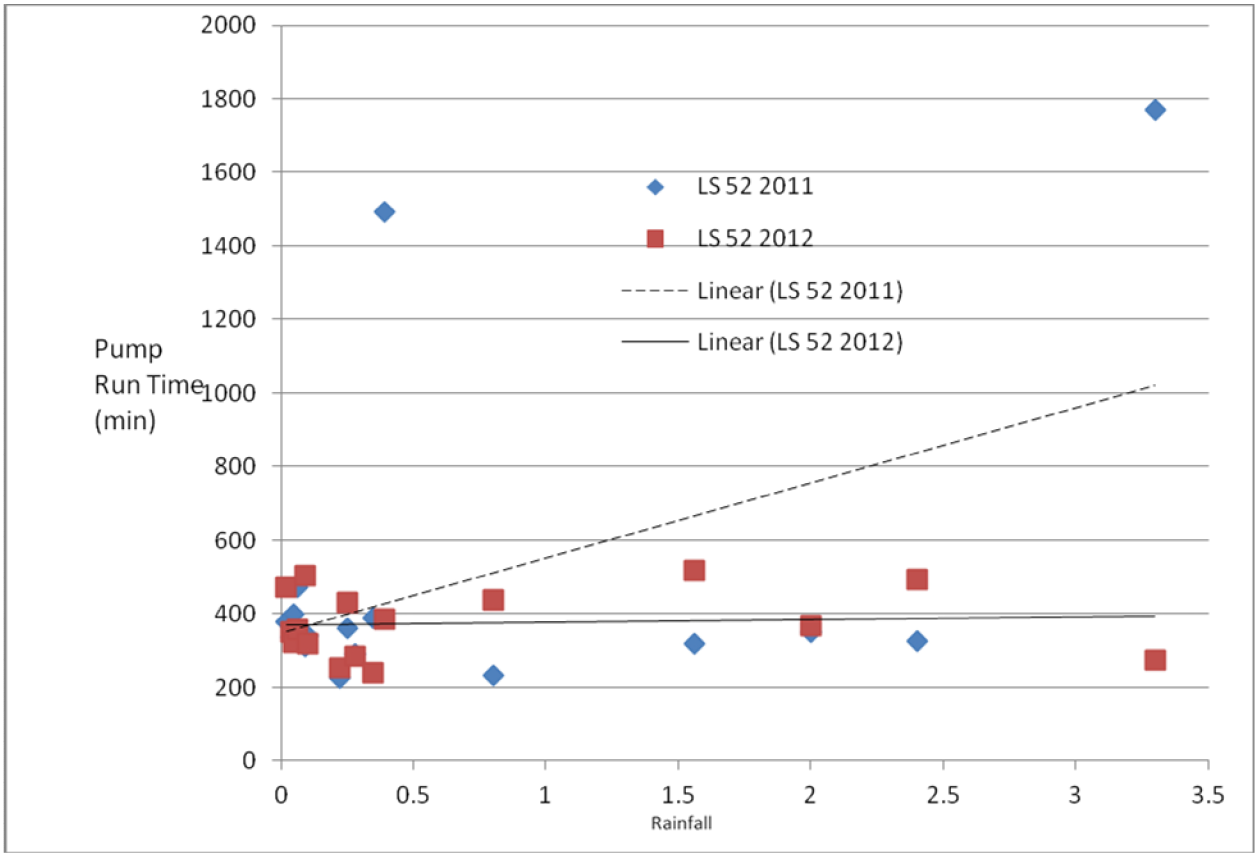

Figure 14. Comparison of rain events (inches) versus pump run times in 2011 and 2012 for Cooper City Lift Station 52. The slope of the lines show that the inflow correction substantially reduced inflow. The 2012 graph shows virtually no effect of rainfall on run times.

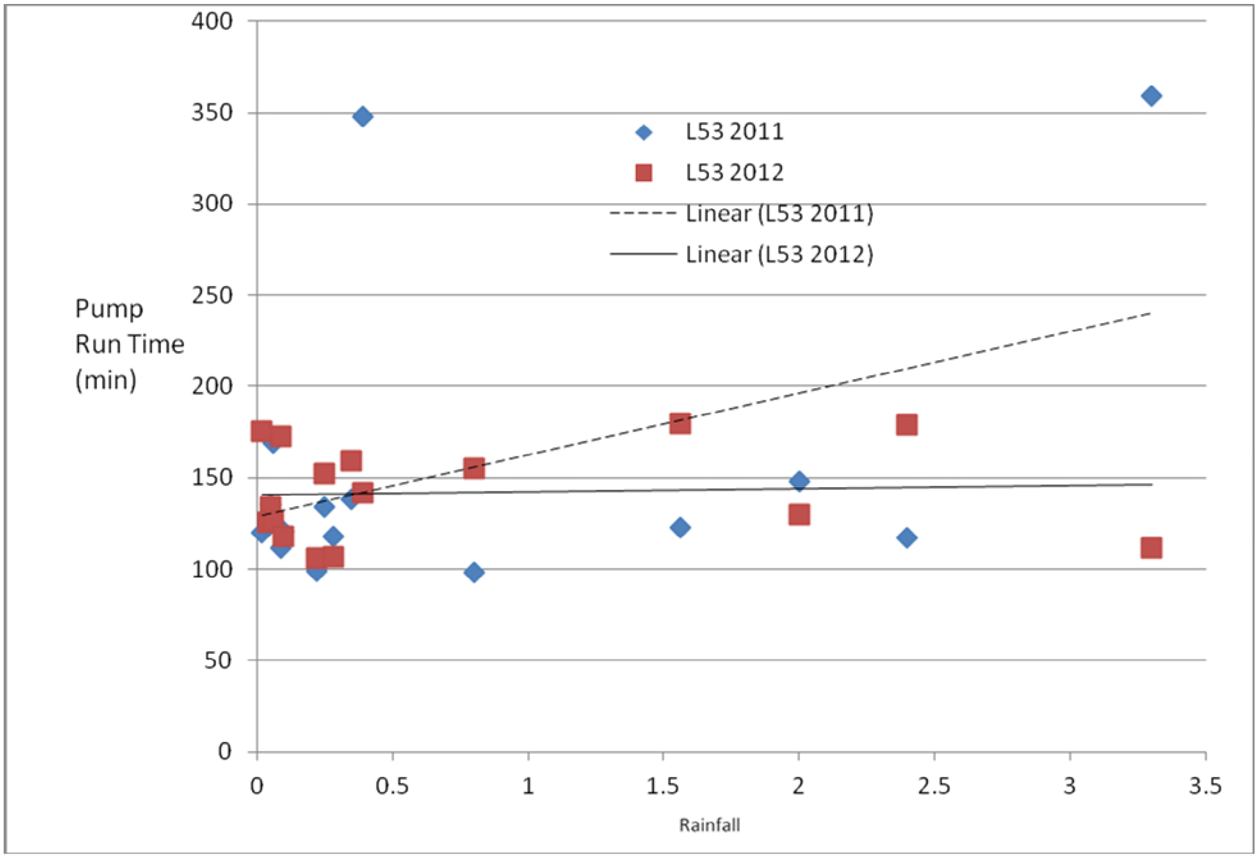

Figure 15. Comparison of rain events (inches) versus pump run times in 2011 and 2012 for Cooper City Lift Station 53. The slope of the lines show that the inflow correction substantially reduced inflow. The 2012 graph shows virtually no effect of rainfall on run times.

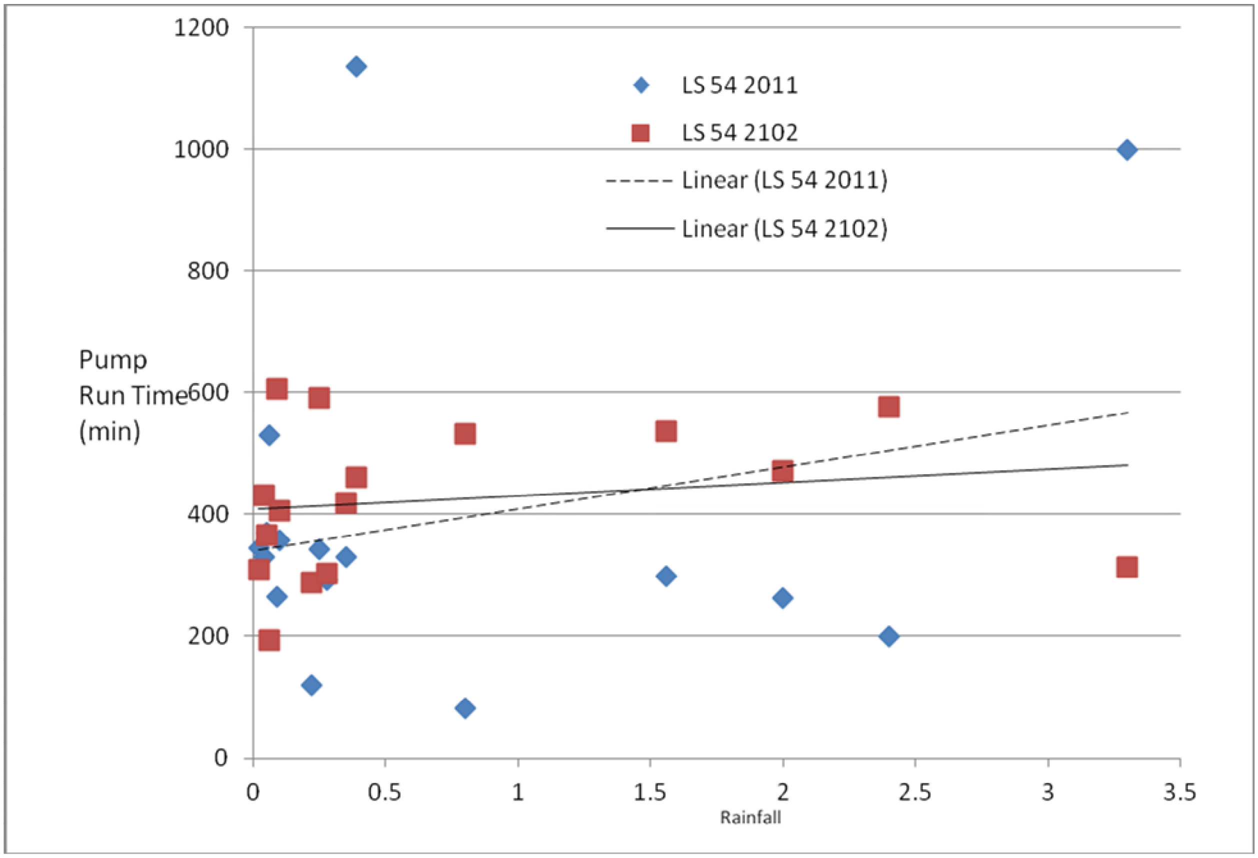

Figure 16. Comparison of rain events (inches) versus pump run times in 2011 and 2012 for Cooper City Lift Station 54. The slope of the lines show that the inflow correction reduced inflow.

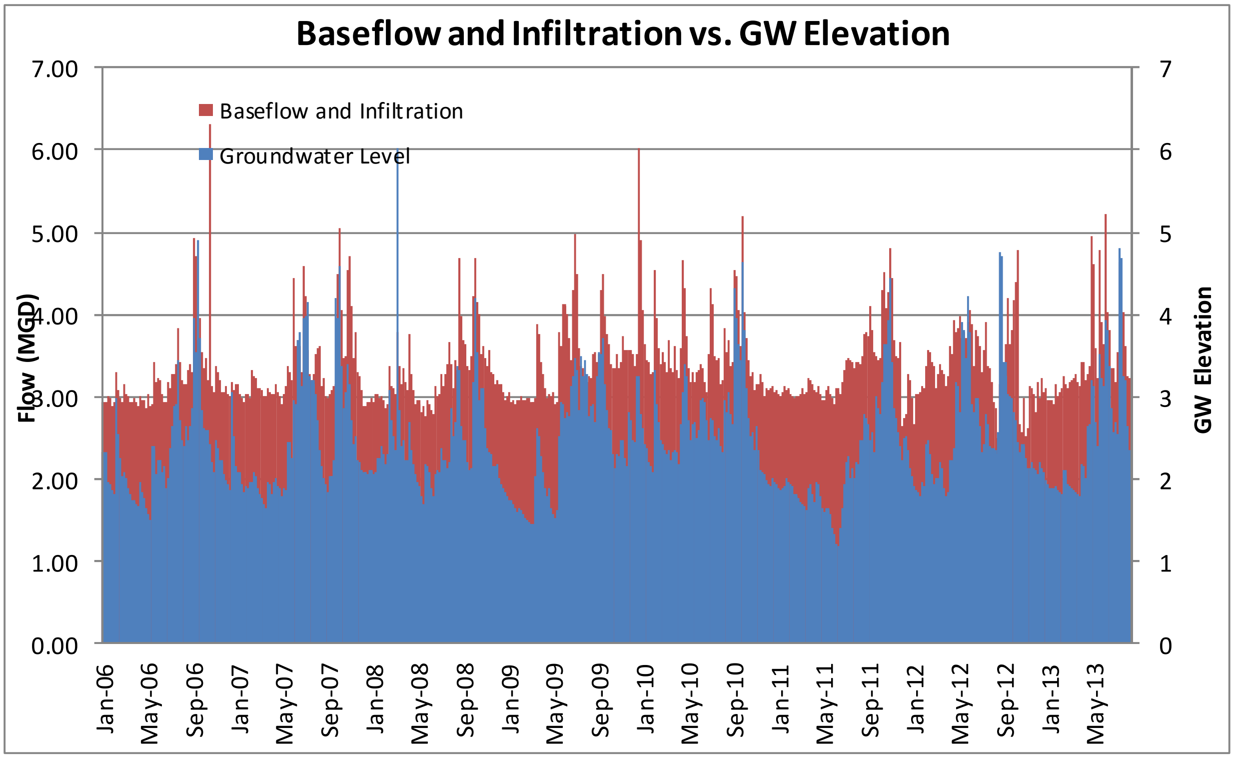

Figure 17 Typical Base+Infiltration flows vs Groundwater elevation

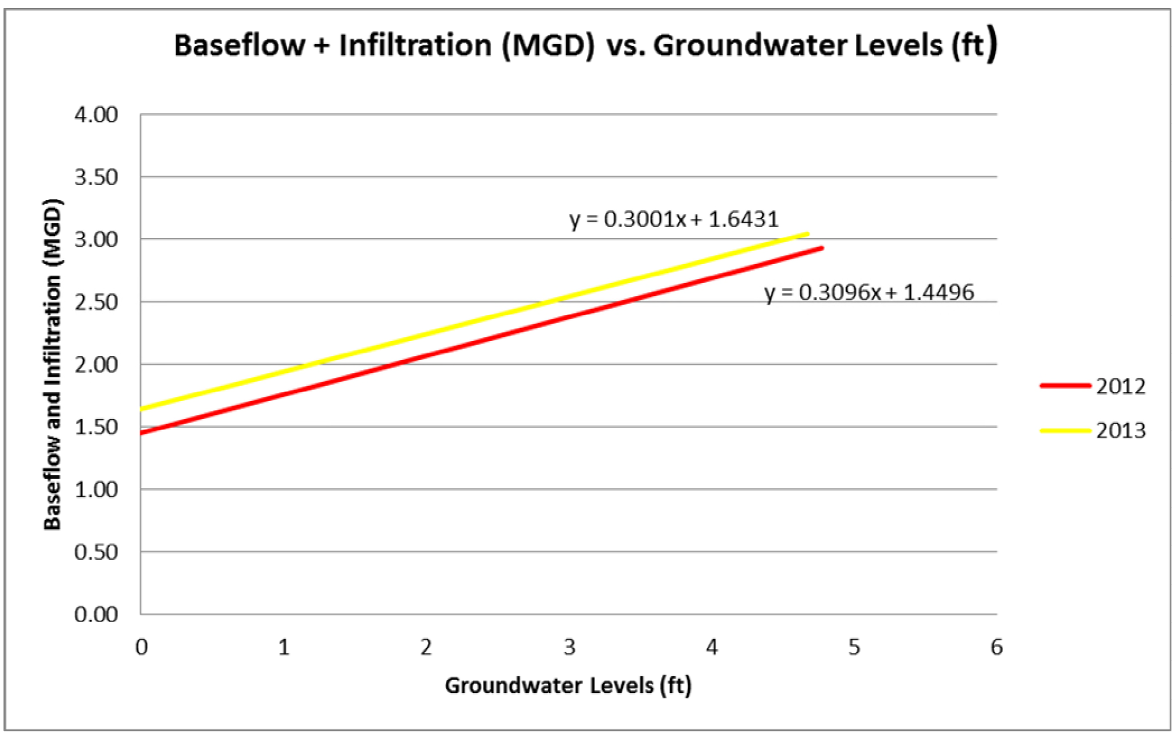

Figure 18 – Note deterioration continues with time

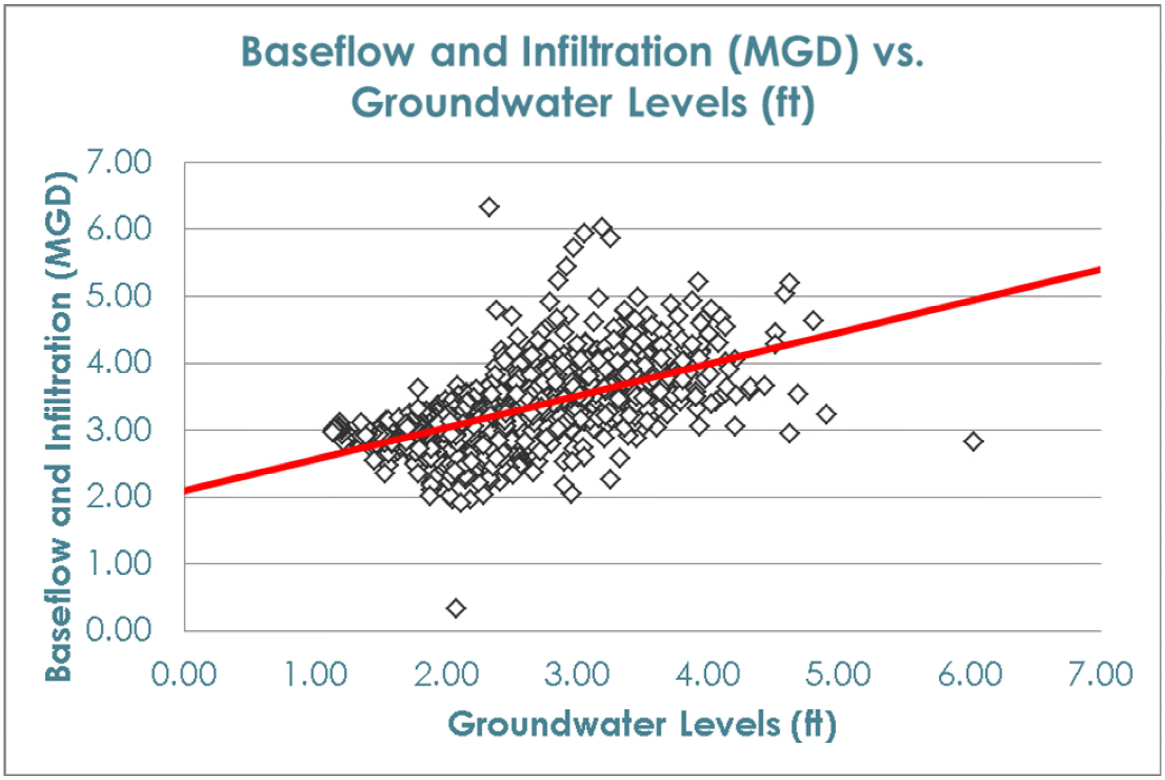

Figure 19 Correlation of Groundwater vs Flow