one, and they began by reviewing the existing hydraulic capacity. It was determined that the WWTPs could hydraulically handle more flow than the transmission system could get to them. The hydraulic capacity of a WWTP is often restricted by the disposal capacity, whether it be injection wells or ocean outfalls. Each of the plants was undergoing some type of improvement to expand the disposal capacity, and although beneficial, these improvements would not be sufficient to handle the 8.76 to 13 m^3/s (200 to 300 MGD) of extra peak flow.

The subcommittee then investigated a few short term ideas that could improve the treatment of peak flows. The first was a polymer addition to the treatment process. Through simulated conditions by routing more flow through one treatment train, it was found that polymer addition increased sedimentation and reduced the effluent suspended solids and biochemical oxygen demand (BOD) concentration. The second improvement involved process changes to increase hydraulic capacity.

The long term solution is more complex however, and will require much more work. The US Army Corps of Engineers and the South Florida Water Management District are currently involved in the Everglades Restudy Project which is a massive effort to return the Everglades to a more natural sheet flow condition. The plan outlines many options including the construction of a West Wastewater Treatment Plant that would discharge to either underground wells or to the Everglades after advanced treatment. This plant would solve some of MDWASD's peak flow problems relieving system pressures in the western portion of the county and providing ample treatment capacity.

The second long term solution is based on wet weather treatment facilities. These could be relatively small structures only activated during peak flow events and could be located at the existing WWTPs or upstream in the collection system. An example of one of these proprietary systems is the Actiflo process. Actiflo is a sand ballasted chemical precipitation treatment system that can treat high amounts of wet weather flows. It has a small footprint per MGD of capacity and can be left dry and unattended until needed, while still being able to start up to near full efficiency in 15 minutes. It is a simple process that uses microsand and chemicals to collect the suspended solids into floc which settles out for later treatment. Although several large companies have performed pilot studies with Actiflo (or similar systems), there is currently no full scale plant in operation in the United States to treat wastewater. Several water plants have been built using this technology, and it has been used many times in Europe and Asia for wastewater treatment.

The USEPA's concern for this type of treatment is that is does not provide secondary treatment as required by the Clean Water Act; however, other types of wet weather treatment facilities have been built around the country (e.g., Houston and Johnson County, Kansas) which have proven very successful in handling peak flow events.

4. System Optimization Pilot Study

The fourth subcommittee formed by the TAC was assigned to perform a System Optimization Pilot Study. The idea behind the concept goes straight to the heart of peak flow management, and clearly has its pluses and minuses. It asks what would happen if the pump station level settings were linked to the ground water level, and as the ground water table rises during a storm event, so would the level settings. This would create a temporary surcharge of the system and prevent additional ground water from entering the collection system, thereby reducing the peak flows. Normally, there is a positive pressure pushing the ground water through cracks into the sewer lines, but if the sewer lines were already full, there would be no additional infiltration.

The plan for the pilot study involves identifying acceptable pump stations, constructing a groundwater monitoring well adjacent to the wet well, connecting the groundwater level sensor to the pump station level controls, and monitoring the flow rate during a storm event. The study is currently in the process of installing the monitoring wells. Due to the controversial concept of surcharging, the Florida Department of Environmental Protection is only allowing the study to be performed on three pump stations and they will be closely monitoring the progress.

It is unclear whether this study will show successful results. Obviously, there will be an upper limit as to how high the system can be surcharged so that domestic wastewater can continue to enter the system. If a large portion of the peak flow does in fact come from the laterals (which are near the surface), then RDI/I will continue to pour into the system, still overwhelming the pumps.

Conclusion

The concept of peak flow management is only beginning to spread across the country. As more regulations are promulgated by the USEPA that enforce the reduction/elimination of SSOs, all wastewater utilities are going to need to see how their system measures up to the requirements.

Considering the case of Miami-Dade, handling peak flow was not an issue six years ago. The only tool that existed to monitor the capacity of the pump stations was weekly pump operating hours. The normal I/I flow data was not always reliable, and no data was available on RDI/I. Pump stations were being designed based on sketchy flow data at best. System pressures were unknown.

Now, tools exist that can record every time a pump starts and stops, what the pressure is, how much night flow a basin has compared to the domestic flow, and even if one pump is running longer than the other and needs maintenance. Breaks in the collection system are identified within days of their occurrence, and it is possible to determine which basins should have only the leaking defects repaired or both leaking and non-leaking. The Model will provide valuable information on what is needed for the future, and the TAC pilot studies will help find the most cost-effective way of doing it.

It is unclear what future lies ahead for the Miami-Dade Water and Sewer Department. After already spending more than $800 million on system improvements, the possibility exists of a need for another $2 billion to meet all of the USEPA peak flow requirements. Even the USEPA has made statements to the effect that previous USEPA I/I removal estimates are unachievable. The water and sewer system is often one of the most forgotten pieces of infrastructure in any city, yet it can be one of the most costly. At least with the new tools and ideas outlined in this paper, the true nature of the peak flow can be seen and strategies can be formulated to address it.

Controlling Inflow and Infiltration
In Wastewater Collection Systems

Mark G. Wade, P.E.[1]

Abstract

Every sanitary sewer system, regardless of its age, size, or location, contributes inflow and infiltration (I/I) to the municipal wastewater collection and treatment facilities. The cause of excessive I/I is due to an aging infrastructure that has not been adequately maintained. This paper presents current methodologies to identify, evaluate, and rehabilitate the municipal wastewater collection system.

Introduction and History

The need to reduce, control, and manage wet-weather induced I/I in wastewater collection systems is becoming an increasing priority to many cities, municipalities and wastewater agencies across the United States. Problems associated with I/I often include one or more of the following:

- Uncontrolled overflows and bypasses
- Basement backups
- Hydraulic impacts to the treatment facilities
- System deterioration

These problems are particularly difficult to address because of the enormity of the infrastructure in place. Currently it is estimated that there are 4.2 billion feet of sanitary sewer in the U.S. This does not include "combined sewers" which serve as both storm and sanitary sewer. If this inventory were laid end-to-end, it would represent 286 parallel pipelines that would stretch from New York City to Los Angeles (or 3 round trips to the moon). For older cities, most pipe inventory pre-dates World War II, and represents materials and methods of construction that are well beyond their reasonable service life.

Since the 1970s, the EPA has required all regulated agencies with NPDES permits to eliminate all wastewater overflows that reach the waters of the United States. Of course, the ability to achieve such a goal is virtually impossible for most

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cities and agencies, since I/I cannot be completely eliminated. The initial efforts to reduce I/I in collection systems were, for the most part, unsuccessful, despite substantial funding through the EPA's Construction Grants Program. During the mid-to-late 1980s, most I/I control programs were reduced to emergency programs that attempted to address problems in isolated sections of the collection system. However, major sanitary sewer evaluation surveys (SSES) in the late 1980s in cities such as Houston, Atlanta, Nashville, and Miami (Dade County) renewed public opinion for the renewal of the sanitary sewer infrastructure. Also, newer and better technologies were improving techniques to eliminate sources of I/I.

Recent studies show that the asset value of this utility is $1.0 trillion, or 16% of the total public works infrastructure. It is an invaluable utility that is deteriorating at a faster pace than it can be fixed. In fact, anticipated rehabilitation needs to upgrade wastewater collection systems in the U.S. now exceed $34[2] billion. Some estimates have pegged this value as high as $80 billion. Currently, annual spending for sanitary sewer improvements (not including new or expanded systems) is $1.0 billion. Why are we in this jam? Herwig[3] stated it better than most:

- Infrastructure deterioration has been gradual
- Structural problems develop slowly
- Equipment wears out gradually
- Utility customers have become accustomed to the low costs associated with new systems
- We have forgotten the notions of design life and replacement costs
- Collection systems have difficulty competing with other community infrastructure for citizens' dollars.

The dilemma of the sanitary sewer has always been the same...undersized, underestimated, and underground!

Assessing the Problem

The reduction and control of I/I in wastewater collection systems must be considered in the context of a disciplined, long-term program. Assessing the problem should always be the first step. For I/I assessment, the most common practice is a sanitary sewer evaluation survey (SSES). The purpose of an SSES is three-fold:

1) Quantify the I/I problem
2) Identify the I/I sources
3) Evaluate the cost-effective correction plan

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[2] National Council on Public Works Improvement, "Fragile Foundations: A Report on America's Public Works", February 1988

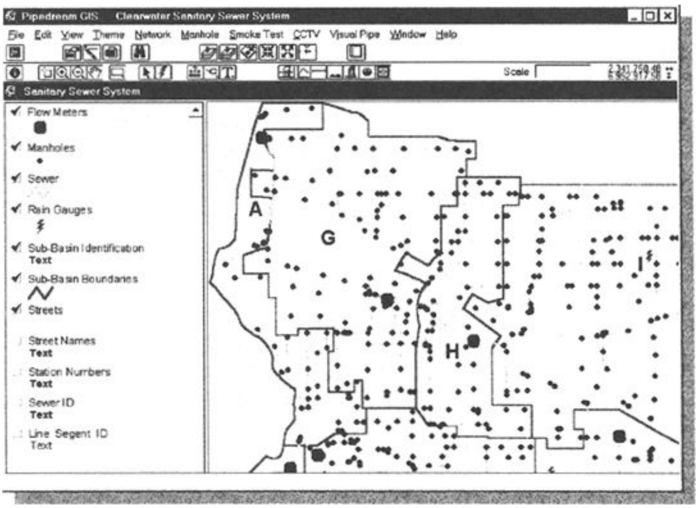
[3] Herwig, Roy, "Collection System Overflows Not a Wet Weather Issue", Water Environment & Technology, December 1999

We will present a brief discussion of each step before moving onto actual rehabilitation methods.

1. Quantify the I/I Problem

It is often said of I/I in collection systems that "…you can't management what you can't measure". Quantifying an I/I problem often begins by assessing (or measuring) the extent of the problem. This means a serious attempt to locate and record information that relates to a variety of problems including observed overflows, measured or observed surcharges, reported bypasses, customer backup complaints, and chronic maintenance activities. This information can (and should) be gathered from a variety of places including maintenance records, work orders, past studies and engineering reports, sewer maps, complaint records, various department files, and interviews with personnel who are responsible for maintenance and management. It is amazing, if not remarkable, to see how much information can be gathered if one is willing to "dig a little". Once this has been done, the data should be recorded and displayed in a manner that will provide possible correlation between overflows and bypasses and other factors such as capacity models, rainfall records, maintenance activities, and reported backups. If electronic maps of the collection system are available, GIS is an extremely useful tool to evaluate these results. The next step in quantifying the problem is to monitor wastewater flows at various key points in the system. Normally, the collection system can be separated into watersheds. Watersheds can be further separated into basins. Depending on the size the system, basins should be further separated into sub-basins. An example of this is shown in Figure A.

Figure A
Example Sewer System Layout.

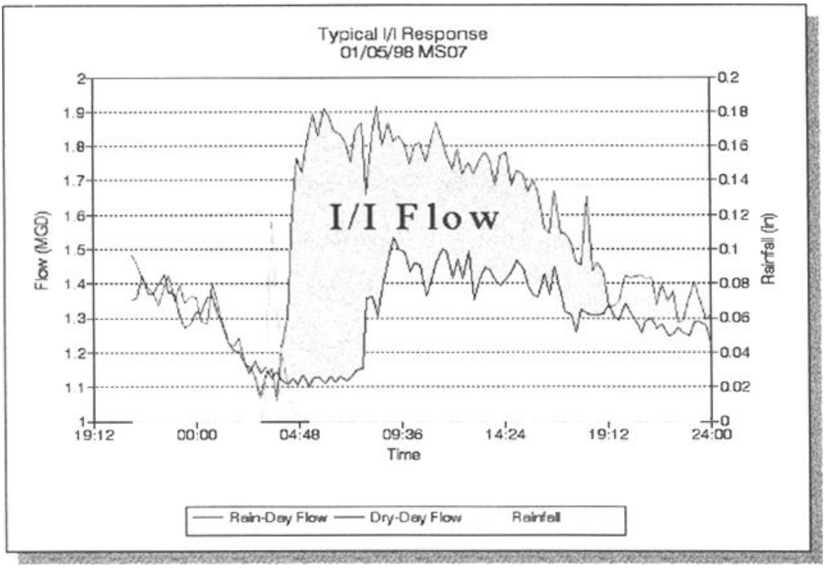


The placement of the appropriate flow monitoring equipment is a critical step and one that needs to reflect the type of data desired. In order to measure wastewater flows and their response to rainfall, it's important to select a flow meter that will record both depth and velocity of flow. There are a number of models available. They can either be purchased or leased. The following "rules-of-thumb" can be followed in order to measure and evaluate the amount of I/I in a collection system. Of course, these parameters can vary depending on the overall program goals.

- One meter for every 30,000 – 50,000 feet of sanitary sewer
- Flow meter recording set at 15-minute intervals
- Flow meter capable of measuring surcharge and flow reversal
- One rain gauge for every 2-4 flow meters
- Minimum monitoring period – 42 days (60 days, optimal)
- Measurement of 6-8 separate rainfall events
- Monitoring period during high seasonal groundwater

The resulting data needs to be carefully evaluated. This includes adjustment of the data to account for periodic velocity profiling at the monitoring site, anomalies associated with grease and deposition, drift of recorded depth or velocity, and downtimes associated with meter malfunction. Examples of a typical diurnal flow cycle and a flow cycle influenced by a storm event is shown in Figure B.

Figure B
Example I/I Response Hydrograph



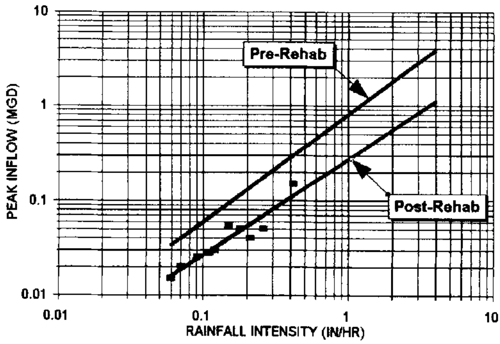
Once it's reasonably certain that the data is accurate, then results can be evaluated for several flow parameters including average dry-day flow, maximum and minimum diurnal flow, inflow, rainfall-induced infiltration, seasonal infiltration, etc. An example flow data summary sheet for several monitoring sites is shown in Table 1. Note that flows are shown in rates and should be expressed in mgd or gpm; depending on the flow regimes that are recorded.

Table 1
Example Results of I/I Quantification

Basin	Avg. Dry-Day Flow Rate (mgd)	Average Infiltration (mgd)	Peak Infiltration (mgd)	Peak Inflow (mgd)	Peak Flow Rate (mgd)	Ratio Peak/Avg
1	0.08	0.06	0.14	0.25	0.47	5.9
2	0.19	0.17	0.39	1.81	2.39	12.6
3	0.18	0.03	0.11	2.67	2.96	16.4
4	0.13	0.10	0.48	1.32	1.93	14.8
9	0.32	0.08	0.59	3.66	4.57	14.3
12	0.80	0.16	0.72	5.56	7.08	8.8
16	0.43	0.09	0.22	5.68	6.33	14.7
17	0.17	0.05	0.40	2.25	2.82	16.6

Once the data has been tabulated, a linear regression analysis can be used to make comparisons between the measured I/I and the corresponding rainfall intensity. This regression analysis will provide two key parameters that will be used in quantifying the I/I problem. First, a regression analysis allows us to make comparisons between each basin in order to identify the top priority basins for further study and possible I/I reduction. Secondly, the analysis will provide useful design information if subsequent relief or replacement sewers are required to reduce or eliminate an overflow or bypass. Results of a typical linear regression analysis for inflow is shown in Figure C. Note that each data point represents measured inflow for a single rainfall event. A crucial step in the regression analysis is to try and avoid using data under surcharge conditions.

Figure C
Example Linear Regression Analysis



The basins can then be ranked in a variety of ways. These could include unit inflow or infiltration rates such as gallons/day/foot, mgd/1,000', gpd/inch-mile of pipe, mgd/acre, etc. By reducing the raw flow data into a measured unit rate, comparisons can be made between basins as well as comparisons with regard to other factors such as general age of the system, frequency of reported overflows, etc. Such a ranking is shown in the following example table.

Table 2
Selection Criteria for SSES

Basin	Basin Footage (ft)	General System Age	Observed SSO/ Bypass	Chronic O&M	Capacity Limitations (wet-weather)	Unit I/I Rate (gpd/lf)	SSES Option
A-1	239,000	Moderate	Yes	Yes	Yes	61	**Yes**
A-2	347,000	Moderate	No	No	Yes	21	No
A-3	6,000	Newer	No	No	No	15	No
B-1	53,000	Older	Yes	Yes	Yes	75	**Yes**
B-2	32,000	Older	No	Yes	No	22	No
C-1	180,000	Older	No	No	No	32	No
C-2	296,000	Moderate	Yes	Yes	Yes	68	**Yes**
C-3	38,000	Moderate	No	No	Yes	57	**Yes**
C-4	439,000	Moderate	Yes	Yes	Yes	82	**Yes**
D-1	130,000	Older	Yes	Yes	Yes	104	**Yes**
D-2	112,000	Moderate	Yes	No	Yes	60	**Yes**
D-3	375,000	Newer	Yes	No	No	19	No

2. *Identify the I/I Sources*

Once the basins or sub-basins have been selected as priority areas for I/I reduction, the next step is to implement a plan to locate and analyze the various sources of I/I in the collection system. This is commonly referred to as a sanitary sewer evaluation survey (SSES) and represents a wide range of field inspections and testing procedures. For most collection systems, I/I is contributed from various defects in the pipelines and manhole structures. I/I can also enter into the system from directly or indirectly connected storm sewers. This area is often referred to as the "public-sector" or that part of the collection system that is owned and maintained by a particular city, utility, or public agency.

a. *Manhole Inspections*

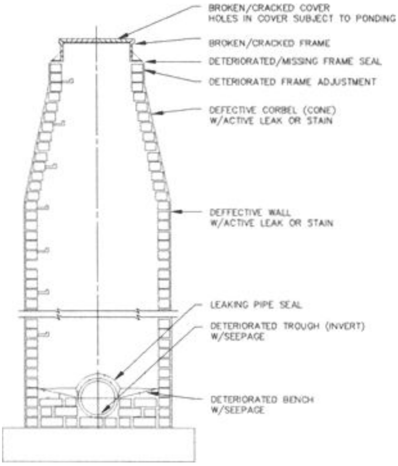
Many communities that have implemented a successful I/I reduction program report that as much as 50% of measured I/I can originate from deteriorated and leaking manhole structures[4]. With more than 18 million manholes in the United States and an estimated renewal cost estimate of $8.5 billion, this makes manhole

[4] "Manhole Inspection and Rehabilitation", ASCE Manuals and Reports on Engineering Practice No. 92, 1997

renewal a growing focal point of the collection system. Prior to the 1960s, most manhole structures were constructed of brick and mortar. Since then, the common materials of construction have been segmented precast concrete with gasketed joints.

Therefore, a proper manhole inspection should include an inspection of every component of each manhole structure. These components and possible causes of I/I intrusion are shown in Figure D. Proper safety procedures, following OSHA regulations for confined-space entry, must be followed. During the inspection, a quick check of the pipe conditions entering and exiting the manholes can be achieved by simply lamping these pipes. A standard inspection format should be followed, supplemented with photographs or video recordings, if there are particular defects or rehabilitation requirements that merit further analysis.

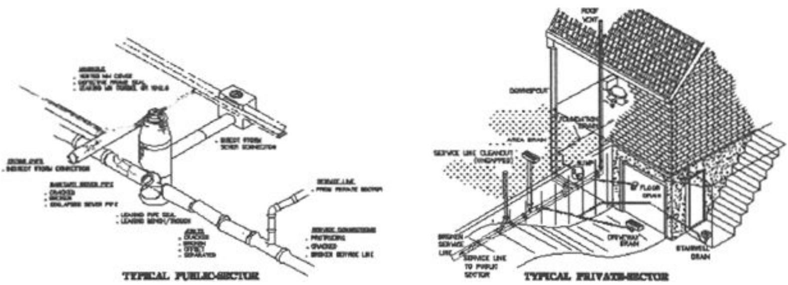
Figure D
Typical Manhole Components



b. Smoke Testing

Smoke testing is, perhaps, the most effective and economical method of locating major sources of I/I such as storm drainage connections, curb inlets, and area drains. Typical I/I connections are shown in Figure E. When implementing a smoke testing program, the following procedures should be considered:

Figure E
Example I/I Sources



- Use high-capacity smoke blowers (>3,500 cfm)
- Isolate individual sewer lines, if possible
- Develop and follow through on a well planned public relations program
- Test only during periods of dry weather
- Target daily production rates of 5,000 – 7,000 feet
- Carefully document all identified defects (photographs or video recording)

Smoke testing will not only identify sources of I/I, but it is an effective technique for locating structural defects such as collapsed, broken or cracked pipe and offsetting, separated, or deteriorated pipe joints. Cities should conduct a once-through smoke testing program every 10 years.

In addition to I/I sources on the "public" side, smoke testing will also locate I/I connections in the "private-sector". This includes all possible ways that rainfall runoff and ground water can enter into the municipal sewer system from private property. Most connections violate current local plumbing codes. However, for older properties, the connections were likely permissible and allowable. Examples of typical private-sector I/I sources are also shown in Figure E.

c. Cleaning and CCTV Inspections

Most cities own and maintain equipment to properly clean their collection system and remove deposition, debris, grease, and other impediments in the flow line. Effective equipment such as high-pressure jetters and jetter/vactor systems have replaced older style mechanical cleaning systems such as rodders, buckets, kites, corkscrews, augers, porcupines, spring blade cutter chucks, and various pick-up tools. However, these same cities limit their use to emergency and non-scheduled responses. By adding a remote CCTV inspection unit and moving to a preventative maintenance platform, many cities would be better equipped to tackle rehabilitation on a more pro-active basis. In addition to data collected from the initial database, and supplemented with the information from the diagnosis program, internal pipe inspections using advanced cleaning and CCTV inspection equipment can confirm and pin-point specific problem areas within the collection system in a very effective manner. As an alternative to purchasing the equipment, smaller communities might consider securing the services of an outside specialty contractor to perform the work, or share equipment with other cities.

d. Dyed-Water Testing (flooding)

During the CCTV inspection, it is not uncommon to miss a potential I/I connection or substantial leak that may have been discovered during smoke testing. Therefore, concurrent dyed-water testing is mandatory in order to observe an active leak. Normally, the adjacent storm sewer, drainage ditch, or creek crossing is flooded while the TV inspection is underway. Using a color TV unit (mandatory), an active leak or I/I connection can be confirmed and quantified.