Unaccounted-For Water Puzzle: More Than Just Leakage

Paul V. Johnson

Most people consider unaccounted-for water and leakage to be the same thing. They are not. Leakage is a part, and sometimes a large part, of unaccounted-for water, but it is just one piece of the puzzle.

Unaccounted-for water is the difference between the amount of water produced, or purchased, and the amount of water sold to all customers. Unaccounted-for water includes underground leakage; unauthorized use; unavoidable leakage, inaccurate master, industrial, commercial and domestic meters; and unusual causes.

To properly determine an unaccounted-for water percentage for a municipality, a running total of water billed versus water pumped needs to be prepared. A one-month balance is not effective because billing cycles often don't occur simultaneously. A twelve-month running total not only balances out any problems with different billing cycles, it also allows you to track trends to see if the unaccounted-for rate is changing.

Puzzle Piece #1—Underground Leakage

The first piece of the unaccounted-for puzzle is underground leakage. Among the causes of underground leakage are age of the pipe, soil conditions, frost upheaval, traffic loadings, pipe movement, poor installation practices, and electrolysis.

The two major problems for controlling leakage are listening surveys and water audits. Each program has its own benefits and drawbacks.

Listening Surveys

A listening survey is conducted by listening for leaks. When a pipe is leaking water, the water passing through the pipe sets up a vibration in the pipe. The noise that the pipe makes is what is traced during a listening survey, not the noise of the water itself. Sound intensifying instrument, either electronic or mechanical, are used to locate leaks in a listening survey. It can be difficult to locate leaks in PVC pipe because it doesn't have the mass to vibrate that cast iron or ductile pipe has.

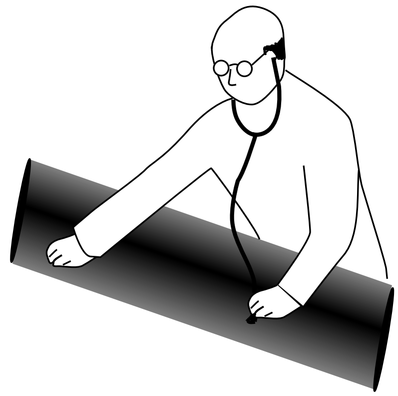
During a listening survey, different parts of the system are checked for indications of leakage. Fire hydrants, valves, services, and other connections are checked for leak noises. Also, the ground above water mains needs to be checked.

Different types of instruments are used during a listening survey. Geophones are a mechanical instrument with one very real advantage—no batteries to run down. Electronic leak detectors have the advantage of having filters to help filter out extraneous noises and meters to show the strength of the noise being investigated.

A leak correlator is a third type of instrument used in listening surveys. A leak correlator works by using two microphones to pick up and transmit sound to the correlator unit. The correlator unit analyzes the sound and determines the location of the leak. A leak correlator is expensive, and no instrument will find all leaks.

All sound intensifying instruments are only as good as the person using them. Leak detection is an art, not a science.

There are problems with listening surveys. Certain conditions can give false leak indications. Valves have more mass to vibrate and can sound like a leak. If a hole is backfilled with a material different from what was originally in place, the new material may conduct sound better and give a false leak indication. You can also have silent leaks caused by abandoned services, waterbound leaks, river crossings, railroad crossings, pipes passing through sewers or sewer manholes, and leaks masked by noise around airports or highways.



A listening survey normally is a fast and fairly inexpensive method of locating leakage, but if unaccounted-for water is caused by something other than leakage, a listening survey will not locate it.

Water Audits

A more comprehensive type of leakage program is a water audit. It accounts for all of the water from where it enters the distribution system to where it is used. It begins with testing the master meters and goes on to break the system up into districts for measurements, which give you a 24-hour picture of the flow into each district. That, in turn, allows you to determine the potential for leakage in each district. You can then concentrate leakage detection in the areas where the best likelihood of finding leakage exists.

Districts are set up by using natural boundaries or valve operations to isolate areas. When measurements are made of the flows in and out of the district over a 24-hour period, the following data can be determined for each district:

- Total consumption—water used during the 24-hours
- Maximum rate—highest rate during 24-hours
- Minimum rate—lowest rate during 24-hours
- Ratio: MNR to TC—helps determine likelihood of leakage
- Minimum night rate per mile of main—amount of leakage likely in a district.

A MNR to TC ratio higher than 40% usually indicated a district with a good potential for leakage, assuming there area no large consumers using water late at night. The minimum night rate per mile of main gives you an idea of the amount of leakage that might be present. A minimum night rate per mile of main of 5,000 gpd means that you will probably not find much in the way of leakage, while 25,000 gpd or higher could represent substantial leakage.

Once the district measurements have been completed and the areas picked for further investigation, subdivision is started. Subdivision is a block-by-block measurement of the district to locate leakage indications. If the subdivision is done at night, usage is not expected to be high and anytime a high rate is measured, that area is then checked for leakage the same way that it is done in a listening survey.

The benefits of a water audit are:

- Training of personnel in a water audit
- Check condition of valves
- Check condition of valve boxes
- Check condition of hydrants
- Update maps and records

There are benefits to any type of leakage program. For a distribution system using 2.0 mgd with a 20% (400,000 gpd) unaccounted-for rate, if half of the unaccounted-for can be recovered through a leak survey, that means:

A. Water for 3,000 new residents @65 gpd
B. An additional 1,000 gpm for 3 hours of fire fighting
C. Savings on production costs if nothing additionally is done
D. Delay or reduction in size of new facilities

Puzzle Piece #2—Inaccurate Master Meters

It should be obvious that accurate master meters are needed to determine your unaccounted-for water. Some of the things that can cause inaccurate master meters are:

- Wear—due to quality or quantity of water
- Improper installation—turbulence
- Improper gearing in register head
- Wrong register
- Reading errors
- Entrained air in the water
- Jetting action at the meter

Master meters can be tested either by using a comparative meter tester or an in-line rodmeter. A comparative test meter, if properly sized, can be very accurate, but the test meter should be tested volumetrically before or after each test. A rodmeter used in-line with the master meter allows the meter to be tested at the regular flow rates and does not require shutting the meter down for testing.

Puzzle Piece #3—Inaccurate Industrial Meters

Industrial meters and master meters have the same problems with inaccuracies. In addition, industrial meters can have an additional source of error if they are compound meters operating in the changeover range of the meter. Meter sizing is important for industrial meters.

Puzzle Piece #4—Inaccurate Commercial Meters

Commercial meters are subject to the same problems that industrial meters face. Commercial meters can be more difficult to properly size than industrial meters because they may be using over a shorter period of time which gives a wider range between peak and low flows through the meter.

Puzzle Piece #5—Inaccurate Domestic Meters

Domestic meters have fewer problems than are found with larger meters, but the problems can be serious. Domestic meters are subject to wear due to water quantity and quality, improper gearing or wrong registers and reading or billing errors. Domestic meters are also subject to poor readings at low flows and a significant amount of the water passing through a domestic meter can be at low flows. As much as 2% of a system's unaccounted-for water can be due to under-registration of low flows on domestic meters.

Puzzle Piece #6—Unauthorized Use

Unauthorized use is an area often overlooked in trying to reduce unaccounted-for water. Unauthorized use can consist of: Unmetered use by contractors; unauthorized or unmetered connections; and theft by bypassing meters.

Unauthorized use, especially in older systems, can be one of the most difficult areas to eliminate in trying to reduce unaccounted-for water.

Puzzle Piece #7—Use From Hydrants

The major uses from hydrants include flushing streets and sewers and fire fighting. In some areas, landscaping firms use water from hydrants for watering new landscaping. Filling swimming pools is another area where fire hydrants may be used and contribute to unaccounted-for water. Any reasonable estimates made of these uses can help reduce your unaccounted-for water.

Puzzle Piece #8—Unavoidable Leakage

Unavoidable leakage is underground leakage that costs more to locate and repair than it would to permit it to exist. This definition means that unavoidable leakage can be different rates in different locations. Present AWWA standards are 3,000 gpd per mile of main. This is mainly due to small joint and service leaks that are very difficult to locate at these low rates of flow.

Puzzle Piece #9—Unusual Causes

This final piece of the puzzle is the "catch all" for the things that don't fit any of the other puzzle pieces. Included in this piece of the puzzle is: recirculating water—water pumped into a pressure zone with an open valve which allows the water to recirculate without being consumed; not accounting for treatment plant use; estimated pumpage due to inaccurate or nonexistent meters; leakage in reservoirs, ground storage tanks or elevated storage tanks; and unintentional inter-system connections—water passing through unrecorded or emergency connections to other distribution systems.

Summary

Unaccounted-for water is born from poor maintenance and can die from effective maintenance. In order to put RIP to unaccounted-for water, you need to:

R– Review what the accounted-for water is in your system
I– Identify areas of unaccounted-for water
P– Purge the system to remove as much unaccounted-for as possible and reach acceptable limits.

Paul V. Johnson, P.E. is with The Pitometer Associates, Orlando.

Effects of Electrical Grounding on Pipe Integrity and Shock Hazard—A National Survey

Steven J. Duranceau, Graham E.C. Bell, and M.J. Schiff

The practice of using metallic water piping as part of the grounding system of a building has been common place for more than 80 years [1]. When grounding to the water pipes was first implemented, the water industry was persuaded by the electric utility industry to believe that grounding effects were small and out-weighed by concerns for the safety of mutual customers. Over the years, electrification of society has increased and the validity of the original assumptions used to persuade the water industry are today questionable. Since 1927 policy statements issued by AWWA opposed to the practice have been periodically issued [2].

The objectives of this research were to investigate on a nationwide scale the effects of grounding electrical systems to water systems in terms of shock hazards to utility employees and reduced service live of the pipe due to possible external corrosion caused by the current flow. Information on the effects on water quality was gathered from the literature and the participating utilities.

Table 1. Alphabetical Listing of Participating Utilities

Blacksburg-Christianburg-VPI Water Authority, VA
City of Altamonte Springs, FL
City of Cape Coral, FL
City of St. Louis, MO
Dallas Water Utilities, TX
Denver Water Department, CO
Detroit Water and Sewerage Department, MI
East Bay Municipal Utility District, CA
Indianapolis Water Company, IN
Irvine Ranch Water District, CA
City of Kansas City, MO
L.A. Department of Water and Power, CA
Louisville Water Company, KY
Marin Municipal Water District, CA
Omaha Metropolitan Utilities District, NE
Onondaga County Water Authority, NY
Orange County Public Utilities Division, FL
Pinellas County Water System, FL
Tualatin Valley Water District, OR

Shock Hazard and Grounding

As explained by Warren [3] and Waters [4], alternating currents are exchanged along water services and distribution piping when houses and buildings share electrical transformers. If a house or building is served by its own electrical transformer, then currents are not exchanged via the water system. In most populated areas, between 4 and 20 buildings are served by the same transformer. Meter readers and field crews routinely interact with water meters and service piping and receive electrical shocks ranging from slight tingling sensations to permanent and temporary numbness in limbs. The most serious problems occur when the neutral path to a consumer shared-power transformer is high resistance ("open") and work is performed on the water meter or service. In this situation, all of the current from the building is returning through the water system and this is when the potential for the greatest danger exists.

Statistics have been presented on the rates of occurrence and fatal accident factors for consumer electrical shock incidents in Israel from 1960 to 1969 [5]. Electrical accidents involving taps and water pipes had the highest rate of occurrence (24.3% of all accidents) and the third highest rate of mortality (1.4%). "Faulty earthing" (i.e. grounding) ranked No. 1 among the seven factors considered and was present in 58% of the fatal accidents in Israel for the nine-year period. Conditions and codes in Israel may be different as compared to the United States, but the statistics are quite sobering.

Project Approach

In order to assess the magnitude of the problem nationwide, the research program included participation by twenty utilities geographically dispersed throughout the U.S. A list of the participating utilities is given in Table 1. The participating utilities include large and small water systems with a range of climatic conditions, urban and rural situations, and provided a broad basis for comparison and data.

The project includes an information gathering phase, in addition to field and laboratory testing conducted at nineteen of the twenty participating utilities. The information gathering phase included a review of the open literature and collection and compilation of the utility internal information. The utility internal information was collected as part of a mail in survey of questions which addressed problems associated with shock and corrosion related failures due to grounding and during the on-site field testing phase.

Utility Survey

A utility survey was developed and distributed to the 20 participating utilities. Selected results of the survey related to shock incidents and corrosion are presented in Figure 1 and Figure 2. The results of the utility survey indicated that most shock incidents occur during meter removal and work on service piping. This is because the worker is in close electrical contact with both sides of the meter piping and is standing in a puddle of water, which served to lower the resistance to ground of his body.

Many of the survey questions dealt with the shock incidents and shock prevention protocols. Other questions were designed to address the incidence of shock on all types of utility piping (transmission, distribution and service) including identifying incidents where meters were involved. More than 86% of the utilities have had some shock incident. Eighty-two of the 86% of all shock incidents occur during meter removal. Despite this high level of shock incidents, only 68% have some sort of protocol or procedure for prevention of shock. These results indicate that there is a significant incident rate of shock incidents in the water utility industry due to grounding.

Additional survey questions asked about the occurrence of distribution main failures due to grounding or unknown stray currents. Approximately 55% of the participating utilities surveyed suspected grounding or stray current as the reasons for some of their failures in the previous five years. The results indicated that although some utilities are certain that grounding causes pipe failures, a significant portion of the water utility industry is unsure of any relation which grounding might have with premature failures of distribution piping.

Summary and Conclusions

The amount of current which flows through the utility worker is dependent on his/her resistance to earth relative to that of the piping system (grounding electrode). The resistance to ground of a grounding electrode is a function of the soil resistivity and the size and shape of the conductive material which is in contact with the soil. Low resistivity soils and large surface areas of bare metal produce low resistance grounding electrodes. However, with the increased use of non-metallic (dielectric) piping underground for distributions systems and the use of well coated or wrapped metallic piping, the water piping may no longer serve suitably low resistance grounding electrode. Therefore, the threat to utility workers is increased so long as water piping is used as grounding electrode over which current can flow. The best solution is prevent and prohibit currents from flowing on water pipe. Other results indicate that:

1) Alternating and direct currents are present in water service and distribution piping due to shared transformers in electrical distribution systems.
2) Vitual DC is present due to speed controlled electronics and appliances.
3) Alternating current causes corrosion albeit at much lower rate as compared to direct current. The rate is material dependent. For iron, copper and lead, alternating current corrodes at about 1% of the rate of a similar amount of direct current.
4) Utility employees are exposed to a variety of shock hazards ranging from slight tingling to temporary and permanent impairment of limbs. The worst incidents occur when neutral connections to power transformers are "open" or disconnected.
5) More than half of the participating utilities feel that some of their corrosion failures on service and distribution piping are due to grounding currents.

Acknowledgments

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Steven J. Duranceau, Ph.D., P.E. is with Boyle Engineering Corporation in Orlando. Graham E.C. Bell, Ph.D., P.E. and M.J. Schiff, P.E. are with M.J. Schiff & Associates, Inc. of Claremont, CA.

Figure 1. Participating Utilities Reporting Shock Incidents Related to Removing Water Meters in the Past Five Years.

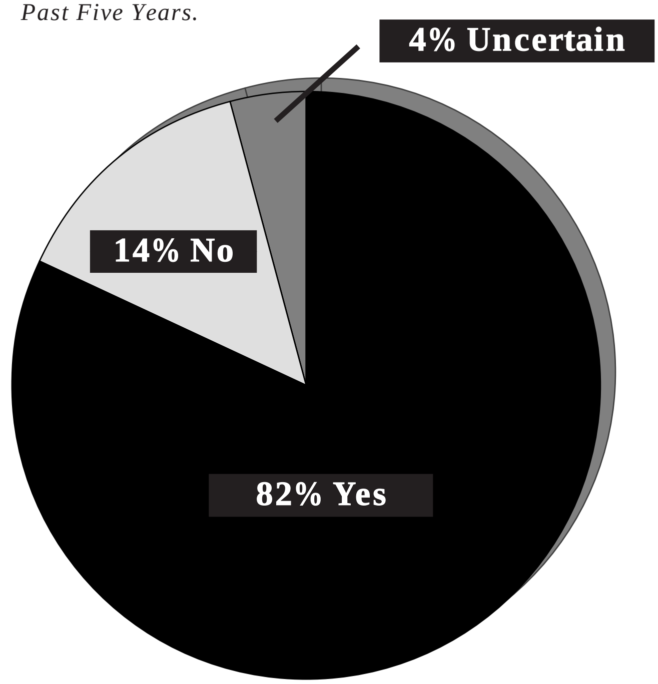
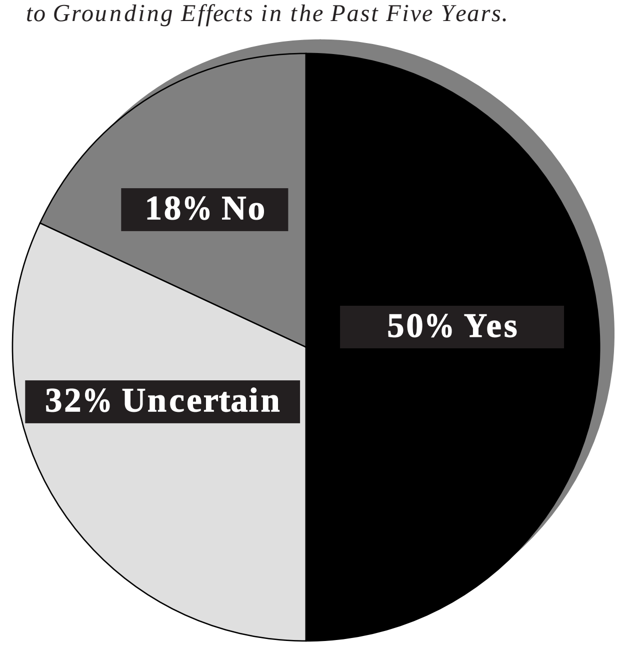


Figure 2. Participating Utilities Reporting Corrosion Failures of Distribution and Service Piping Due to Grounding Effects in the Past Five Years.



Sewer System Renovation in South Florida—Improved Techniques for Coastal Cities

James T. Cowgill, Fred Bloetsher, and J. Peter Larsen

The Broward County municipalities contributing to the 42 MGD Hollywood Southern Regional Wastewater Treatment Plant—Hollywood, Pembroke Pines, Miramar, Hallandale, Dania, Pembroke Park, and areas of unincorporated Broward County—have concluded a major collection system renovation program to eliminate excessive infiltration/inflow (I/I).

Wastewater generated by each city (large user) is collected in gravity sewers and transported to the regional wastewater treatment plant through a series of pump stations and force mains. The service area, with a 1990 census population of 288,600, has 536 miles of gravity sewers and 11,455 manholes. It is estimated that 82 percent of the total population (236,000) is currently connected to a sanitary sewer collection system.

Large volumes of groundwater enter the gravity sewers, increasing costs of collection and treatment while wasting a portion of the hydraulic capacity of existing facilities. The infiltration/inflow is caused by a combination of factors: high water table, excessive rainfall, type of pipe material and joints, poor bedding conditions in older portions of the system, and porous soil conditions.

Increased I/I flows resulted in the total plant flow exceeding its design rating, which led local and state regulatory agencies to notify the city of Hollywood, the lead agency, to increase the plant capacity and reduce the infiltration/inflow. Additionally, EPA issued an Administrative Order requiring that an I/I flow reduction program be undertaken within a stipulated time frame. The program was initiated in July 1991 by following the three traditional steps in implementing an I/I reduction program: infiltration/inflow analysis, sewer system evaluation survey (SSES), and rehabilitation program.

I/I Analysis Results

In accordance with the EPA mandate, the city of Hollywood and the large users undertook an I/I study for the entire regional collection system. The first major task of the study was to measure wastewater flows in each drainage area during dry and wet weather conditions, to quantify the extraneous flows, and to determine which drainage areas with excessive I/I were cost effective to repair.

A total of 77 drainage areas were reviewed. Flows from the areas were monitored for an average of six weeks. To determine the flow response to various rainfall events, ten continuously recording rainfall gauges were installed at strategic locations within the regional collection system.

During the monitoring period, a 100-year storm event occurred on October 8-9, 1991. During a 24-hour period, approximately fourteen inches of rainfall was recorded at the South Regional Wastewater Treatment Plant. The overall impact of the storm on the wet weather infiltration/inflow was analyzed. The storm event and subsequent rainfall continued to impact the plant flows until November 18. During the 24-hour period on October 8, the daily average wastewater flow approached 80 MGD. The flow components are tabulated in Table 1.

Table 1. Southern Regional Collection System Flows Before and After 100-Year Storm Event.

Condition	Dry Weather Flow (MGD)	October 8, 1991 Flow (MGD)
Wet Weather I/I	0	39.9
Dry Weather I	15.2	15.2
Wastewater Contribution	22.5	22.5
Total Flow	37.7	78.6

The extreme storm event did not cause peak flow conditions as expected, possibly because the collection system was overloaded and the system peak pumping capacity was the testing factor.

The chloride measurement of the wastewater stream in tidal areas can be an indication of infiltration. Over 100 wastewater and groundwater samples were collected throughout the study area and were analyzed for chloride concentration in order to assist in determining the volume of saline groundwater entering the collection system.

High chlorides in the wastewater limit treated effluent reuse options. Sewer rehabilitation projects in the coastal areas can result in lowering the overall effluent chloride concentrations.

A mass balance analysis using the salinity data was performed to determine the effect of a sewer rehabilitation program on the overall treatment plant effluent salinity. It was determined that the dry weather infiltration would have to be reduced 82 percent to allow the entire plant flow to be within the chloride level recommended for landscape irrigation. Since a 30 percent reduction in dry weather infiltration is considered typical of sewer rehabilitation programs, the treated effluent will continue to have chloride concentrations, which may limit its use for unrestricted irrigation.

An analysis of cost-effectiveness was performed for each of the 77 drainage areas based on the total amount of dry weather infiltration and wet weather infiltration/inflow found during the field monitoring program. Potential savings and costs were compared using EPA guidelines. It was found to be cost-effective to remove excessive I/I in 43 of the 77 drainage areas. The analysis indicated that a cost effective I/I reduction of 4.32 MGD would be realized with a total program expenditure of $10,700,000.

SSES Findings

The sewer system evaluation survey is the second stage of a three stage program to locate, identify and remove sources of infiltration and inflow. The SSES field work included a visual inspection of each located system manhole, smoke testing the system for inflow sources, isolating areas of the system to measure infiltration sources, dye water testing to confirm findings, cleaning and television inspection of line segments and monitoring of flow rates from the collection system to establish a flow data base enabling confirmation of I/I flow quantities, and documentation of future I/I flow reductions.

Based on the results of smoke testing, visual inspection, and flow isolation, 237,300 linear feet of sewer lines were cleaned and televised. Videotapes were recorded and reviewed for determining the best rehabilitation technique. The SSES field investigation identified and quantified I/I sources. The system defects were then analyzed and sewer system repairs were developed. The cost of each proposed sewer repair was then determined.

Rehabilitation recommendations were based on several factors which should be considered when selecting a particular sewer repair method: excavation versus "no dig" or "trenchless" technologies, traffic disruption, desire to maintain wastewater flow versus bypassing, location (street or backyard) and long-term effectiveness of the rehabilitation method. Forty-three different repair technologies were recommended during the SSES.

The SSES, excluding the city of Hallandale, identified 6.56 MGD with a repair cost of $7,940,000.

Table 2. Sewer Repair Summary.

Repair Type	Quantities	Units	Repair Frequency Percentage of SSES Quantities[(l)]
Line Repair			
Cured-in-place Liner	30,803	L.F.	2.89
Fold-Formed Liner	47,317	L.F.	4.43
C.I.P. Sectional Liner	36	EA.	0.87
Testing and Chemical Grouting	83260	L.F.	7.80
Robotics Point Repair	501	EA.	12.06
Excavated Point Repair	196	EA.	4.72
Total Line Replacement	3,075	L.F.	0.29
Manhole Repair			
Cementitious Liner	333	EA.	8.02
Realign Manhole Cover	59	EA.	1.42
Install Cover Inserts	58	EA.	1.40
Replace Frame and Cover	32	EA.	0.77
Install Fiberglass Liner	10	EA.	0.24
Lateral Repair			
Cleanout Cap Replacement	156	EA.	3.76
Cleanout Repairs	234	EA.	5.63
C.I.P. Lateral Liner	42	EA.	1.01
Point Repair/Replacement	148	EA.	3.56

(l) Based on 4,154 manholes and 1,067,100 linear feet of lines inspected during the SSES.

Rehabilitation Phase

Three construction contracts were awarded by the city of Hollywood in July 1993. Each contract included different rehabilitation technologies. Contract "A" consisted mainly of cured-in-place pipe lining and manhole rehabilitation utilizing spray-on urethane and prefabricated fiberglass liner inserts. Contract "B" included fold-and-formed pipe liners, cured-in-place sectional pipe liners and cured-inplace manhole liners. Contract "C" consisted of air testing and chemical grouting of pipe, total line replacement, point repair with robotics, remote stainless steel grouting sleeves, installation of manhole cover inserts, realignment and grouting of manhole castings, replacement of manhole frames and covers, and calcium-aluminate cement manhole liners. The following items were common to all contracts: bypass pumping of sewers, open cut repairs, surface restoration, root removal in sewer lines, and warranty TV survey.

Table 2 presents a summary of major repairs performed in Hollywood, Miramar, Pembroke Pines, and Dania. Data were not available for Hallandale and Broward County District 3A, which undertook a separate rehabilitation program.

The repair frequency may be used to estimate I/I repair requirements in other South Florida areas with similar I/I correction programs.

Post construction flow monitoring of the entire region concluded in mid-January 1995. A total of 50 flow meters were installed in the system for a two- to three-week monitoring period. The data analysis indicated that the projected I/I removal will be 6.27 MGD at the individual pump stations.

Over 1,940 repairs were performed by contractors and city crews at a construction cost of $6,811,000 in the cities of Hollywood, Pembroke Pines, Miramar, and Dania. Each contractor is required to televise and videotape all repairs (warranty TV) before the one year warranty period expires. Results of this television inspection will allow the engineer to determine the success of each repair technology utilized in this program.

Conclusions

The first large scale sewer system renovation program in South Florida concluded in January 1995. Through a fast-track approach—implementing a detailed I/I analysis followed by a sewer system evaluation survey/rehabilitation combination—the program was completed in three years. A full scale utilization of new trenchless technologies was successfully implemented during the rehabilitation phase.

The timing of the various investigations is important. Smoke testing should be performed during low groundwater table conditions. Flow isolation and television inspection should be done during high groundwater conditions (wet season), and, where groundwater is influenced by tides, the activity should take place during high tides. High saline groundwater infiltration, which is typical of portions of coastal cities, can only be eliminated partially through rehabilitation, thereby still posing a problem for reused wastewater applications.

Considering the four cities for which full program data is available (Hollywood, Pembroke Pines, Miramar, and Dania), by repairing 1,948 of the 2,696 identified I/I sources at a program cost of $9,962,000, a total 5.65 MGD of I/I was eliminated. This represents a cost of $37,260,000 in treatment and transportation (20-year present worth value).

I/I reduction is an ongoing program that all municipalities should consider. All contributors to the Hollywood Southern Regional Wastewater Treatment Plant are planning further steps to reduce I/I. Among these are: address remaining areas which were not surveyed (SSES); implement a 100 percent television inspection program utilizing pan and tilt cameras; television inspection of all suspect laterals; implement policies for lateral repairs in private property; and procure annual contracts with specialty contractors.

James T. Cowgill, P.E., is a vice president with Hazen and Sawyer, P.C., Hollywood. Fred Bloetsher, P.E., is deputy public utilities director for the city of Hollywood. J. Peter Larsen, P.E., is a principal engineer with Hazen and Sawyer, P.C., Hollywood.