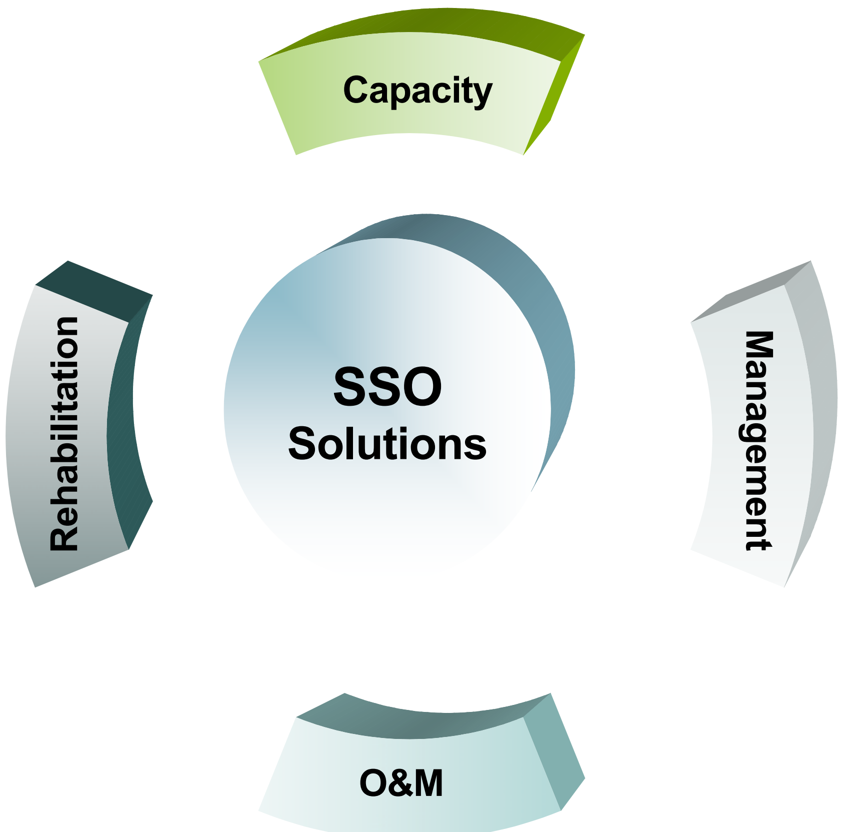
Sanitary Sewer Overflow Solutions



American Society of Civil Engineers
EPA Cooperative Agreement CP-828955-01-0

April 2004

Sanitary Sewer Overflow Solutions

Guidance Manual

Prepared By Black & Veatch Corporation for

American Society of Civil Engineers

Under Cooperative Agreement With

U.S. Environmental Protection Agency

Office of Wastewater Management Washington, DC

EPA Cooperative Agreement #CP-828955-01-0

April, 2004

Notice

Acknowledgments

The authors of this report wish to thank the United States Environmental Protection Agency (USEPA), the Black & Veatch Corporation, and the American Society of Civil Engineers (ASCE) for their support of this study. The authors acknowledge the critical input provided by the members of the Technical Advisory Committee (TAC).

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6. New Castle County, DE
7. Rockwood, TN
8. Sacramento County Regional Sanitation District, Sacramento, CA
9. Three-Rivers Wet Weather Demonstration Program, Pittsburgh, PA

Executive Summary

The objective of this project was to develop a Guidance Manual that presented a range of solutions for sanitary sewer overflows (SSOs). For the purpose of this project, an SSO was defined as the discharge of untreated sewage from a separate sanitary sewer system. This includes both overflows from the collection system as well as backups into homes. This project identifies solutions for both wet and dry weather SSOs.

The process of reducing SSOs involves three steps. First, the location of SSOs, particularly chronic SSOs, should be identified. Second, measures should be taken to eliminate the causes of the SSO, thereby minimizing the potential for their occurrence. Third, a proactive program that invests in maintenance, rehabilitation and capacity enhancement as appropriate is necessary to eliminate the precursors to future or prospective SSOs.

Data collection included two major tasks - a literature search and case studies of nine utilities. The literature search was conducted in order to obtain key publications, articles, and other materials related to solutions for SSOs. The availability of materials related to SSOs has expanded significantly during the last 10 years. Several hundred papers were identified as candidates for review during the literature search. Of these, 120 papers were reviewed and summaries of each paper were developed. The extensive material developed during the literature search was used as a reference to assist in development of the guidance manual. Additional material located in a variety of sources including industry and agency web pages, as well as personal communications with project team members and advisory panel members also were used in assembling the solution information. The SSO literature summaries provide an additional resource for agencies to locate additional background information.

Case studies were performed by contacting collection system groups within selected cities and agencies and researching available information on their application of solutions for SSOS. The underlying theme for identifying candidate agencies was to highlight a variety of approaches and investments applied by agencies to reducing their SSO problems.

The organization for presenting the SSO solutions in the Guidance Manual was derived from the Capacity, Management, Operation and Maintenance (CMOM) proposals that dominate the current compliance and enforcement information. Chapter 5 addresses capacity solutions, including developing the capacity assurance plan which incorporates determining existing and future capacity needs, identifying capacity limitations under those flow regimes, and developing operating, capital, and financing plans to satisfy those capacity needs. The impact of infiltration and inflow (I/I) in peaking wet weather flows and existing guidance for determining excessive I/I are also summarized. Solutions for increasing capacity, both for collection and treatment, as well as ways to address hydraulic bottleneck problems, are also provided.

Management contributions to resolving overflows are detailed in Chapter 6. This includes overviews of asset and environmental management systems available to agencies. Resource (staff and equipment) and information management concepts are discussed to help make the most efficient use of available assets. A significant portion of this chapter is devoted to the legal ordinances or authorities that are necessary to effectively combat fats, oils and greases (FOG) and private property I/I that contribute to both dry and wet weather overflows.

Operation and maintenance (O&M) solutions and techniques are described in Chapter 7. In this section, the variety of maintenance tools for clearing and removing debris, grease and roots from the collection system are summarized. The relative effectiveness of the tool and the range of sewer conditions for which it is appropriate are discussed. Roots and grease are the two major contributors to stoppages and loss of capacity in the collection system. Techniques for cutting and removing roots as well as chemical treatment and other containment and control mechanisms are discussed. Grease removal and bioremediation of grease in the

pipe are also addressed, as is the other topics covered included frequency of maintenance, primarily in the context of cleaning and maintenance for pump stations and treatment plants.

Condition assessment techniques are utilized to develop an understanding of the nature and causes of SSOs in an agency's collection system. By defining the existing sewer conditions that lead to overflows and backups, the necessary resources to preclude future occurrences can be deployed. The techniques available to inspect and evaluate the collection system are summarized in Chapter 8.

Rehabilitation solutions to SSOs are provided in Chapter 9. Technologies available for resolving leakage and structural problems that contribute to overflows, including trenchless and other rehabilitation are summarized. Techniques for creating additional capacity, both in a parallel alignment or by using the annular space of the existing pipe are included. Manhole, sewer lateral, connection and other appurtenance rehabilitation is also discussed.

Chapter 10 identifies future research considerations to make the growing collection of information more accessible to the agencies that wish to review it.

Chapter 1 Introduction

1.1. Introduction

Sanitary sewer collection systems play a critical role in protecting human health and the environment in developed areas. Sanitary sewer overflows (SSOs), which are releases of raw sewage can result when the systems fail, posing health and environmental risks. The performance of collection systems can also influence the performance of pumping stations and wastewater treatment plants.

Many collection systems exhibit poor performance due to a variety of factors, including structural, hydraulic, and maintenance deficiencies. The Environmental Protection Agency (EPA) estimates that there are at least 40,000 SSOs per year (EPA, 2001). A 1984 Urban Institute study of urban infrastructure indicated that sewer backup rates tend to be the highest in the Northeast and in economically distressed municipalities, and are generally higher in communities with the oldest sewer systems. Sewer line break rates tend to be highest in the South and West, and are particularly associated with large, growing cities.

The poor performance of many sanitary sewer systems and resulting potential health and environmental risks highlights the need to increase regulatory oversight of management, operation, and maintenance of these systems. This will in turn provide benefits in the form of:

- Reduced health and environmental risks by reducing SSO occurrences and improving treatment facility performance, and
- Added protection to the nation's collection system infrastructure by enhancing and maintaining system capacity, reducing equipment and operational failures and extending the life of system components.

SSOs are a key indicator of system performance. The process of reducing SSOs involves three steps. First, the location of SSOs, particularly the location of chronic SSOs, should be identified. Second, measures should be taken to eliminate the causes of the SSO, thereby eliminating the potential for its recurrence. Third, a proactive program that invests in maintenance, rehabilitation and capacity enhancement as appropriate is necessary to eliminate the precursors to future SSOs.

The American Society of Civil Engineers (ASCE) recently completed a research project entitled "Protocols for Identifying the Location of SSOs" (ASCE, 2000), which provided guidelines for wastewater utilities to implement the first step of the process, identifying locations of SSO's. This study, Solutions for Sanitary Overflows, provides guidelines for the second and third steps.

A wide variety of SSO solutions are available. The solutions presented in this Guidance Manual have been organized into three major categories:

- Capacity enhancement
- Utilization of effective management tools,

- Proactive operation, maintenance and rehabilitation of collection system

For the purpose of this study, an SSO is defined as the discharge of untreated sewage from a separate sanitary sewer system. This includes both overflows from the collection system as well as backups into homes. This project addresses both wet and dry weather SSOs.

This project was performed by Black & Veatch Corporation under a Cooperative Agreement between ASCE and EPA. Funding was provided by the Environmental Protection Agency.

1.2. Objectives

The objectives of this project are to:

- Build upon two prior studies performed by ASCE on Optimization of Collection System Maintenance Frequencies and System Performance (ASCE, 1999) and SSO Identification Protocols (ASCE, 2000) to provide SSO resolution strategies
- Identify and evaluate existing solutions for resolving both dry and wet weather SSOs
- Develop a guidance manual on solutions for both dry and wet weather SSOs
- Disseminate project's findings

1.3. Approach

The approach to the project consisted of six major tasks as described below:

Task 1: Project Kick-off Meeting

The Project Team held a joint meeting with EPA staff, ASCE staff and Advisory Panel members to fully develop the overall objectives of the project and receive the Advisory Panel's recommendations on how best to achieve them.

Task 2: Literature Search

A literature search was conducted to obtain key publications, articles, and other materials related to solutions for SSOs (see Appendix I). The availability of materials related to SSOs has expanded significantly since the SSO rulemaking was first proposed in the mid-1990s. The extensive material developed during the literature search was used as a reference to assist in development of the Guidance Manual.

Task 3: Case Studies

Collection system performance at nine communities and wastewater agencies was profiled for an investigation of SSO solutions used by these utilities. The reviews covered a variety of topics such as management practices, operation and maintenance practices, condition assessment, system renewal, and regulatory issues. The findings of the case studies were documented in detail and a separate report was issued for each utility (see Appendix II).

Task 4: Development of SSO Solutions

The information collected during the literature survey and in-depth investigation of utilities was used to develop SSO solutions that involve both wet weather resolutions such as peak flow storage, extraneous flow reduction and capacity augmentation, and dry weather resolutions such as enhanced preventive maintenance and stoppage removal.

Task 5: Development of a Guidance Manual

The material developed in Tasks 1, 2, 3, and 4 was organized into a Guidance Manual. The Advisory Panel provided input to the outline of the manual and the final draft. The manual includes information sufficient to enable a utility to evaluate the applicability of each SSO solution to its particular circumstance.

Task 6: Dissemination of Informational Material

The Guidance Manual will be made available through the ASCE website. A brochure will be developed for distribution at ASCE, American Public Works Association (APWA), and Water Environment Federation (WEF) conferences to promote the availability of the Guidance Manual. Target conferences will include:

- ASCE (National)
- ASCE (Pipeline specialty conference)
- WEFTEC (National)
- WEF (Collection system specialty conference)
- APWA (National)

References

American Society of Civil Engineers (1999) “Optimization of Collection System Maintenance Frequencies and System Performance”

American Society of Civil Engineers (2000) “Protocols for Identifying Sanitary Sewer Overflows”

EPA (2001) “Proposed Rule to Protect Communities From Overflowing Sewers,” EPA-833-01-F-001.

Chapter 2 Data Collection

2.1. Introduction

Data collection included two major tasks – a literature search and case studies of nine utilities.

2.2. Literature Search

The literature search was conducted in order to obtain key publications, articles, and other materials related to solutions for SSOs. The availability of materials related to SSOs has expanded significantly since the SSO rulemaking was first proposed in the mid-1990's. The extensive material developed during the literature search was used as a reference to assist in development of the Guidance Manual.

The literature search utilized the following sources:

- ASCE Online Database
- EPA Website
- Internet Search Engine Alta Vista
- Water Online Website
- Public Works Online Website
- Water & Environment Technology Magazine
- Public Works Magazine
- Proceedings of the National Conference on SSOs, April 1995, Washington, DC
- Proceedings of the WEF Collection Systems Specialty Conferences, 1993, 1997-2001
- Proceedings of the WEF Sewers of the Future Conference, September 1995, Houston, TX
- Proceedings of WEFTEC 1993, 1994, 1995, 1996,1997, 1998, 1999, 2000
- Proceedings of the WEF Conference on Advances in Urban Wet Weather Pollution Reduction, July 1998, Cleveland, OH
- ASCE Publication on Urban Drainage Rehabilitation Programs and Techniques, 1994
- Proceedings of the ASCE Pipeline Conference, June 1994, Phoenix, AZ

- Proceedings of the ASCE Conference on Infrastructure Condition Assessment, August 1997, Boston, MA

- Proceedings of the North American Society of Trenchless Technology No-Dig Conferences, 1995-2001

- Proceedings of the ASCE Pipeline Conferences, 2000-2003

2.3. Case Studies

Extensive information was collected on nearly 50 utilities during the development of two previous ASCE guidance manuals, *Optimization of Collection System Maintenance Frequencies and System Performance* (ASCE, 1999) *and Protocols for Identifying Sanitary Sewer Overflows* (ASCE 2000)*.* This information was used to identify nine utilities for case studies. The goal was to target programs that have distinguishing characteristics and broad application to SSO solutions.

Collection system groups within the following cities and agencies were selected:

- Auburn Hills, MI

- Clean Water Services, Portland, OR

- City and County of Denver, CO

- Fayetteville, AR

- Miami-Dade Water & Sewer, FL

- New Castle County, DE

- Rockwood, TN

- County Sanitation District 1 of Sacramento County (CSD-1), Sacramento, CA

- Three-Rivers Wet Weather Demonstration Program, Pittsburgh, PA

Figure 2-1 shows the general location of the nine agencies selected for case studies. The selected utilities cover a broad geographical area of the United States.

Background material was reviewed and collection system and/or engineering staff from these utilities were interviewed for an in-depth investigation of SSO solutions used by these utilities. The interviews covered a variety of topics as shown in Table 2.1.

The findings of the case studies were documented in detail and a separate summary was developed for each utility that can be found in Appendix II.

Figure 2-1 Location of Utilities for Case Studies

Table 2-1 List of Topics Discussed at Utility Interviews

General Area	Topics
I. General Information	• Name of Organization • Contact Information
II. Customer Base	• Population • Service Area • System Size (miles) • Average Age
III. Flows	• ADDF • Maximum Daily Flow • Maximum Monthly Flow • Minimum Monthly Flow
IV. Management Practices	• Organizational Management • Asset Management • Financial Management • Costs • Information Management • Human Resources
V. Operation & Maintenance	• Pump Stations/Force Mains • Maintenance Frequencies • Equipment • Standard Operating Procedures (SOP) • Emergency Action Plans (EAP) • Customer Communication • Safety • Training
VI. Condition Assessment & System Renewal	• Capacity Assurance • Condition Assessment Methods • System Rehabilitation Methods • Performance Evaluation
VII. Regulatory Compliance	• NPDES • CMOM • Regulatory Tiers

Table 2-1 List of Topics Discussed at Utility Interviews	
General Area	**Topics**
	• Legal Authorities -Private Lateral Ordinance -Grease Ordinance -Satellite Systems • Design/Installation Requirements
VIII. Other	• Lessons Learned • What Has Worked? • What Has Not Worked?

References

ASCE (1999), "Optimization of Collection System Maintenance Frequencies and System Performance"

ASCE (2000), "Protocols for Identifying Sanitary Sewer Overflows"

Chapter 3 Reported SSO Solution Results

3.1. Introduction

This chapter provides a summary of the findings from the literature search and utility case studies. These findings formed the basis for developing the SSO solutions that will be presented in later chapters.

3.2. Literature Search Results

Several hundred papers were identified as candidates for review during the literature search. Of these, 120 papers were reviewed and a summary of each paper was developed. These summaries are included in Appendix I to this report.

After the summaries of all the papers were prepared, the topic of each solution discussed in the paper was identified. Papers with similar solutions were extracted and organized under the categories presented in Table 3.1.

Some topics were more frequently reported in the literature than others. Figure 3.1 shows the number of papers reviewed for each category. As illustrated, rehabilitation was the most frequently reported category, followed by maintenance, technology, management, financial and capacity enhancement solutions. Very few papers were found to present solutions based on modification of design criteria or research, including development and pilot trial of emerging technologies. These two areas, design criteria and research, appear to deserve more attention in the future.

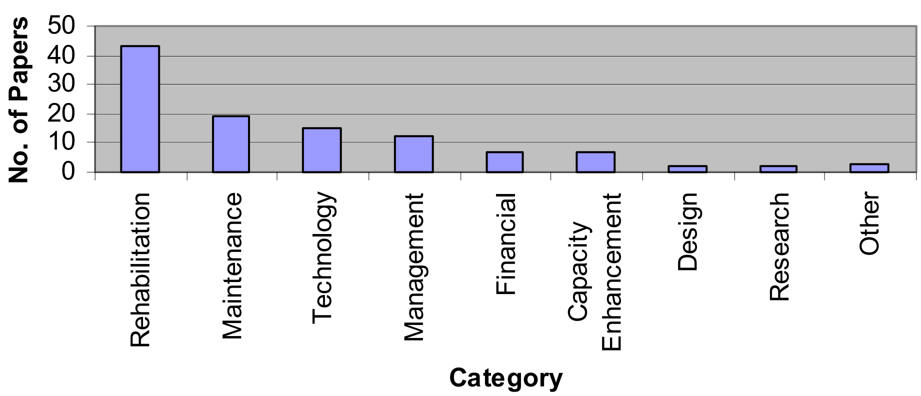


Figure 3-1 Number of Papers per Category

Table 3-1 SSO Solutions from Literature Search		
Item No.	**Category**	**Solution**
1 2 3 4 5 6 7 8	Maintenance	• Preventive maintenance, focused cleaning • Fat, grease abatement program • Installation of alarm systems • Corrosion monitoring & control • Spill prevention program/response plan • Spill prevention due to construction activity • CCTV/sonar combo for inspection • Inspection process standards
9 10 11 12 13 14 15 16 17	Rehabilitation	• Pipe, force mains, manholes, laterals, and spot repair rehabilitation • Total rehabilitation of mini-basins • Mini-basin approach to make work manageable • Crossing rehabilitation (siphons) • Financial incentives for rehabilitating laterals • Joint grouting • Sag/depression elimination • Post-construction rehabilitation • Inflow source/illegal connection elimination
18 19 20	Capacity Enhancement	• Master Planning • Re-routing of flow • Flow equalization/off-line storage
21 22 23 24 25 26 27 28 29 30 31	Technology	• Modeling • GIS • SCADA • SSMS/MMIS • Decision support systems/predictive modeling • Asset management/GASB-34 • Benchmarking • Employee empowerment/training/financial incentives • System performance optimization • Watershed management approach • Customer service
32 33 34 35	Financial	• Adequate budget • Cost-effectiveness analysis • Life cycle cost analysis • Rehabilitation contract size for cost reduction
36	Design	• Design improvements, minimum slope, I/I flows, etc.
37 38	Research	• Identify research needs and contribute to research • Participate in EPA demonstrative projects

3.3. Case Studies

The SSO solutions used by each of the nine case study utilities are documented in separate reports and are included in Appendix II. The specific solutions used by each utility are listed in Table 3.2. For more details on each solution, see the case study reports in Appendix II.

Table 3-2 SSO Solutions from Case Studies

Utility	Solution
Auburn Hills, Michigan	• Foot drain disconnection project (FDDP), city-funded • Public outreach program
Fayetteville, Arkansas	• Comprehensive sewer line rehabilitation • Pump station elimination by developing a new sewershed with in-basin treatment • Public outreach program • Special sales tax for funding Wastewater Improvement Project (WSIP)
Miami-Dade Water & Sewer, Florida	• Pump station improvement program • Pump station operation manipulation • SCADA data to detect problems • Satellite system peak flow exceedance charge plan • Sewer rehabilitation by CIPP • Manhole rehabilitation • Grouting
New Castle County, Delaware	• “Bug Truck” for FOG (Fats, Oil & Grease) control
City of Rockwood, Tennessee	• MOM plan • Sewer system rehabilitation by mini-basin • Equalization basin
CSD No.1, Sacramento, California	• Benchmarking study to identify “best practices” • Condition assessment utilizing statistical approach • Condition assessment by Sewer Scanner & Evaluation Technology (SSET) • Electrode leak locators technology application • Prioritized five-Year rehabilitation plan • Design criteria modification to eliminate 6-inch sewer lines
Clean Water Services (CWS), Portland, Oregon	• Comprehensive Sanitary Sewer Evaluation Survey (SSES) • Sewer system rehabilitation on a mini-basin level • Sewer rehabilitation by CIPP • Monolithic HDPE manholes in sensitive and high groundwater areas • Construction Acceptance Testing (air test for rehabilitated sewers and laterals, and vacuum test for rehabilitated manholes) • Cleaning of all sewers15 inches and smaller every two years • Chemical root control • Lateral rehabilitation

Table 3-2 SSO Solutions from Case Studies	
Utility	**Solution**
Three-Rivers Wet Weather Demonstration Program, Pittsburgh, Pennsylvania	• Demonstration projects (evaluation and rehabilitation) • Mechanisms for developing regional solutions and improving communication among regional wastewater agencies • Mechanism for administering EPA grant funds • Abandoned mine voids developed for storage of wet-weather flows • Regional calibrated rainfall data system
City & County of Denver, Colorado	• Benchmarking study to identify best management practices • Performance goals • Prioritized six-year rehabilitation program • In-house sealing (grouting) program • Aggressive cleaning schedule of entire system every 1.5 years. • CCTV inspection covering the entire system every seven years • Equipment standardization

Chapter 4 Overview of SSO Solutions

4.1. Introduction

The results of the literature search and case studies presented in Chapter 3 indicate that there are a variety of SSO solutions that utilities may consider using in reducing the occurrence of SSOs. Effective management, maintenance, operation, capacity enhancement and rehabilitation of collection system will inevitably reduce the number of SSOs. While any single solution would prove useful under a certain set of circumstances, there is no single and universal solution that would eliminate all SSOs. Combinations of solutions are normally required to bring about the expected results.

In 2001, EPA drafted proposed rulemaking for sanitary sewer overflows (EPA, 2001). Although the proposed rule was initially published in the Federal Register and subsequently withdrawn, it is the best reflection of the Agency's perspective on the problem. This rule, if adopted, will lead to major revisions to the NPDES permit regulations to improve the operation of municipal sanitary sewer collection systems, reduce the frequency and occurrence of sewer overflows, and provide more effective public notification when overflows do occur. The EPA draft proposal will provide communities with a framework for system operation and maintenance to reduce the incidence of overflowing sewers. The result should enhance the performance of the collection system, provide better and timelier information for local communities, and improve the condition of the sewer infrastructure.

A major component of the draft rule is a requirement for wastewater utilities to develop and implement a Capacity, Management, and Operation & Maintenance (CMOM) Program. The framework established by CMOM provides a logical structure for organizing SSO solutions. As such, the SSO solutions presented in this Guidance Manual are organized along the requirements of a CMOM program, as presented in Figure 4.1.

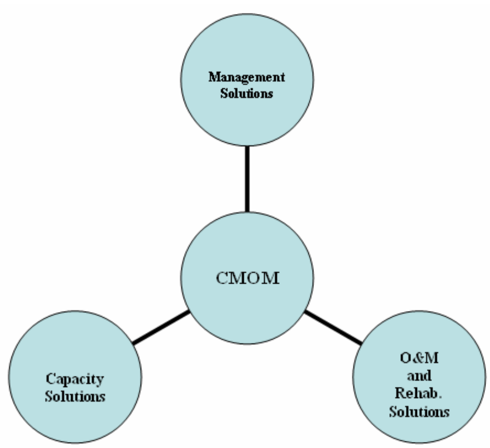


Figure 4-1 CMOM-based SSO Solutions

4.2. Capacity Solutions

Most sewer systems are designed for the peak diurnal wastewater flows with an allowance for infiltration and inflow. Experience has shown that the infiltration and inflow allowance used in the original design of older sewer systems is significantly below the wet-weather flows these systems experience. It is not uncommon for wet-weather peak flows to be an order of magnitude larger, or ten or more times the peaking factor, than the average daily flow of wastewater. Such large peak flows are primarily due to the numerous defects in the collection system caused by system deterioration and illegal connections over the years. In addition to excessive infiltration and inflow, a sewer system capacity can be taxed by population growth resulting in flows that exceed design flows. Most capacity-related SSOs are generally wet-weather related events.

Specific capacity solutions are described in detail in Chapter 5. Solutions to capacity-related problems fall under the following general categories:

- Capacity assurance planning
- Master planning
- Capacity enhancement

4.3. Management Solutions

Effective management of personnel, equipment, systems, processes and other resources can result in a reduction in the number of SSOs. Collection system management requires good recordkeeping, planning, and the appropriate tools to measure desired performance and ensure regulatory compliance. These tools enable managers to develop a trained and competent workforce capable of operating a collection system efficiently with the appropriate amount of reinvestment to minimize the occurrences of SSOs.

The management of a utility's organization, human resources, information database, finances, and assets has a direct impact on the utility's operational efficiency and financial status. In turn, this affect both the level of service that a utility provides to its customers and the amount that a customer is charged for the service provided.

Recognizing the critical role of resource allocation, the industry has introduced new management strategies, such as asset management. Asset management is a comprehensive framework which, when fully implemented, can lead to an optimally operated and efficient collection system. Both the proposed EPA CMOM program (EPA, 2001), and the Government Accounting Standards Board (GASB) Statement 34 "Modified Approach," (GASB, 1999), recommend implementation of asset management systems to preserve and maintain the wastewater collection system infrastructure.

Management solutions are presented in Chapter 6 and are categorized under the following category areas:

- Asset management,
- Environmental management systems,

- Benchmarking,
- Organizational management,
- Resource management,
- Information management,
- Financial management,
- Legal ordinances,
- Permitting,
- Standards,
- Progress monitoring & self assessment
- Overflow response plan
- Monitoring & reporting plan,
- Training, and
- Certification

4.4. Operation, Maintenance & Rehabilitation Solutions

Maintenance and operation solutions are the most readily available and most extensively used by wastewater agencies to reduce SSOs. An aggressive maintenance program can both mitigate the impact of the overflow and significantly reduce the frequency of occurrence of dry-weather SSOs. The operation and maintenance solutions are presented in Chapter 7. Solutions for grease and roots, two of the more significant collection system impacts, are offered. Operational strategies are discussed which can be developed and adopted to prepare for and prevent wet-weather overflows both in the collection system and the facilities.

Condition assessment is an integral element of an ongoing maintenance program. A variety of techniques and inspection methods, including those for private property I/I, that can be incorporated into an agency's SSO mitigation program are presented in Chapter 8.

Comprehensive rehabilitation programs can significantly reduce the occurrence of both wet-weather and dry-weather overflows. Specific techniques can be targeted to structural or leakage problems, whether they are in the mainline, manhole or building sewer. Rehabilitation solutions are presented in Chapter 9.

References

EPA (2001) "Proposed Rule To Protect Communities From Overflowing Sewers," EPA 833-01-F-001

Government Accounting Standards Board (1999) “Statement No. 34 of the Government Accounting Standard Board: Basic Financial Statements – and Management’s Discussion and Analysis – for State and Local Governments,” Norwalk, Connecticut

Chapter 5 Capacity Solutions

5.1. Introduction

Increasing system hydraulic capacity is one of several solution elements for resolving system SSOs. This can be done by increasing the conveyance capacity or by storing peak flows until the existing system can safely convey the wet-weather volume stored. Determination of the timing, sizing and scheme for capacity solutions is a major consideration in effectively addressing existing and potential future SSOs due to hydraulic overloads. The need for capacity solutions is identified by executing a series of master planning tasks associated with flow analysis, hydraulic evaluation and sizing and locating potential improvements.

5.2. Capacity Assurance Plan

The Capacity Assurance Plan (CAP) identifies necessary remedial measures that will lead to the elimination of capacity-related SSOs up to the selected design condition and ensure that the system has adequate capacity under existing and projected future design conditions. CAPs are developed based upon analysis of system capacities, knowledge of the condition of the collection system, future expansion considerations, a basis of design and projected impacts of the planned Capital Improvement Projects.

The analysis of the capacity needs and deficiencies can be performed in a master planning context. A master plan will determine existing and future capacity needs, identify existing and projected capacity limitations, evaluate alternatives to address capacity deficiencies and develop solutions. Master plans are updated on a regular basis, usually three-to-five years, to account for changes in land use, annexations, growth and other impacts to the service area and collection system that drives peak flow. The master plan defines the design assumptions for sizing the pipes to accommodate the projected flow.

Flow metering, performed either as an element of the master plan or as a regular feature of an agency's monitoring program, provides the basis for determining peak flows within the system. Since sewer capacity is driven by peak flow, and infiltration and inflow generate the peaks, initial qualification of the measured flows yields a basis for prioritizing subsystems within the collection system.

CAP remedial measures to address capacity-related problems may include elimination of cost-effective infiltration/inflow (I/I) sources, provision for increases in pump station and sewer capacities, incorporation of storage and/or equalization facilities for capturing the excess flow for treatment, or recommendation of increases in wastewater treatment plant capacity.

The CAP also contains provisions to measure the effectiveness of the remedial measures on reducing SSOs. In addition, the plan should provide probable construction costs and annual operation and maintenance costs. Another component of the Capacity Assurance Plan is a schedule of all design and construction elements of the proposed remedial measures. The schedule should present the major milestones for each subsystem.

5.2.1 Infiltration/Inflow

An additional benefit to collecting flow data for incorporation into the master planning component of the CAP is the preliminary evaluation of whether subsequent condition assessment work is needed through a sewer system evaluation survey (Chapter 8). Historical wastewater flows, gathered either at the treatment plant or at key subsystem locations, provide a preliminary basis for determining whether infiltration or inflow is excessive.

The October 1991 EPA handbook Sewer System Infrastructure Analysis and Rehabilitation is one resource available for determining whether the level of I/I in a collection system is excessive. The 1991 EPA criteria define the non-excessive infiltration as a flow rate that does not significantly exceed 120 gallons per capita per day (gpcd), typically in the range of 130 gpcd. This sum of domestic base flow and infiltration, based on a 7-14 day average during high groundwater conditions, is used as a basis of comparison when applying the EPA criteria. This assessment uses readily-available information that an agency can assemble from existing sources.

This criteria was prepared over a decade ago and was used primarily in administering the grants program of that era. However, the current EPA discussions involving the “blending” rule for wet weather treatment plant operation again raised the issue of what constitutes excessive I/I. This 1991 handbook was again cited in the 2004 EPA documentation as the best available guidance for the preliminary evaluation of whether a collection system is subject to cost-effective I/I to pursue.

The value of these I/I criteria is that data is generally readily available. Population tributary to a control meter or a treatment plant, measured wastewater flows from within the collection system or at the plant, and a high groundwater reference, such as a geological survey groundwater well (state or federally maintained), provide three basic elements for the analysis. A possible limitation of these per capita measures is that population densities often have little to do with leakage characteristics of the pipe. Sewer pipes leak due to external loading, weakening or deteriorating pipe and manhole materials, ineffective joint compounds, poor trench and bedding conditions, and the presence of groundwater or rainwater, not as the result of tributary population.

To overcome this drawback, another measure developed during the period of the I/I federal grants program may be more useful. Leakage quantified as gallons per day per inch-diameter mile of sewer (gpdim) measures was routinely utilized to qualify individual sewer segments initially and later entire subsystems or sewersheds for further infiltration evaluation. The inch-diameter miles of a collection system are derived from the length of the sewer expressed as miles times the diameter in inches. This computation is typically performed incrementally by each sewer segment or estimated by multiplying an average diameter across the length of the entire collection system in the study.

These inch-diameter mile measures were useful because they incorporated properties or measures of the leakage expressed by the physical characteristics (length and diameter) of the pipe. The rates also provided standardized units for ranking or prioritizing subsystems for subsequent study, independent of the differences in the size or lengths of the pipe in the actual subsystems. Table 5.1 presents a series of these non-excessive criteria devised by EPA over the years of the grants program.

Both the 1991 handbook criteria and the inch-diameter mile criteria have also been developed as threshold criteria for the inflow assessment (Table 5.1). Cumulative and subsystem inflow rates should be determined for each subsystem to provide a spatial distribution of inflow. In systems with significant inflow, a comparison of cumulative inflow and subsystem-generated inflow rates should show that the cumulative inflow for interior subsystems is less than the sum of individual subsystem-generated inflows. This would be consistent with expected system flow dynamics in which peak flows are dampened as they travel through the system.

Table 5-1 Selected Historical Excessive Infiltration Inflow Criteria

<table>
<tr><th>Criteria Source</th><th colspan="2">Criteria for Non-Excessive Infiltration Determination</th></tr>
<tr><td>EPA Program Requirements Memorandum (PRM 78-10, 1978)</td><td colspan="2">Established 1500 gpdim as non-excessive leakage allowance, perform a cost-effective analysis to determine if the leakage is possibly excessive and qualifies for investigation</td></tr>
<tr><td>Draft Program Requirements Memorandum (PRM) 80 ,1980</td><td colspan="2">Proposed 3,000 gpdim as non-excessive allowance, maximum of 30% infiltration removal for use in cost-effectiveness analysis (CEA)</td></tr>
<tr><td rowspan="2">EPA Handbook: Procedures for Investigating Infiltration/Inflow, EPA 68-01-4913, 1981</td><td colspan="2">Non-Excessive Allowance Ranges</td></tr>
<tr><td>Non-Excessive Rate

2,000-3,000 gpdim

3,000-5,000 gpdim

5,000-8,000 gpdim</td><td>Length of Sewer

>100,000 lf

50,000-100,000 lf

1,000-50,000 lf</td></tr>
<tr><td>EPA Handbook: Facilities Planning, 1981</td><td>Non-Excessive Rate

2,000-3,000 gpdim

3,000-6,000 gpdim

6,000-10,000 gpdim</td><td>Length of Sewer

>100,000 lf

10,000-100,000 lf

<10,000 lf</td></tr>
<tr><td>EPA Handbook: Sewer System Infrastructure Analysis and Rehabilitation

EPA 625/6-91/030, 1991</td><td colspan="2">Non-Excessive Infiltration

-Preceding year’s 7-14 day high groundwater wastewater flow ≤ 120 gpcd

Non-Excessive Inflow

-Total daily average storm flow ≤ 275 gpcd

-No operational problems in collection system and WWTP</td></tr>
</table>

5.3. Master Planning

Master planning, sometimes referred to as capacity planning or facility planning, is a rigorous and systematic analysis of a collection system to:

- Determine its existing and future capacity needs,
- Assess its current conditions,
- Identify existing and projected capacity limitations,
- Evaluate alternatives to address capacity deficiencies and select the most cost-effective alternatives, and
- Develop both short term recommendations and long term Capital Improvement Plans (CIPs), including probable construction costs, implementation schedules and financing impacts, to address collection system deficiencies and capacity constraints in the system.

Master planning projects can be either broad or focused in scope. The broad scope will address all the deficiencies of the system, while the focused scope will address one or more deficiencies. For example, a focused master planning project may be implemented to address capacity-related issues without any regard to other issues such as maintenance deficiencies. The elements of a capacity-focused master plan include:

- Population projections,
- Land use projections,
- Flow and rainfall monitoring,
- Flow and rainfall analysis,
- Future flow projections,
- Hydraulic modeling, and
- CIP development

5.3.1 Population Projection

Current and future population projections are used to estimate wastewater flow productions. The United States Bureau of Census provides both historical population data and national population forecast for high, medium and low growth rates at the national level (see Figure 5.1). State and local planning agencies also develop population forecasts at the state and local level that take into consideration regional and local economic conditions, and positive or negative migration patterns.

There are a variety of other planning tools developed by local and state organizations involved in regional planning efforts. Metropolitan Planning Organizations (MPO) and similar planning commissions develop long range projections for growth and economic development in regional areas. Transportation planners utilize traffic analysis zones (TAZ) for assessments of future dwelling units and employment centers to determine the “trip” potential and impacts on arterial and primary roads. The value of TAZ is in providing a spatial distribution to the future population, enabling the allocation of the population to sewered envelopes and the sewers that will serve them.

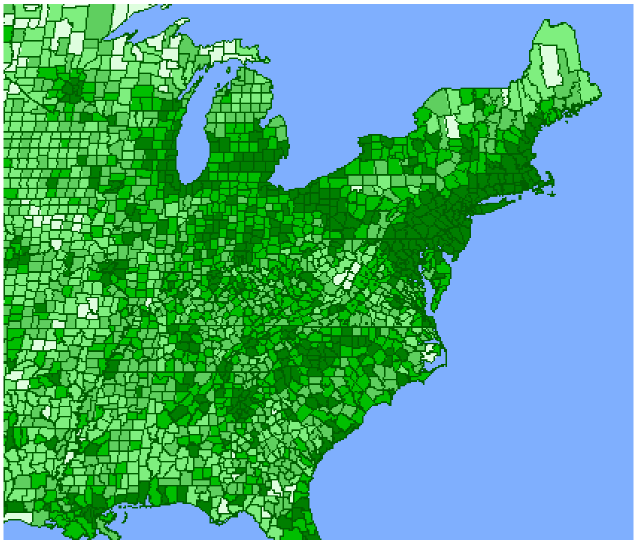


Figure 5-1 Population Density of Eastern United States

There are a number of methods for population forecasting including:

- Extrapolation of the current growth rate into the future,
- Economically-based models which take the economic growth potential of the area into consideration, and
- Land-use models which allow population projections to be developed based on future land-use trends.

The critical issues involved in completing wastewater planning projections are the amount and spatial distribution of the population and future growth.

5.3.2 Land Use Analysis

Land-use information may be used for developing population forecasts. Land-use data is often developed in electronic medium by local planning agencies. Assessments of the percentage of the land developed, the density of the development and the type of development are keys for translating this land use information into useful population forecasts within the sewered subsystems. The major categories used in a land use plan include:

- Residential areas,
  - Low density,
  - Medium density,
  - High density,

- Commercial areas,
- Institutional areas,
- Industrial areas, and
- Agricultural areas

In rapidly developing areas, current land-use may not be a valid indicator of future potential. “Smart-growth” and other planning advocacies that seek to limit urban sprawl try to leverage existing infrastructure such as water, sewer, roads, and schools for future development. These initiatives encourage the use of in-fill and higher density development around urban or suburban cores. Smart-growth planning enables future populations to maximize the use of the infrastructure systems already in place. This is a positive development in planning for the future collection systems.

5.3.3 Flow & Rainfall Monitoring

Flow and rainfall monitoring is used to quantify wastewater production (base) and infiltration and inflow (I/I) in the collection system. The data collected can be used for hydraulic evaluation of the sewer system, calibration of hydraulic models, assessment of I/I, and assessment of effectiveness of rehabilitation measures in eliminating I/I.

In areas experiencing high flows during wet weather, an important parameter for proper interpretation and extrapolation from the flow data is the gathering of rainfall data. Rain gauges have traditionally been ground-based equipment, ideally synchronized to collect calibrated rainfall with the wastewater flow data with 15 minute temporal resolution. Achieving adequate density in the deployment of the rain gauges to capture the variation in the size and intensity of storm cells is critical to developing reasonable relationships between rain and peak wastewater flows. Average rainfall for the study areas are developed using spatial relationships such as Thiessen analyses derived from the individual rain gauges locations. Increased accuracy is achieved through greater frequency and density in establishing rain gauge sites (Seremet, 2002).

Alternatively, rainfall data may be captured and incorporated into the flow analysis through a combination of ground-based rain gauges and Doppler radar rainfall data gathered by Next Generation Weather Radar Systems (NEXRAD) established at all major United States airports. With Doppler radar rain data, a cell or pixel, representing 4 square kilometers or approximately 1.5 square miles, is the standard spatial measure for the virtual rain gauge data. Additional levels of precision can be secured from third party providers of the radar data if warranted by the study needs or the storm characteristics.

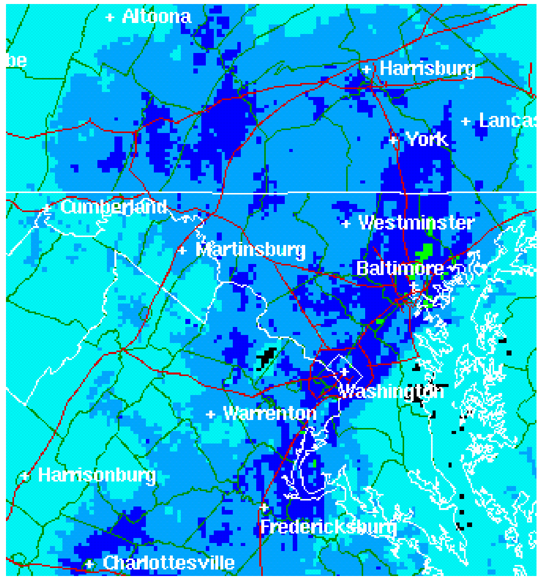


Figure 5-2 Sample NEXRAD Rainfall Data for Washington DC Area

5.3.4 Rainfall Analysis

The data from rain gauges is analyzed to characterize the intensity of the rainfall in any given basin. When there is more than one rain gauge in a sub-basin, the Thiessen Method is used to determine the average rainfall intensity for the sub-basin. The Thiessen method involves drawing polygons around each rainfall gauge indicating the areas most influenced by each gauge. The percentage of the total area tributary to each metering site falling within each rainfall gauge polygon is determined. The percentage of the area for each rain gauge is multiplied by the rainfall intensity measured by that rain gauge and the results are summed up for all the gauges for the sub-basin.

The impact of accurately capturing the spatial distribution and intensity of rainfall was documented in a Trinity River Authority (TRA) rain and flow analysis performed in Texas. A comparison of rain and flow data recorded in 2000 documented a variation in rainfall totals from +55.8 percent to -92.5 percent between ground-based gauges and Doppler radar rainfall calibrated using those same ground-based gauges for a single storm event. The smaller spatial coverage provided by the pixels of the virtual rain gauge yielded more accuracy in quantifying the rain falling within the sewershed tributary to the flow meters. The impact in the rainfall variability is further magnified when the data is used to develop rainfall/flow relationships for extrapolation to design or recurrence interval storm wet-weather flow responses (Seremet, 2001).

In addition to the Thiessen analysis, it is necessary to develop Intensity-Frequency-Duration curves specific to the area being analyzed (see Figure 5.4). These curves are often readily available from local or state agencies, such as the Departments of Transportation, Environment, or Natural Resources or can be derived independently from the National Weather Service's historical records documented in Technical Paper No. 40, Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 224 Hours and Return Periods from 1 to 100 Years, (US Department of Commerce, 1961).

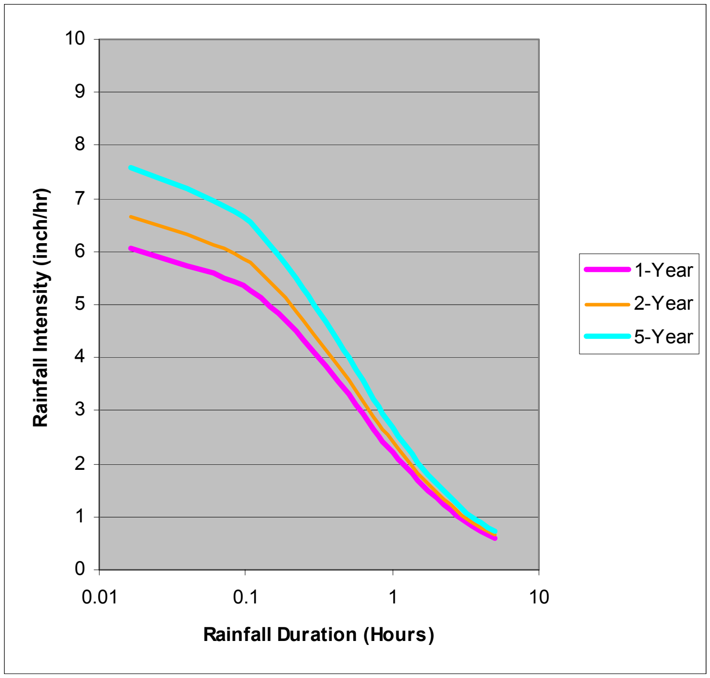


Figure 5-3 Sample Rainfall Intensity/Frequency Duration Curves

5.3.5 Determination of Total Peak Design Flow

Design flow for a sewer is defined as the maximum flow rate that occurs under selected weather and growth conditions. Since a significant portion of the peak flows do result from rainfall, the design flow that the sewer must convey is related to the probability of occurrence of a design storm event. Design flow for a selected rainfall event is the sum of peak wastewater production, infiltration, and inflow.

A summary of the probability that a storm event having a prescribed recurrence interval will not be equaled or exceeded during a specified period is given in Table 5.2. For example, a design based on a 10-year storm event has a 59% chance of not being exceeded during a five-year period.

Table 5-2 Probability of Non-Exceedance								
Design Storm (years)	**Period (years)**							
	1	**5**	**10**	**20**	**50**	**100**	**200**	**500**
1	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
2	0.50	0.03	0.01	(1)	(1)	(1)	(1)	(1)
5	0.80	0.33	0.12	0.01	(1)	(1)	(1)	(1)
10	0.90	0.59	0.35	0.12	(1)	(1)	(1)	(1)
50	0.98	0.90	0.82	0.67	0.36	0.13	0.02	(1)
100	0.99	0.95	0.90	0.78	0.61	0.37	0.13	0.01
200	0.995	0.975	0.95	0.90	0.78	0.61	0.37	0.08
500	0.998	0.989	0.98	0.96	0.90	0.82	0.67	0.37

(1) Values are near zero (0).

The design storm or storm recurrence interval is also the basis for prescribing a level of protection to the pipe capacity to carry the design flow. The selection of design storm becomes an integral component of the CAP since it determines the threshold flows at which the sewer will be expected to surcharge and potentially overflow.

5.3.5.1 Flow Analysis Components

Flow data should be reviewed to select representative days for determination of dry and wet weather flow parameters. The analysis of wet weather flow data should be based on the best available flow data during rainfall events.

Wastewater production flow (WWP) is the wastewater without infiltration and inflow. The daily wastewater production flow rate can be approximated using either direct measurement of average daily dry weather flow (ADDF) during dry weather/low groundwater conditions or winter month water consumption data. The instantaneous wastewater production flow rate varies throughout each day, with the highest rates normally occurring between 8:00 a.m. and 11:00 a.m., depending on collection system size and characteristics. The ratio of peak 60-minute flow to total average daily flow is defined as the diurnal peaking factor.

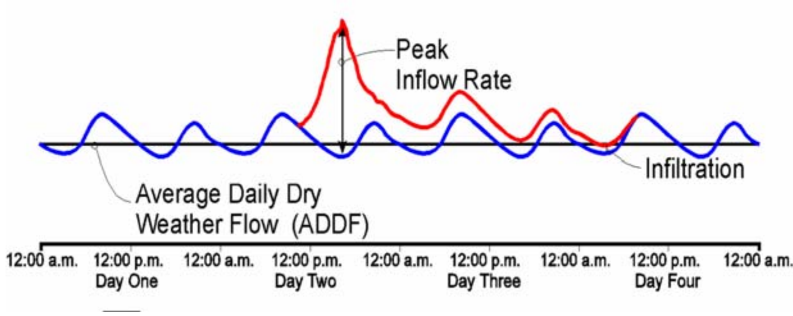


Figure 5- 4 Wastewater Flow Components

Infiltration occurs when groundwater enters the wastewater collection system through defective pipes, pipe joints, and manhole structures. The rate of infiltration depends on the depth of groundwater above the defects, the size of the defects, and the percentage of the collection system submerged. The variation in groundwater levels and the associated infiltration is seasonal and dependent upon the weather.

Inflow occurs when rainfall-related water enters the collection system from private property sources such as Building sewers or laterals, downspouts, foundation drains, yard and area drains, and storm water sump pumps. Typical public property inflow sources include manholes, defective piping and connections, public portions of the building sewer and cross-connections with storm drains. Inflow quantity is directly influenced by the nature of the sewer defect, intensity and duration of the storm event and any antecedent soil or groundwater conditions, such as high-standing water table or snow melt.

5.3.5.2 Determination of Average Daily Dry Weather Flow

Daily fluctuations in flows during dry weather are attributable to variations in domestic, industrial, and commercial wastewater production. Average daily dry weather flow (ADDF) is a flow parameter measured directly by flow monitoring and includes wastewater production (WWP) plus infiltration that occurs during low groundwater conditions. The WWP component of the ADDF can also be estimated if winter quarter water meter billing records can be aggregated to match the wastewater metered area. Sometimes, an allowance for water not returned to the collection system is incorporated in the WWP estimate if a winter estimate is not available.

A flow balance can be performed comparing the ADDF recorded at each metering site to cumulative flow downstream to ensure that flow continuity exists in the metering program. The total ADDF from in-system meters should also be compared with ADDF measured at the wastewater treatment plant. In many cases, some adjustments are needed to obtain meaningful flow values. This process is an accounting procedure for balancing flows recorded and distributing meter error throughout the system.

5.3.5.3 Determination of Infiltration

Infiltration can be estimated from flow meter data collected during periods of dry weather and high groundwater conditions. Infiltration rates can be refined by taking flow isolation measures at selected locations and by conducting detailed analysis of night flows and/or water consumption records.

5.3.5.4 Determination of Inflow

Inflow for a specific storm event typically includes all extraneous flow discharged to a sewer as a direct result of rainfall. Flow data from moderate and significant rainfall events should be analyzed to determine system inflow. There are a number of methods used to evaluate inflow that have been briefly described in the flow monitoring section of this report. The total peak flow measured during inflow periods includes wastewater production flow, infiltration, and inflow. Inflow for a particular rainfall event is determined by subtracting the wastewater production and infiltration flow from the measured peak flow. Analyzing a series of rainfall and wastewater flow responses enables a mathematical relationship to be developed that may allow characterization of higher intensity or longer duration storm impacts through extrapolation of the data. This characterization can then be related to a design standard or recurrence interval storm when performing capacity assessment or level of protection evaluations.

Inflow for a specific storm event includes all rainfall-induced flow, including direct storm water inflow and rapid infiltration. Flow data for each significant rainfall event was analyzed for inflow. The total peak flow measured during inflow periods includes wastewater production flow, infiltration, and inflow. Inflow for a particular rainfall event is determined by subtracting the wastewater production and infiltration flow from the measured peak flow.

The magnitude of peak inflow depends on rainfall distribution, intensity, antecedent groundwater conditions, types and locations of inflow sources, and time of concentration of the system to the monitoring point.

5.3.6 Hydraulic Modeling

Hydraulic modeling is particularly useful in addressing and evaluating the effectiveness of solutions to SSOs caused by hydraulic conditions. Hydraulic analysis for existing and future conditions can be performed to develop capacity related solutions for existing and potential future SSOs. Hydraulic models should be updated on a regular basis and system hydraulic analysis be made on at least an annual basis to assess the impacts of any system changes, including growth and rehabilitation. Hydraulic analysis should be performed for areas that have experienced an SSO.

Generally speaking, hydraulic models can be divided into two types - steady state (or static) models and unsteady state (or dynamic) models. Steady state models are not able to incorporate the effects of overflows and surcharge on the hydraulic response of the system. As a result, the location and quantity of overflows can be difficult to reliably determine with steady state models. Dynamic flow models can be used to predict the location and flow rates of SSOs. Such models have the ability to evaluate hydraulic surcharging, backwater effects, and overflow conditions. Dynamic models are also better suited for complex systems which include diversions, parallel lines, and special structures. Dynamic models can route hydrographs through the modeled sewer system and predict a time-varying series of flows and water surface elevations.

A hydraulic model should be able to evaluate system capacity with enough reliability to analyze existing and potential SSOs.

The extent of a hydraulic model depends on the analysis objectives, but at a minimum should include pipes and facilities with influence on SSOs.

5.3.6.1 Hydraulic Modeling Inventory

Inventory for hydraulic modeling can be obtained from record drawings, maps, databases, and Geographic Information Systems. Data must be checked for accuracy and completeness. Dynamic models require elevation data based on one datum to properly route flows through the modeled network. Special care must be taken to collect data related to pump stations, siphons, and special structures.

The pipe data needed to build a model is as follows:

- Details of the sewer network and connectivity;
- Pipe sizes;
- Ground levels;
- Pipe invert levels;
- Pipe roughness.

A "line segment" is defined by an upstream manhole, a down stream section of pipe, and a downstream manhole. Most models consider manholes and wet wells as "nodes" and pipes, force mains, pumping stations, and control structures as "links".

Data on ancillary structures, such as overflow structures, diversions, tanks, control structures and pumping stations, can profoundly affect the results of a sewer model. It is recommended that all special structures that may have a significant effect on the flow conditions are fully surveyed.

The information required for pumping stations includes the location, number and sizes of pumps, total capacity (all pumps operational), firm capacity of the station, size of the wet well, and inlet and discharge elevations. The firm capacity is defined as the capacity of the pumping station when the largest capacity pump is out of service.

Particular care should be taken where unusual or difficult flow conditions are likely to arise such as:

- low weirs;
- side weirs;
- structures where screens, or scumboards restrict the flow;
- structures where pipes or outfall conditions may limit flow over a weir or orifice;
- structures where the direction of the main flow changes through the structure;
- structures where hydraulic jumps are likely to occur;
- diversions in free surface flow;
- variable speed pumping installations;
- automated gate control systems;

- other automated control systems;
- manually controlled pump stations.

5.3.6.2 Model Set-up

The building of the sewer network inventory results in an input file to be used by the hydraulic model. The file contains inventory and flow data to be used for modeling. The extent of the model will depend on the modeling objective. For example, the user may wish to model sewer sizes larger than 30 inches in diameter. The flow data should be applied at the appropriate nodes.

5.3.6.3 Model Calibration

Calibration is the process of adjusting model parameters to make a model fit with measured conditions (usually measured flows). The model parameters are adjusted until hydraulic model flow values reasonably represent actual recorded wastewater flows. Wet weather flow calibration may also be performed against a projected design recurrence flow event using the selected design rainfall. This is especially effective for systems that have significant hydraulic restrictions during peak flow.

During model calibration, it is necessary to achieve a reasonable match between observed and modeled peak flow, time of concentration, and total volume. The accuracy of calibration is often best visualized through use of flow hydrographs. Figure 5.5 shows an observed and predicted hydrograph during calibration of an unsteady-state hydraulic model.

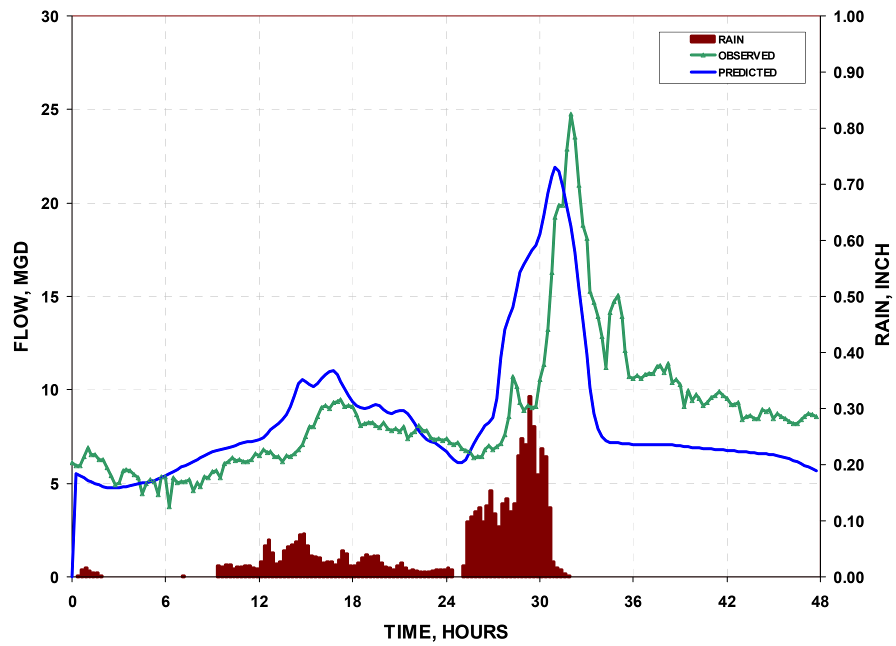


Figure 5-5 Observed and Predicted Hydrographs

5.3.6.4 Model Simulations

Once the model is calibrated, it can be used to analyze the hydraulic response of the system under different conditions including the following:

- different design rain events;
- performance of the sewer system for a variety of future design years;
- hydraulic problems within the sewer system such as surcharged pipes, hydraulic bottlenecks, and reverse flows;
- assess the impact of proposed developments;
- identify the need for possible hydraulic upgrading schemes and to carry out initial scheme appraisals.

5.3.6.5 Evaluation of Results

In evaluating the results of hydraulic model simulations, it is necessary to consider whether a model prediction is reasonable and/or can be supported by historical knowledge and experience of the system's operation.

Errors in inventory data can substantially affect the output results of a hydraulic simulation. However, present day hydraulic modeling software incorporates many built-in data checking and validation routines to help the hydraulic engineer identify potential errors.

5.3.7 Capital Improvement Program Development

The results of the hydraulic analysis combined with physical inspection data are used to develop a series of projects to meet the current and future needs. These projects constitute the Capital Improvement Programs (CIPs). In order to evaluate the capacity of the existing system and facilities, it is necessary to develop the design criteria against which existing systems and facilities are evaluated. The design criteria are also used to size future systems and facilities. An appropriate balance must be made with selected criteria so that sizing is not overly conservative or undersized. Design criteria for consideration in sizing the relief pipes are given in Table 5.3.

Table 5-3 Sewer Design Criteria

Criteria	Comment
Collection System:	
Peak flow (design flow)	Define recurrence storm interval and/or components of peak flow
Friction factor	Set friction factors to be used for analysis
depth/Diameter (d/D) for existing pipe evaluation	Set d/D criteria for when existing pipes need to be relieved or replaced
depth/Diameter (d/D) for future pipe conditions	Set d/D criteria for future pipe sizing
Improvement sizing, year	Define design year basis
Potential I/I removal	Base on analysis of I/I rates, variable by subsystem
Future design flow curve	Establish design curve to evaluate flows for future service areas
Type of Improvement	Determine if additional capacity should be parallel, relief sewer or replacement sewer
Pump Station:	
Pump station evaluation	Define evaluation and improvement criteria for pumping stations
Force main	Define evaluation and improvement criteria for force mains

5.4. Capacity Enhancement

Capacity enhancement may be required to safely convey existing and future wastewater flows or address existing overflow problems. Factors affecting capacity for pipe include flow area, pipe shape, slope of the pipe, and internal pipe roughness. Capacity enhancement can be achieved by utilizing techniques which affect these parameters in such a way as to increase the capacity.

When major capacity enhancement is required, consideration should be given to installing parallel relief lines, replacing existing lines with larger ones, expanding the capacity of existing pump stations and flow equalization basins, or building new ones. Parallel relief lines are often used when the existing line cannot be placed out of service, or when it is more cost-effective to install a parallel relief line than to replace the existing one. Installation of parallel relief lines may require additional rights-of-way.

While rehabilitation techniques are not primarily used for capacity enhancement, they provide some level of enhancement. For example, when a sewer line is rehabilitated with a thin liner, such as Cured-in-Place-Pipe, the internal pipe roughness decreases. This increases the hydraulic capacity of the system even though there is a slight reduction in pipe cross sectional area due to the thickness of the liner. An added benefit is the elimination of the I/I, freeing up a portion of the hydraulic capacity. When utilizing liners for capacity enhancement, one should understand that liners are a "mirror" technology. Poor line and grade are reflected in the final condition and appearance. Hydraulic jumps may occur as the liner bridges over offset, broken, and missing pipes in the renovated segment. These factors may limit the improvements in hydraulic capacity due to the myriad of head losses remaining within the pipe.

The level of capacity enhancement is often determined by hydraulic modeling. Hydraulic evaluation of the sewer system determines existing hydraulic capacity, identifies undersized sewer lines, and sizes sewer lines for future conditions.

The following options are available for capacity enhancement:

- Relief sewers,
- On-Line replacement,
- Rehabilitation,
- Elimination of hydraulic bottlenecks,
- Wet-weather storage facilities,
- In-line storage,
- Off-line storage,
- Equalization basins,
- Peak excess flow treatment facilities (PEFTFs), and
- Pumping station capacity enhancement.

5.4.1 Relief Sewers

Installation of relief sewers is an effective method of increasing hydraulic capacity. Parallel relief lines may be installed in cases where the existing line cannot be placed out of service or it is more cost effective to install a parallel line than to replace the existing line with a larger one. The relief line may be installed utilizing a variety of techniques, including:

- Open cut,
- Microtunneling,
- Auger boring, and
- Horizontal directional drilling

Replacement relief lines can be installed by either open cut or on-line replacement techniques.

5.4.1.1 Open Cut

Open cut has been the traditional method of installing relief lines. With the advent of trenchless technologies, collection system utilities prefer to avoid open cut trenching to minimize surface disruption and traffic impact. A cost-effectiveness analysis is usually performed to determine whether open cut is more cost effective than trenchless options. If social costs are considered, trenchless options almost always end up being more cost effective. However, not all utilities consider social costs in their cost-effectiveness analysis. Without including social costs, open cut becomes a cost-effective option under certain conditions. For example, when the depth of installation is shallow, the soils are stable, and no ground water is present, open cut may be more cost effective than trenchless options. The advantage of open cut is that it does not need sophisticated equipment and extra skilled personnel. There is also the opportunity to inspect the pipe fully and ensure it is constructed according to the specifications. Site conditions, such as soil type, also may limit the options to open cut only. As a general rule, open cut should not be the first choice, if trenchless options are feasible and cost-effective.

Figure 5-6 Open Cut Installation of Sewer Pipe

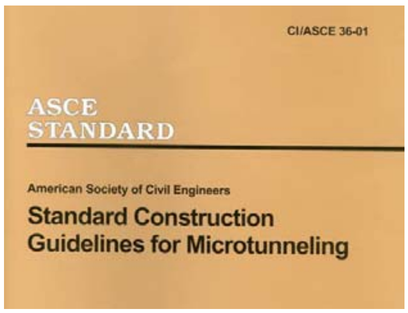
A case of open cut installation is presented as an example. Open cut was utilized for installing shallow depth segments of the new St. James Avenue Interceptor in Boston, MA (Goldberg & McSweeney, 1997). The original system was found to be in a deteriorated condition including non-uniform settlement of the pipe, sags and structural deficiencies, surcharging in the system, and extensive groundwater infiltration. The project removed a significant amount of groundwater infiltration that previously discharged into the sewer. The elimination of this infiltration translated into a reduction in the treatment cost at the Deer Island Wastewater Treatment Plant. By separating sanitary and storm sewers, the potential for sewer overflows into the Charles River was also decreased.

5.4.1.2 Microtunneling

Microtunneling was developed in Japan in the mid-1970s. The first use of microtunneling technology in the United States occurred in 1984 when a 72-inch boring machine was used to install a pipe under Interstate 95 in Miami, FL. Microtunneling has since been extensively used in the Houston area for upgrading the sewer system.

The North American definition of microtunneling describes a method and does not impose size limitations on that method. The tunnel may be considered a microtunnel if all of the following features apply to construction: the microtunneling boring machine (MTBM) is remotely controlled, a laser guidance system is employed, a jacking system is used for thrust, and continuous pressure is provided to the face of the excavation to balance groundwater and earth pressures. Microtunneling can handle very difficult flowing ground conditions. While advances are being made for microtunneling in rock, those challenges are significant.

The process starts with the MTBM being lowered into a jacking pit and proceeding along the desired path until it reaches the exit pit. The face of the machine provides positive support for the face of the excavation. Pipes are jacked behind the MTBM as it progresses through the ground. The jacked pipes provide the support for the excavated tunnel during the tunneling process and can be used as the carrier pipe without a need for installing a separate pipe inside the existing pipe.



The American Society of Civil Engineers (ASCE) has developed Standard Construction Guidelines for Microtunneling, ASCE 36-01, (ASCE, 2001). This document covers the planning, design, pipe materials, and construction of microtunneling.

Numerous applications of microtunneling have been reported in the technical journals and conference proceedings. For example, Boyce & Fowler (2000) reported on the successful application of microtunneling for installation of new sewer lines at the San Francisco Zoo. Many of the Zoo's older sewer lines had inadequate slopes which caused clogs, backups, and flooding throughout the zoo. Although the sewers were initially designed to be installed by the open cut technique, there were concerns about potential impacts to the zoo animals and visitors. The adopted solution was to use microtunneling to minimize the impact, even though the cost of microtunneling was higher ($8.6 million versus $6.3 million for open cut). Approximately 2,707 feet of 36-inch Class V reinforced concrete pipe was installed in four segments and the project was completed with minimal impact to the Zoo's operation.

5.4.1.3 Augor Boring

Auger boring is a trenchless excavation technique used for road and railway crossing. This method utilizes a process of simultaneously jacking a casing through the soil while removing the spoil inside the encasement by means of a rotating flight auger. Bentonite slurry may be injected to reduce friction between the casing and the surrounding soil. Since the grade cannot be controlled very accurately, the auger-bored pipe is often used as a casing, with the carrier sewer pipe installed in it. The carrier pipe is held in place by a tie-down assembly, or the annular space is grouted. Auger boring may be used for casing sizes from 4 inches to 72 inches in diameter. The drive length can be as long as 600 feet, even though the most common length is between 175 feet to 225 feet. The accuracy is approximately +/- 3 inches for every 300 feet. Better accuracy can be obtained by using guided auger boring.

Figure 5-7 Typical Augor Boring Tunnel Head

Auger boring can be used in a variety of soil conditions from wet running sand to hard pan clay. Auger boring can also be used in rock and in areas where small boulders may be present.

The application of auger boring has been reported frequently in technical journals and conference proceedings. For example, the City of Billings, MT, used guided auger boring for installing 440 feet of 36-inch casing through solid rock for a sewer line (Billings, MT Webpage, 2003). On this project, a remote grade indicator was used which allowed the crew to monitor the elevation of the lead casing.

5.4.1.4 Horizontal Directional Drilling

Horizontal directional drilling is a suitable method for trenchless installation of siphons and force mains. It also has been used to install small diameter sewer lines over short distances. Maintaining grade for pipe installations is a challenging requirement when this technique is used for installing gravity sewer. This method is especially suitable for crossing rivers, large streams, and wetlands.

Directional drilling is a combination of conventional road boring and directional drilling of oil wells. Directional drilling as long as 6,000 feet and up to 48-inch diameter pipe has been performed in the past. The technique includes drilling a pilot hole along a desired path, followed by enlarging the pilot hole by a reamer and pulling a pipe through the hole. Bentonite is used to support the hole and lubricate the pipe to reduce the pulling force. The technique can negotiate both vertical and horizontal bends. The radius of the curvature is based on the type and diameter of the pipe to be pulled through the hole. The recommended minimum radius of curvature for high density polyethylene pipe (HDPE) is 100 feet per inch diameter of the pipe.

Figure 5-8 HDD Equipment

The successful application of horizontal directional drilling techniques for installation of siphons and force mains has been reported frequently in technical journals and conference proceedings. For example, Staheli, et. al. (2000) reported on the application of horizontal directional drilling for the installation of a 1,200-foot long 30-inch HDPE siphon under the Alameda Channel in the San Francisco Bay area. The estimated construction cost was $1 million. The new siphon replaced an existing 20-inch force main which had to be abandoned.

5.4.2 On-line Replacement

Increasing capacity in the collection system used to be the sole province of relief or replacement sewers. An entire generation of maturing trenchless technologies has increased the options for cost-effective capacity increase. On-line replacement is the practice of using the existing pipe annular space as a guide for insertion of a larger diameter pipe, resulting in the additional capacity. On-line replacement is favored when additional sewer capacity is needed, limited additional easements for relief or new sewers are available, the line and grade of the existing sewer are reasonably consistent, and other pre-design issues are satisfied. Often the upsized pipe costs are less than the alternatives. On-line replacement has become common in those regions of the country where wastewater agencies, consultants, and contractors have become comfortable with the technology application.

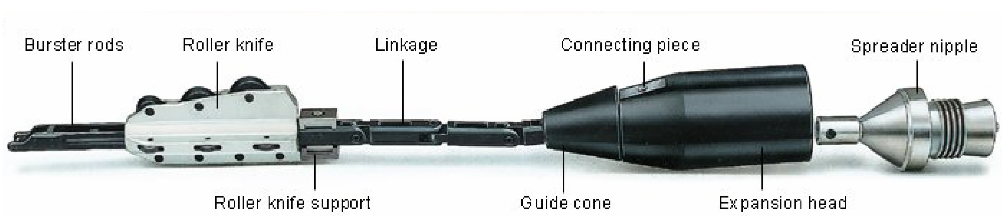


Figure 5-9 Typical Pipe Bursting Equipment

Pipe bursting is a common technique for on-line pipe replacement. One advantage of this technique is that the new pipe can be larger in size than the existing pipe. This upsizing capability is very helpful when additional hydraulic capacity is required. Pipe bursting can be achieved with diameters up to 30 inches. The upsizing is usually up to two pipe classes, although larger upsizing has been achieved on some projects. As an example, an 8-inch pipe may be upsized to 12-inches without encountering much resistance from the surrounding soils.

Sims (2000) reported that the City of Nanaimo, British Columbia, utilized pipe bursting to upsize approximately 12,900 feet of existing 14-inch inside diameter asbestos cement sanitary sewer with a 26-inch outside diameter SDR17 HDPE pipe. Due to the relatively long length and level of upsizing, a demonstration section was undertaken to test the viability of pipe bursting. The demonstration section was 1,900 feet, consisting of four runs of pipe, ranging in length from 360 feet to 600 feet. Approximately 560 feet was burst in about four hours. The demonstration project was successful, highlighting the speed and efficiency of the technology.

The Metropolitan Sewerage District (MSD) of Buncombe County, NC executed a challenging bursting project to upsize existing 10" ductile iron pipe and 12 inch cast iron. The resulting pipe size was 18 inch SDR 17 HDPE pipe installed at depths to 40 feet adjacent to a pair of railroad tracks, an interstate highway and a river. The new interceptor was designed to supply needed capacity for the Swannona River basin. After employing several field adjustments, the project was successfully completed under difficult field conditions (Gribbins, 2002).

Further information on pipe bursting is presented in Chapter 9 of this report.

5.4.3 Rehabilitation

A variety of techniques are available for pipeline rehabilitation including:

- Cured-in-place-pipe,
- Fold and form lining,
- Spirally wound pipe, and
- Segmental lining

The rehabilitation techniques are described in detail in Chapter 9.

5.4.4 Elimination of Hydraulic Bottlenecks

Hydraulic bottlenecks are caused by insufficient capacity in the sewer collection network to convey peak flows. These bottlenecks, which can be a single sewer segment or extended portions of the sewer, cause pipe to surcharge, backup and potentially overflow. This type of surcharge causes flows to back up into upstream pipes, thereby extending the impact well beyond the limited area of the bottleneck.

Hydraulic restrictions are manifested through a variety of conditions. Sewers derive their capacity through properties of the pipe, such as material roughness, diameter and grade. The pipe with the least capacity is a critical component in the capacity assessment review. This may be due to topography or other factors resulting in a flatter grade and lower capacity than the adjacent sewer segments. Any potential for future surcharge and overflow driven by peak wet-weather flows will begin in the pipe segment with the least capacity. The technical portion of the evaluation is to determine those conditions that are generating the peak flows. The cost evaluation is to determine whether it is less expensive to reduce the excessive I/I or to increase the capacity of the deficient segments.

Minor sewer defects, such as leaking joints, can lead to major structural problems in certain soil conditions when the sewer is subjected to regular surcharge. If an exfiltration/infiltration cycle occurs, it is possible to cause migration of fine soil particles into the sewer and subsequent voids or loss in soil density in the vicinity of the sewer. Lack of trench side wall support to the sewer can lead to cracks, fractures, and eventually collapse. Since a pipe must become surcharged before an SSO can occur, it can be seen that structural and hydraulic problems can be closely interrelated. Also, as sewers deteriorate physically, it can be shown that their effective roughness increases, causing their hydraulic capacity to decrease. This increases the likelihood of surcharge and accelerates further structural deterioration.

Sewer grade, pipe diameter, and pipe friction factors were described earlier as contributing to the capacity determinations of pipes in the collection system. Existing conditions of the pipes can reduce the design capacity to something significantly less. Any loss of grade within a sewer segment, such as sags, bellies or depressions, is a major detriment to the capacity performance of the sewer. Sags are caused by both poor compaction during construction and settling over time. In Austin, TX, sags are identified as the foremost cause of sewer malfunctions, as they promote deposition and accumulation of grease (Conegliano, 1999).

5.4.4.1 Bottleneck Analysis

Dynamic or unsteady-state models have the ability to handle surcharging, backwater and overflow conditions, and thus enable the user to analyze the potential locations and flow rates for SSOs. Hydraulic modeling is but one technique for identifying and analyzing hydraulic bottlenecks. Surcharge, building backups and overflow are indicators not only of the nature of the problem but also its location. The flow impact will manifest itself immediately upstream of the bottleneck or location of restricted flow.

While pipe capacity is a more traditional version of the flow impedance, there are a host of other reasons as well. There is a school of thought that all backups and overflows are capacity related. Even partial stoppages caused by roots and grease are forms of capacity restrictions that predominate during dry weather. Blockages serve as impediments to the free discharge of the wastewater flow through the collection system.

A frequently used tool for identifying and analyzing these potential hydraulic restrictions is flow monitoring (See Section 8.3.1). Flow monitoring results can be used directly in the interpretation of "scattergraphs," two-dimensional plots of velocity versus depth of flow.

Depending on the shape, a potential overflow occurrence may be identified from the scattergraph, but not the quantity of overflow. An increase in velocity while maintaining a relatively constant depth is indicative of a downstream overflow. Likewise, clusters of closely plotted constant depth and velocity points may identify an upstream SSO.

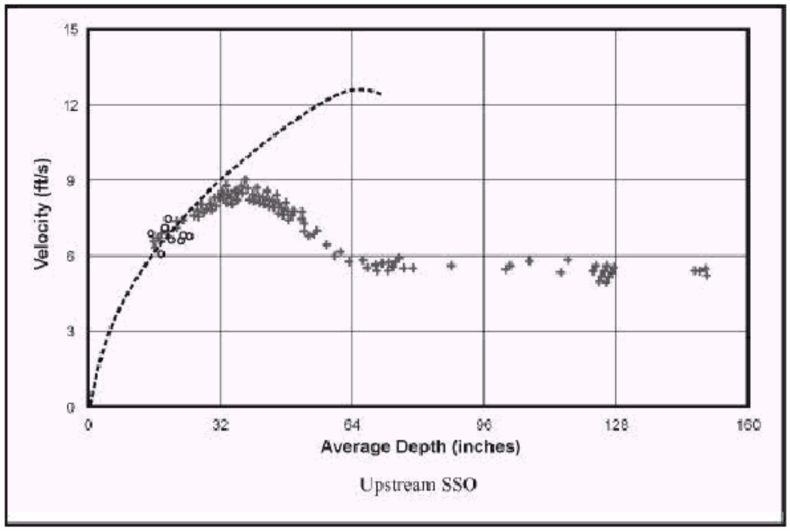


Figure 5-10 Scattergraph

Not all bottleneck problems are identified through engineering analysis. Empirical observations have also led to deductive understandings in problem areas. Manholes play a key role in moving wastewater through the collection system network. In nearly all instances, the manhole will be the critical capacity as head losses are induced through the structure which are not typically in play through the pipe.

The variety of junctions within the manhole to merge flow can help or hinder the free passage of the wastewater. Severe bends, channels cut below the springline of the pipe, drop connections, plugged drop connections, free fall discharges, and matching inverts of flows with significant differential velocities are just several of the field conditions which will induce hydraulic restrictions and create the potential for surcharge, backup and overflow during times of peak flow. Field observation, as-built and plan research, and condition assessment surveys will identify these localized, potential problem areas for further study.

5.4.4.2 Bottleneck Solutions

There are many ways of solving hydraulic bottleneck problems. The solution involves not only providing increased conveyance capacity for overloaded sewer lines, but also the method to be used in the implementation of the preferred rehabilitation option. Traditionally, pipe repair or replacement by open-cut methods has been used. Modern advances in trenchless techniques mean that this is often the more cost-effective pipeline rehabilitation option, and is becoming more popular.

Capacity of the entire length of sewer is often not the issue, but rather a limited segment of flat pipe with a lesser capacity than the balance of the sewer. Relief and/or replacement techniques found in Sections 5.4.1 and 5.4.2 are appropriate and can be tailored to selectively increase the capacity of the sewer segments involved.

Separating sewers is often a term only associated with combined sewers. However, it has been used effectively in sanitary sewer applications to isolate and separate troublesome hydraulic junctions in manholes, enabling the merging flow components to flow freely. The Washington Suburban Sanitary Commission (Hannan, 1999) undertook a series of sewer relocation projects which had a common theme of rerouting hydraulically restricted flow to a more downstream location where it could discharge at improved velocities and more favorable elevations for better performance.

These relocation techniques were used to eliminate several common geometry and velocity problems found in troublesome junction manholes. One manhole junction included sewers with minimum grades or flat slopes merging at 90-degress with flows at high velocity, drop connections. This created backwater effects in the minimum grade sewer at elevated wet weather flows and led to backups in the homes connected to the sewer just upstream of the manhole. The relocation routed the flat sewer around the drop connection and created a new junction manhole downstream where more favorable grade conditions existed.

In another problem, a prior relocation of a 36-inch sewer had created multiple 90-degree bends in manholes through a series of short sewer segments. The head losses through the series of manhole bends were the limiting capacity constraint on the system. The resolution was to "straighten" out the bends through another relocation, resulting in full capacity being restored to that portion of the interceptor.

Neighborhood sewer connections to trunk sewers have also led to other manhole junction issues. In one instance, the invert of smaller-diameter, slow-flowing local sewer was cut low in the channel with respect to the larger diameter interceptor, routinely restricting the local discharge during the high flow portion of the diurnal cycle. The resolution was to relocate the minimum slope sewers parallel to the larger sewers for several hundred feet to regain vital elevation. This enabled the local sewer to free fall into the channel of the interceptor from a higher elevation in a new manhole downstream, rather than having the higher velocity interceptor restrict the slower local flow.

5.4.5 Wet Weather Storage Facilities

Storage of peak wet weather flow has become an option for a variety of communities where limited downstream collection system capacity or satellite agreements limit the rate of flow that may be delivered through a tributary system. Storage can be in the form of covered or uncovered basins, in-line or off-line.

5.4.5.1 In-Line Storage

In Europe, in-line devices that slow the flow and limit the velocity are potential adaptations in areas where excess capacity in specific sewer segments exists upstream of problem areas. Stationary flow regulators such as the "Steinscruv" are installed in the pipe, causing flow to fill the pipe with excess capacity by limiting the release of wastewater to the downstream, capacity-impacted sewers. Designed to be self-cleaning, these devices may be applicable where a capacity imbalance exists in the collection system that can be utilized (EPA, 1998).

5.4.5.2 Equalization Basins and/or Off-line Storage

Equalization (EQ) basins are used for temporarily storing excess flows from a wastewater collection system. The effluent is allowed to re-enter the collection system as peak flows recede. Therefore peak flows are attenuated, or equalized, thereby eliminating or reducing the need for major capacity expansions downstream of the EQ basin. Although EQ basins are traditionally used for the detention of storm water runoff, they are also used for the attenuation of peak sanitary sewer flows. The annual cost maintenance of EQ basins is typically estimated at between three and five percent of the construction cost.

The typical life expectancy of EQ basins is more than 20 years, and can be more than 50 years, allowing the capital investment required can be spread over a long period.

The dry extended detention pond is an EQ basin whose outlets have been designed to detain water a minimum amount of time, usually 12 to 24 hours, to allow particles and associated pollutants to settle. Unlike wet basins, these facilities do not have a large permanent pool of water. However, they are often designed with small pools at the inlet and outlet of the basin structure.

Dry detention basins are similar in design to wet EQ basins except that they do not detain effluent from small flow events. Dry basins can help to provide flood control and channel protection in a watershed. A concern with dry basins is the potential detrimental impact on nearby property values. One study (Emmerling-Dinovo, 1995) found that dry basins can detract from the perceived values of homes by between three and 10 percent.

The Washington Suburban Sanitary Commission (Hannan, 1999) utilizes a 6-million gallon storage tank adjacent to the Rock Creek trunk sewer to limit peak wet-weather flows in order to comply with an inter-municipal agreement. Taking advantage of the existing topography at the site, the tank, which is predominately above-ground, is shielded on the subdivision side of the facility from the public view by an existing hill and provides dual function to the community by offering sports fields and courts on the roof deck. During periods of high flow, gates are opened remotely by SCADA controls to divert a portion of the peak flow into the influent pump station for the storage tanks. Sufficient flow is diverted to keep the flow at the metering point below the agreed upon limits. When flow is retained in the tank, the wastewater is kept aerated in individual one million gallon cells. The wastewater is then released by gravity back into the system at a controlled rate when the flows in the interceptor recede. The cells must be cleaned manually after each use, a significant maintenance impact when the tank use is required.

A variation of the EQ basin is the tank, or pipe tunnel, storage option. These are generally used in urban built-out locations, on small sites. This is because tunnel storage for a large area would not normally be economically viable. However, the small size of tunnel storage structures causes problems in itself. The outlet control diameter required for attenuation of the flows is correspondingly smaller than in conventional EQ basins. This creates the potential for debris blockages at the outlet, and the resulting maintenance and access problems with underground structures in the urban environment.

EQ basins can be used in a variety of applications. Some minor modifications may be needed in cold or arid climates where the flow is exposed to the elements. In general, the EQ basins should be used on sites with a minimum area of 10 acres. On smaller sites, the orifice diameter at the outlet needed to control relatively small recurrence storms becomes very small and thus prone to clogging. Also, it is generally more cost-effective to control larger drainage areas due to economies of scale.

5.4.5.3 Peak Excess Flow Treatment Facilities (PEFTF's)

Peak wet weather flows strain most collection systems and treatment plants at some point during the infrastructure's life cycle. Similar to the central tenet involved with combined sewer systems, the separate system is required to transport the all the wastewater flow during peak wet-weather flow conditions to the facility for treatment. There are a variety of options available for transporting and storing wastewater flow, both in-line and off-line, and there is now a growing number of treatment technologies capable of handling high rates of influent and discharging it at secondary effluent levels.

These designated wet weather, peak excess flow treatment facilities (PEFTF) are alternatives to flow reduction, capacity expansion, and wastewater flow storage/equalization modifications in the collection system. The PEFTF acronym is attributable primarily to the designation adopted by the Sanitary Sewer Overflow (SSO) Subcommittee of the Urban Wet Weather Flows Federal Advisory Committee (FAC) in the Fall of 1999 (EPA, 1999). Meeting since 1995, the SSO Subcommittee of the FAC expressed support for basic principles applicable to future federal discharge permit conditions.

The group explored a number of factors relevant to the performance of PEFTFs. These included preconditions for approval of a PEFTF, the level of the treatment, permit conditions, and whether such facilities should be temporary or permanent additions to the treatment train. The premise for consideration of the high rate facilities is that targeted agencies experiencing SSOs would conduct a thorough review of the collection and treatment capabilities with regards to overflows. An enforcement order would then provide the mechanism for scheduling and executing the PEFTF construction.

The consensus recommendations of the FAC for facilities that propose PEFTFs include:

- Targeting for consideration those agencies proposing PEFTF
- Targeted agency conducts a collection system evaluation, implements a CMOM program and determines the PEFTF is the most feasible SSO correction measure,
- An administrative order or consent decree identifies the schedule for implementation,
- PEFTFs may be a temporary or permanent solution, depending on the findings of the agency and concurrence by the regulators,
- The CMOM program must remain active and in effect with a review conducted every five years to determine if the PEFTF should remain or be modified.

Ultimately, if a PEFTF could meet secondary effluent standards, it could be covered by a permit and the enforcement mechanism would not be necessary. While a PEFTF is an alternative to more costly SSO elimination concepts, it is not a replacement for continuing to address the proper operation and maintenance of the collection system where the peak wet weather flows originate.

The National Sanitation Foundation International (NSF) and the EPA have joined together to sponsor and promote an Environmental Technology Verification (ETV) Program. The ETV Program results from a Cooperative Agreement between the EPA and NSF International to make “objective, quality-assured performance data available to all parties” in the twelve current areas of environmental technology. One of these twelve, the Wet-Weather Flow Technology Pilot, evaluates commercially available technology in several broad categories.

The areas of interest for PEFTFs are associated with advanced high-rate treatment technologies (Figure 5.11) including sedimentation, filtration, biological processes, and disinfection. Through the availability of credible performance data that may include contaminant removal efficiencies, applicability to a variety of flow regimes and quality, space requirements, maintenance requirements, and cost, technology users and regulatory agencies will have better information upon which to make an informed decision.

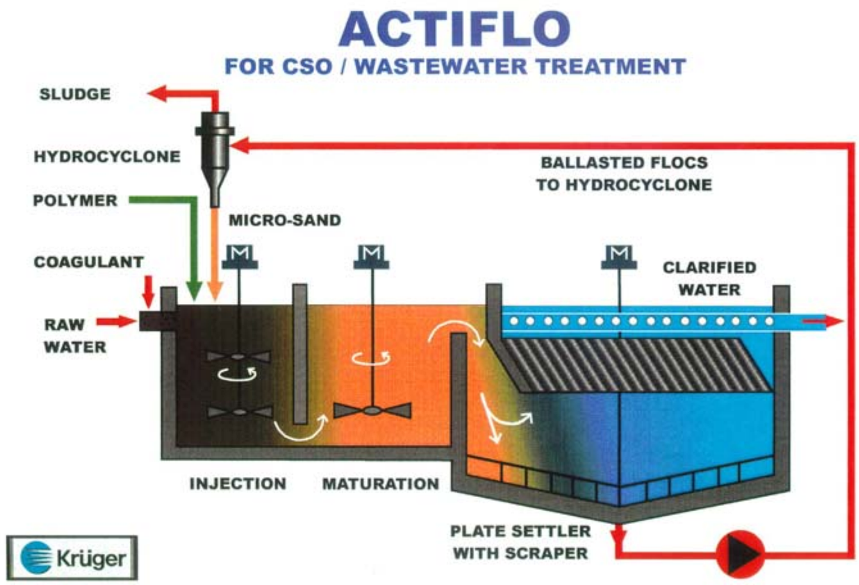


Figure 5-11 ActiFlo High Rate Treatment

The ETV Program places a premium on stakeholder involvement from advisory groups, technology panels, organizations contracted to develop testing protocols and perform the trials, and the technology vendors themselves.

5.4.6 Pumping Station Capacity Enhancement

If the diagnosis for an overflowing pump station is capacity, several options are available. Most stations are designed with pumping redundancy. Should the lead pump be lost, the lag pump(s) can handle the flow. If wet weather flows should overwhelm the existing station capacity with all pumps operational, then several parameters should be evaluated.

- Additional Pump **-** Most stations have been designed with expansion in mind, generally by providing for a “blank” where a pump can be added in the future to supplement capacity. Pumping head and force main limitations need to be verified, but the pump addition can significantly expand the capacity of the station at minimum cost.

- Impeller **-** The size of the impeller is a key factor in the capacity of an individual pump. By augmenting the scroll casing or through other modifications, many pumps can receive a larger impeller. The larger impeller enables more flow to be moved at the same speed than a smaller impeller. This is often a very cost-effective way to handle marginal increases in flows in smaller stations without the need for major modifications in the footprint of the station.

- Larger Pumps/Higher Speed – Pumps with higher capacity can often be installed in the same slot as the existing pump

- Variable Frequency Drive (VFD) – The variable frequency drive provides the flexibility to change the pumping rate to meet the rate of flow into the station.

- Station Expansion - There may be a need to expand the footprint of the existing station to increase the wet well capacity or to add an additional pump.

- Force Main Upgrade – In conjunction with pumping station capacity expansion, associated force mains should also be analyzed and be upgraded, as necessary.

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Chapter 6 Management Solutions

6.1. Introduction

Collection system management requires good record keeping, planning, and the appropriate tools to measure desired performance and comply with regulatory requirements. These elements enable managers to develop a trained and competent workforce, capable of operating a collection system efficiently with the appropriate amount of reinvestment to minimize the occurrences of SSOs.

The management of a utility's organization, human resources, information database, finances, and assets has a direct impact on the utility's operational efficiency and financial status. This in turn affects the levels of service that a utility provides to its customers and the amount that a customer is charged for the service provided.

6.2. Asset Management

The American Public Works Association (APWA) defines asset management as a methodology to efficiently and equitably allocate resources among valid and competing goals and objectives (APWA, 2003). The allocation of resources occurs within a particular class of assets, such as sewers, and the needs of that asset are determined by managers or management systems. An asset management process will optimize the investment in the infrastructure while helping control the day-to-day operating costs.

Asset management is an important element in the effective operation and maintenance of a utility as well as a key component for complying with changing government and accounting regulations. Government Accounting Standards Board (GASB) Statement 34 requirements address restructuring the model used by municipal utilities for presenting asset information in their financial statements (GASB, 1999). The requirements include reporting of historical cost and an annual depreciation amount for infrastructure. GASB 34 also includes a "modified approach" that involves establishing a condition rating system and setting minimum performance levels for infrastructure maintenance. The EPA's proposed CMOM regulations will mandate new requirements for management of wastewater utility infrastructure (EPA, 2001). Both of these changes are to encourage utilities to better manage their assets.

The purpose of wastewater utility infrastructure is to provide cost-effective, reliable collection and treatment of wastewater. Each component of the infrastructure should be planned, designed and specified by professionals who are certified, licensed or accredited to perform the required task. Installation of each component should be performed by competent, trained, certified utility staff or licensed contractors. The complete system should be maintained by adequately trained personnel to ensure satisfactory performance. When the continued performance of a component cannot be cost-effectively assured through prescribed maintenance, it should be rehabilitated or replaced using qualified professionals, trained utility staff, and/or licensed contractors.

An asset management plan for the operation and maintenance of each system component should be established prior to its commissioning. Monitoring of this plan should be part of the management plan for the utility. Criteria that will signal the need for rehabilitation or replacement should be identified in the asset management plan and monitored during the operation and maintenance stages. Monitoring of the asset management plan components such as operation and maintenance plans, and ongoing component condition assessments, should be included in the asset management plan for the utility.

A typical approach to asset management includes five basic steps as shown in Figure 6-1 and described below:

- Inventory Assets. A comprehensive inventory of system assets requires a combination of records research and field verification. Electronic databases linked to GIS for mapping of the assets can also provide a basis for maintenance, modeling and valuation.

- Value Assets. Condition and cost data allow for an accurate accounting of the fair market value and for projecting future financial decisions.

- Evaluate Asset Capabilities. System hydraulics and condition assessment for existing infrastructure and projected future conditions enable system improvements to be implemented in a cost-effective manner.

- Maintain Assets. The condition of the assets must be maintained in order to sustain the desired level of service.

- Optimize Assets. Measuring performance is the key to improving work processes. The proper balance of maintenance staff, equipment, and reinvestment in the collection system is an essential element of asset management.

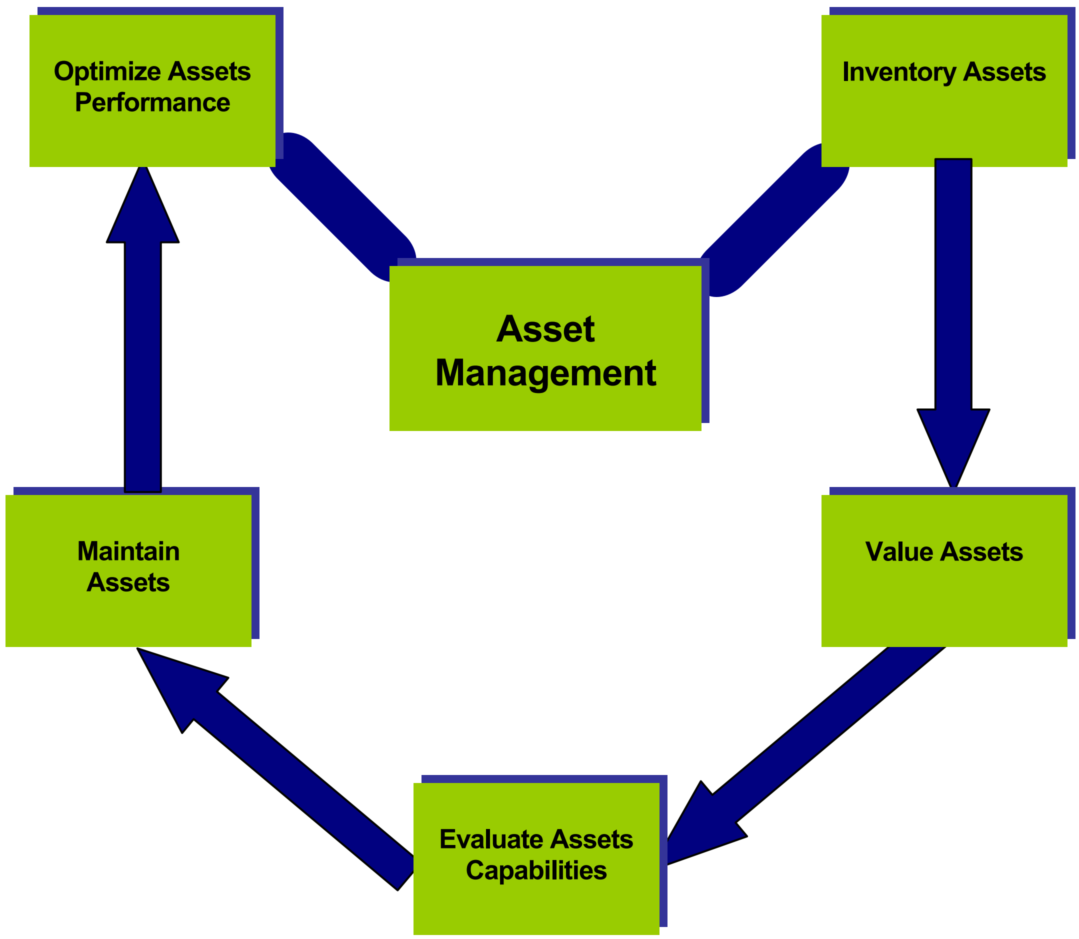


Figure 6-1 Asset Management Steps

Asset management seeks to concentrate the efforts of municipalities and utilities on optimizing the replacement cycle of their assets in order to provide maximum financial leverage for the future. Premature replacement results in a negative impact on the Profit & Loss account as the undepreciated residual asset value is written out of the balance sheet. This, in effect, requires communities to fund the replacement of assets before they reach the end of their useful life. In some cases, the loans which were taken out to pay for the assets will not have been redeemed before the assets are retired and further loans are sought.

The management of asset serviceability is achieved through the establishment of an asset inventory and an assessment of serviceability. The concept of serviceability can be defined by performance and condition.

A systematic and consistent scheduling system is required to ensure that the right job is performed on the right assets, at the right time, with the right materials.

6.3. Environmental Management Systems

An Environmental Management System (EMS) is defined as a continual cycle of planning, implementing, reviewing and improving the processes and actions that an organization undertakes in order to meet its business and environmental goals (EPA, 2004). EPA supports the application of EMS to encourage organizations to improve compliance, pollution prevention, and other measures of environmental performance. Many EMSs are built on the "Plan, Do, Check, Act" model (EPA, 2004). This model leads to continual improvement based upon:

- Planning, including identifying environmental aspects and establishing goals [plan];
- Implementing, including training and operational controls [do];
- Checking, including monitoring and corrective action [check]; and
- Reviewing, including progress reviews and acting to make needed changes to the EMS [act].

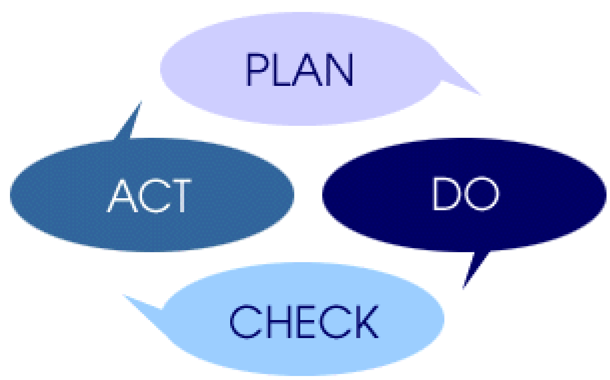


Figure 6-2 EPA's Plan, Do, Check, Act Model

EMS establishes what the organization does in order to manage its people and activities, including development of procedures, work instructions and controls to ensure that implementation of the policy and achievement of targets can become a reality. Communication is a vital factor, enabling people in the organization to be aware of their responsibilities, to be aware of the objectives of the scheme, and to contribute to the success of the management system.

The International Organization for Standardization (ISO) 14000 series of standards provides guidelines for implementing environmental management systems. ISO describes “environmental management” as the practice of managing the impact of an organization’s activities on the environment. The ISO 14000 series provides a set of tools for determining the environmental aspects of an organization’s activities, establishing goals and targets for those aspects, evaluating how well those goals and targets are being achieved, and continuously improving performance.

The series does not provide specific environmental targets or describe ways of achieving them, as these will be different in every situation. Instead, the documents provide generic frameworks and general principles that can be applied to a variety of organizations of any size, in any industry, with any number of products and services. This can include business enterprises, public administration, or government departments.

ISO's Environmental Management Systems (EMS) include a series of voluntary standards and guideline reference documents which include environmental management systems, eco-labeling, environmental auditing, life cycle assessment, environmental performance evaluation, and environmental aspects in product standards. EMS helps an organization to establish and meet its own policy goals through objectives and targets, organizational structures and accountability, management controls and review functions, all with top management oversight. The Environmental Management Systems specification document calls for environmental policies which include a commitment to both compliance with environmental laws and prevention of pollution.

The environmental policy provides the initial foundation and direction for the management system and will be stringently audited. The policy statement must be publicized in non-technical language so that it can be understood by the majority of readers. It should relate to the sites within the organization encompassed by the management system, and provide an overview of the company's activities on the site and a description of those activities, thus giving a clear picture of the organization's operations.

Many of the environmental assessments undertaken thus far have indicated that organizations are often unaware of all of the legislation that affects them, and frequently do not meet the legislated requirements as a result.

6.4. Benchmarking

Benchmarking is a process of gathering information on the performance of other collection system agencies and then comparing actual information from an agency that wishes to improve its levels of production and performance. Benchmarking consists of four steps as shown in Figure 6.3 and described below:

Step 1: Collect Current Data - The first step in benchmarking involves determining the current system performance based on available data. The types of data collected should capture the key parameters of the activities and performance to be measured. There needs to be some consistency in collected data within the industry in order to ensure comparable data is available for other agencies.

Step 2: Select Comparable Peer Agencies - The next step is to select comparable agencies for which data is available for comparison. These agencies probably have similar climates, topography, soils, and groundwater levels. Other important factors include age of system, pipe materials, number of lift stations, and limits of responsibilities regarding house service lines.

Step 3: Conduct Performance Comparisons with Other Agencies - The third step is to compare a utility's performance to the performance of other agencies. Comparisons of this type will indicate whether an agency's performance level falls within the general range reported by high-performing agencies. It is important to use caution when making comparisons in order to avoid reaching erroneous conclusions. Results from the comparison of performance indicators may reveal that an agency is performing below the level of other similar agencies. If an agency wishes to improve its performance, it must compare production and performance with other similar agencies and search for areas where changes in the operation and maintenance (O&M) program will produce improved performance.

Step 4: Make Year-to-Year Performance Comparisons – The final step is to compare similar segments of sewers within an agency's collection system on a year-to-year basis using different methods of inspection, cleaning, or chemical application to evaluate trends in performance. If results from the comparison of performance indicators reveal an adverse trend in certain performance indicators, the agency should identify the causes of these trends and implement corrective action.

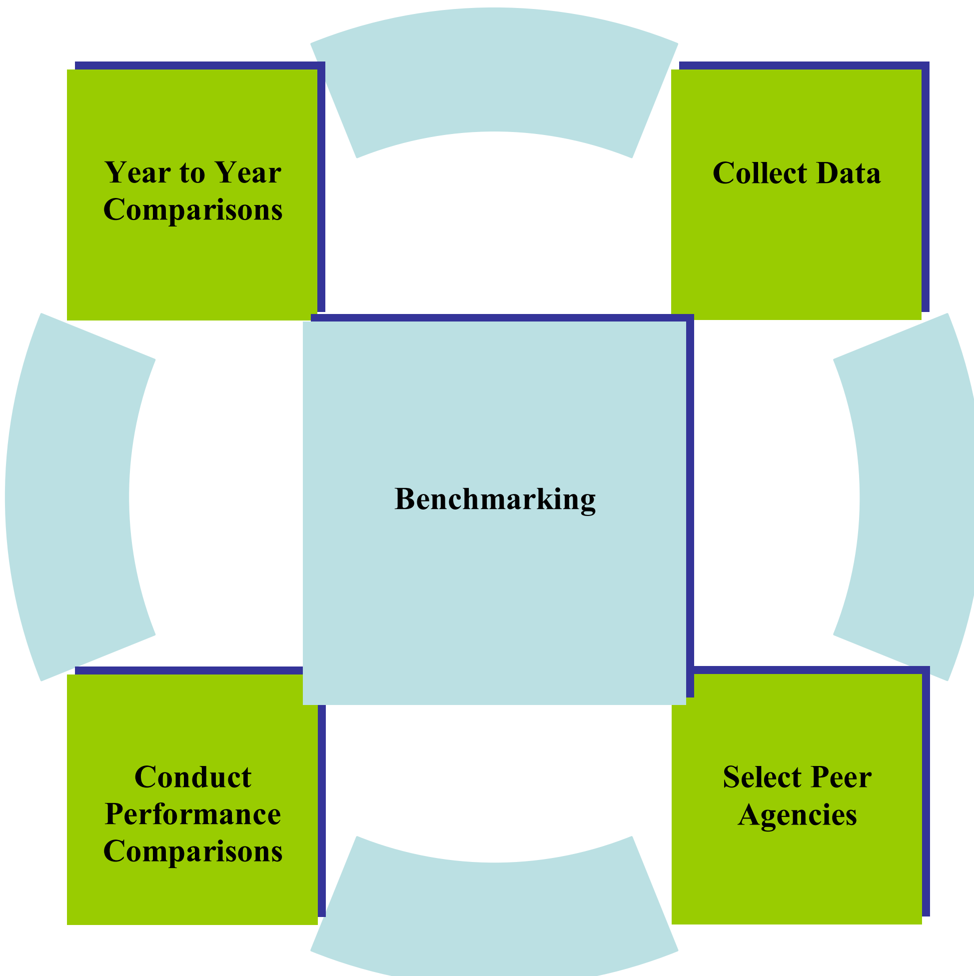


Figure 6-3 Benchmarking Steps

6.5. Organizational Management

An efficient organizational management is critical in both large and small organizations to ensure that resources are deployed effectively to accomplish the mission and objectives. Several principles are common to effective management, regardless of the mission or responsibilities of the organization. These include:

Planning - This is an ongoing process of developing the mission and objectives of the organization, and assessing how they will be accomplished. In the CMOM approach, the planning strategies for reducing SSOs and back-ups will play a significant role in allocating the appropriate resources needed in order to achieve the objectives.

Organizing - Through division, coordination, and control of the task to be performed, managers control the flow of information and distribute and/or delegate the authority necessary to accomplish the task. The ability for units or individuals to react independently but within the organizational structure to respond to emergencies and other collection system events is a critical element of a utility's response to CMOM requirements.

Coordinating - This ensures that a proper relationship exists among the various units within the organization, resulting in effective operation and decision-making. For example, if flow reduction is a critical component of the capacity strategy within CMOM, there must be a coordinated approach that incorporates both the legal authority to regulate satellite flows and private property I/I, and the means to address it.

Decision-Making - This is the process of reaching a conclusion or resolution after the consideration of future action. Analyzing the causes of SSOs is important to understanding the true nature of the overflows, but the implementation of the solution is critical.

Control - This is the process by which both the objectives and the performance in achieving the objectives are measured and corrective actions taken as necessary. Within the context of CMOM, this is the self-audit evaluation to determine if the actions taken to reduce or mitigate SSOs and backups are successful or need revision.

6.6. Resource Management

Effective and optimal utilization of resources can help the wastewater utility to achieve its objective of minimizing the occurrence of SSOs in the most efficient way possible. While equipment and other resources are important to the execution of the cleaning requirements, the most valuable tools are the personnel and staff. This section presents a number of innovative ideas to improve the effectiveness and efficiency of both human and equipment resources.

6.6.1 Human Resources

Human resources are the most important component of the resources available to manage, maintain and operate the collection system. A certified operating staff, professional supervisors, enlightened management, and appropriate incentives that reward high performers and eliminate poor performance are essential to effective maintenance of the collection system. Achieving the right balance of staff levels and supervisor-to-staff ratios is critical to optimal cost efficiencies for these services.

High-performing organizations have found motivational tools to encourage efficiency and effectiveness that can lead to reductions in overall size of the staff performing the services. The Washington Suburban Sanitary Commission (WSSC) in Laurel, MD was able to achieve field staffing reductions of 50 percent and increase supervisor-staff ratios in excess of 1:10 by restructuring the field units into teams and providing financial incentives for high performance (WERF, 2003).

Appropriate performance measures that address both quantity and quality are keys to ensuring that fast and efficient execution of the maintenance tasks is also effective. Fairfax County, VA (WERF, 2003) was able to reduce staff by 25 percent, eliminating non-productive activities such as in-house grouting and sliplining crews and by outsourcing other activities performed more efficiently by private vendors procured in the competitive services market, such as grass mowing, CCTV camera repairs, and easement clearing work. This permitted them to focus on what they do best and optimize those operations.

Reducing staff size often requires changing the way that a utility has traditionally done business. Purchasing new equipment that may require fewer personnel to operate, re-structuring preventive or proactive maintenance cleaning schedules to obtain favorable geographic distributions for daily assignments, incorporating GIS and electronic notebooks or laptops in the transfer of information to and from the field, adopting team- oriented management approaches and other fundamentally different methods of performing the work can lead to opportunities to reduce staff numbers and enhance the responsiveness and effectiveness of the resulting smaller unit.

6.6.1.1 Second and Third Shifts

For many small- and medium-sized collection system operators, the second and third shifts are the most troublesome for staffing. In addition to the potential difficulties of securing reliable personnel on a shift where there generally is limited staffing and supervision available, there are basic questions as to whether staffing these hours is necessary to maintain effective customer response.

Effective mangers identify the needs for these shifts by moving from reactive to proactive work, understanding their customers' expectations, and assessing their own work requirements. Decisions about permanently staffing these shifts or providing on-call response depend in part on the following issues:

- Those agencies making the transition from reactive to proactive work achieve the objective in part through investment in rehabilitating and replacing the deficient parts of the collection system generating the emergency or after-hours staffing requirements.
- Agencies perform a historical review of the frequency of second and third shifts emergencies or requirements to determine if part-time or other staffing resources are possible.
- Agencies explore whether limited or non-productive activity on second and third shift often can be handled more effectively and at less cost through on-call emergency responders. Both Fairfax County, VA and Johnson County, KS have successfully employed this strategy (WERF, 2003).
- Some agencies successfully integrate routine or proactive cleaning with emergency response. Some sewer locations, such as arterial or primary streets and commercial or industrial locations, may be more effectively cleaned when the traffic volume is less

during the second or third shift. This provides the rationale for the routine staffing of the third shift.

- More agencies are incorporating flexible worker concepts into their staffing. This philosophy enables a crew to handle any type of emergency within the wastewater infrastructure. This can provide a basis for effectively performing a variety of third-shift operations when fewer staff are usually available.

- Some agencies use effective communications and responsiveness to enable rapid and timely response by a crew brought in from their homes for a specific emergency response. Utility-assigned pagers and beepers are used successfully by many utilities including Washington Suburban Sanitary Commission and Fairfax County (WERF, 2003).

- Third-shift schedules that may be required to respond to seasonal or weather-related events, such as hurricanes or significant rainfall, can provide as- needed responsiveness without requiring year-round scheduling of the shift.

6.6.1.2 Flexible Worker

A concept that more collection system operators are moving toward is the “flexible worker” concept. The Washington Suburban Sanitary Commission (WSSC) has adopted such a program over the last three years and incorporated it into their maintenance approach (WERF, 2003). This program is based on the premise that a maintenance staff can perform a variety of tasks. It was developed out of a workload analysis that identified tasks that were routine and repetitive and could be considered part of an everyday workload. Overall, these tasks represented about 80 percent of the workload. The remaining 20 percent was identified as work performed by specialists because of the very high skill levels required or the infrequency of performance.

These tasks were then divided into three levels of skill, each with increasing difficulty. This was used as the basis for three job descriptions used for workers who would have a broad range of skills rather than one particular specialty. These jobs were then titled Utility Technician I, II, and III. Employee feedback was solicited throughout the entire process.

An additional skill assessment tool was developed in conjunction with the Flexible Worker Program. This tool is used to ensure that employees had the right skills for their job level, and to ensure that their skills were recognized. The tool is a self-assessment checklist that provides each employee with an opportunity to identify his or her skills. A panel of subject matter experts reviews each self-assessment. This panel has the power to approve the employee’s self-assessment, or in cases where there is a question concerning the employee’s ability, request a demonstration. Once the panel approves an assessment, the employee is slotted at the appropriate Utility Technician level. What makes WSSC’s program somewhat unique is that their flexibility covers both water distribution and wastewater collection operations. Sewer cleaning and broken water main repair operations are integrated within the same team of employees. The flexible worker concept allows for optimal utilization of available staff and permits shifting of human resources to those types of work that may have seasonal peaks, such as winter water main breaks. This permits streamlining of the workforce through greater utilization of existing staff.

6.6.1.3 Employee Empowerment

In accepting the benefits that empowerment brings to the employee, there is an obligation to embrace the changes necessary to improve performance. A concept that is often utilized within empowerment programs is pay-for-performance. The theory is that personnel will work harder and more efficiently when they have a stake in the outcome and if that effort results in working more productively, they should be compensated appropriately. Fairfax County, VA has developed such a pay-for-performance program whereby each employee sets a number of specific performance goals with his/her supervisor (WERF 2003). Improved decision-making has been a major benefit of employee empowerment.

A pay-for-performance approach can be used so that every year, each employee sets a number of goals with his/her supervisor. Each employee is evaluated by his/her supervisor (60 percent weight), him/herself (10 percent weight), and a minimum of two and maximum of four peers selected by the employee (30 percent weight; the employee decides the distribution of the 30 percent weight among the peers he/she selects for reviewing his/her performance). This system has been very effective, although the volume of paperwork and administrative requirements are relatively high.

WSSC in Laurel, MD approaches the issues of pay-for-performance from a different perspective (WERF, 2003). An incentive program has been developed to reward workers for accomplishing the base workload more efficiently. This program was developed as a component of their reengineering program to accomplish the workload with fewer staff.

The incentive program's goals are:

- Each team is required to achieve 70 percent or better of the performance measures.
- Each team is required to meet five out of the six service measures listed below:
- Percent response within two hours.
- Percent customer units out of water for less than six hours due to broken water main repairs.
- Percent customer units where broken main repairs were completed within 24 hours.
- Number of fire hydrants inspected (scheduled amount based on four-year average).
- Number of preventive maintenance sewer segment cleanings completed (as a function of the scheduled amount).
- Average rating from customer satisfaction survey cards (door hanger cards distributed to all customers receiving service).

Each team member rates all other team members. A team member is required to achieve a minimum score from his/her teammates to receive the incentive bonus. To be eligible to receive the incentive bonus, the team must meet the customer service and performance goals. Individuals have to meet or exceed the minimum score on the team behavior evaluation in order to receive the incentive. The incentive is paid quarterly with a maximum of $1,250 per quarter, per individual. If the team achieves 70 percent or less of the four-year average for that quarter, the team has not completed its workload and is not eligible to receive any incentive bonus. If the team accomplishes 90 percent of the base number, the team is eligible for the entire $1,250 incentive bonus for that quarter. If the team achieves 70 to 90 percent of the base workload, the amount of the incentive bonus would be prorated. Team members have formed sub-teams to address issues and problems that the team confronts. They have a keen awareness of how their behavior impacts the success of the team and this has proved to be a positive motivation for them.

6.6.2 Outsourcing

Frequent and repetitive cleaning requirements dictate the equipment and staff that are onsite and available to respond to both routine and emergency conditions. Leased equipment provides lower cost opportunities when the anticipated need is limited in scope or duration. Another alternative that many utilities have found to be effective in both reducing personnel and equipment costs is to outsource the cleaning of part or all of the collection system.

Outsourcing is the procurement of services to be performed by a third party. These could include situations where sewer cleaning is difficult to perform, such as large diameter sewers, extended lengths between manholes, access involving stream crossings or overgrown right-of-ways, where the utility doesn't desire to maintain seldom-used capabilities. Routine applications include contracting all the cleaning of a particular type, such as jet, combination jet/vac, cable drag, chemical root control, and rodding, cleaning within a particular diameter, or cleaning within a distinct geographic region. Outsourcing can be used to procure all the cleaning required or just to supplement existing utility operations.

Outsourcing has also been used to secure personnel and equipment as well. Washington

Suburban Sanitary Commission has procured field service personnel from vendors as a lower-cost alternative to bringing full-time employees on board. Fairfax County, VA employs a "limited-term" personnel concept where full-time temporary employees receive comparable pay as their co-workers but no benefits (WERF, 2003). These limited-term employees are generally used for seasonal tasks such as raising manhole frames during Virginia Department of Transportation street repaving program. These employees also serve as a low-cost resource, providing the County an opportunity to observe their performance and bring already trained candidates into full-time vacancies as they develop.

Keys to effective outsourcing include comprehensive specifications to guide the execution, performance measures to be obtained, inspection of the ongoing effort, and follow-up quality assurance. The QA/QC step is critical to monitoring the effectiveness of a contract operation that is not readily observable without closed circuit camera inspection. Random or targeted follow-up inspections prescribed within the contract can validate the performance of the vendor. Observed deficiencies can generate additional re-inspection as well as secure remedial cleaning from the vendor. Outsourced services include chemical root control, rehabilitation, cleaning, insect control, corrosion control, and CCTV.

6.6.3 Equipment: Ownership vs. Leasing

Having the right tools available when needed is a key to effective maintenance. However, collection system operators don't want to carry extra costs for equipment that see little productive use through significant portions of the year. The size of the system, the anticipated cleaning frequency for both the emergency and proactive components of the program, and the range of diameters all factor into decisions on what type of equipment to have on hand and the method of procurement.

Ownership: For utilities of all sizes, there is equipment that comprises the backbone for cleaning responsiveness where 24/7 availability is required. In these circumstances, there isn't the time or the opportunity to wait for a piece of leased equipment to be delivered. This equipment is not only reasonable to own but is required for effective customer service. Jet machines, power rodders, and other equipment with a wide range of applications fit this stipulation.

Lease: Leasing may be advantageous in several applications. Some cleaning requirements may have an extended frequency cycle or require specialized cleaning tools. In these instances, leasing may provide the necessary equipment, when needed, and at a lower cost than owning the equipment. Depreciation for costly capital equipment and significant overhead costs aren't carried on the financial balance sheet for equipment that may only see several weeks of service a year. Agencies may also employ similar leasing strategies for expensive jet-vac cleaning machines targeted for periodic, scheduled pump station wet well cleaning

6.7. Information Management

Information technology has become recognized as a critically important business tool. As well as traditional data processing applications designed to increase business efficiency through cost-reduction, information technology is being used to improve effectiveness, for example, through improved information for decision-making and faster speed of response to the customer.

It is clear that while developing these IT systems is a necessary business practice, the systems alone are not a guarantee of success. The question, therefore, is how new products, services, processes, and ways of working involving IT can be managed and integrated into the business practices to obtain business benefits. Today, availability and cost of information technology are not the major constraints on its effective application. The potential applications of information technology which can be cost-justified and are technically feasible far exceed the capability of organizations to exploit these opportunities.

An Information Management System (IMS) is a system with a comprehensive database including inventory, condition assessment, and asset management features. A Maintenance Management System (MMS) system incorporating IMS can be used to store information and generate work orders. Such a system would have a number of modules including:

- Customer service,
- System inventory, and
- Equipment and facilities.

MMS can also be used to link an existing inventory of as-built drawings which is maintained in a dBase format. This can eliminate the need to update the inventory information in both the MMS and dBase systems.

While information management systems are seen by utilities as an effective tool, its full potential is only realized when the data is transformed into a knowledge base through analytical means.

6.7.1 Geographic Information System (GIS)

A GIS is a computer system for capturing, storing, checking, integrating, manipulating, analyzing and displaying data related to positions on the Earth's surface. Typically, a Geographical Information System (or Spatial Information System) is used for handling maps of one kind or another. These might be represented as several different layers where each layer holds data about a particular kind of feature. Each feature is linked to a position on the graphical image of a map.

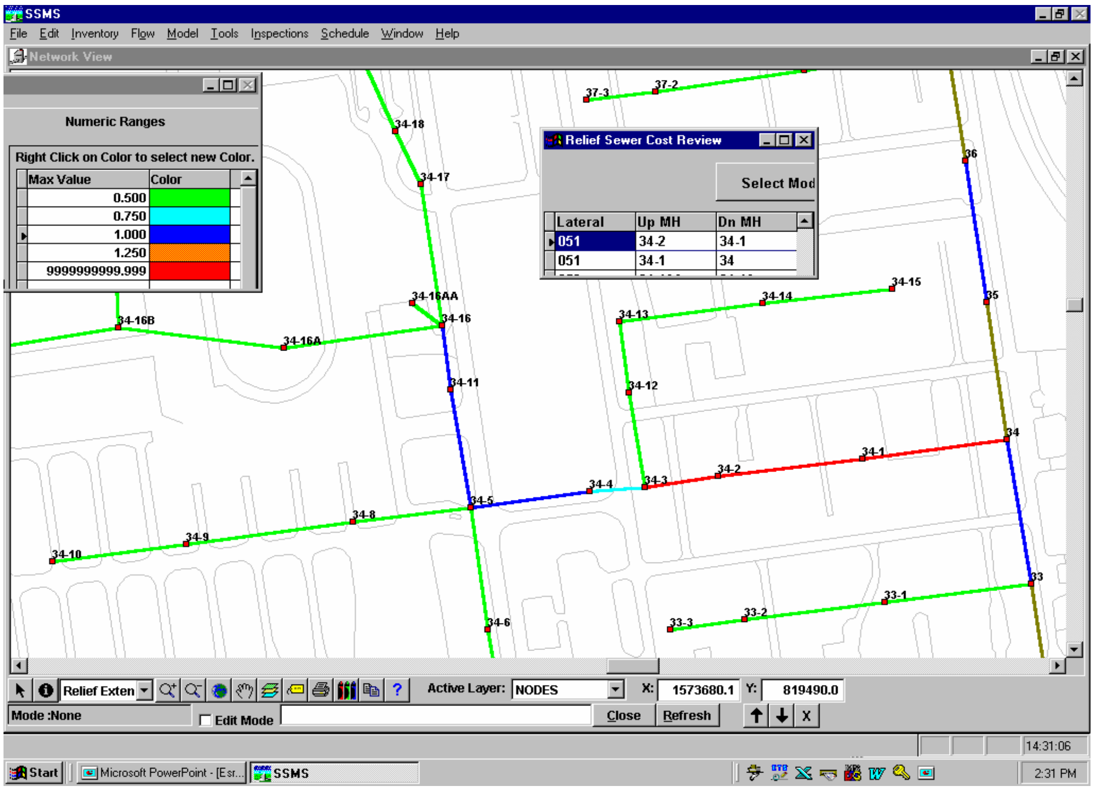


Figure 6-4 Sample GIS Screen

GIS allows utilities to collect, store, analyze, and combine the data needed for the management of a sewer system. It can also generate much of the geographically-referenced data needed to feed hydraulic modeling programs.

A full GIS, requires:

- Hardware (computers and peripherals),
- Software,
- Data,
- People, and
- Training.

GIS is mapping software that links information about where things are with information about what things are like. Unlike a paper map, where "what you see is what you get," a GIS map can combine many layers of information. As on a paper map, a digital map created by GIS will have dots, or points, that represent features on the map such as cities, lines that represent features such as roads, and small areas that represent features such as lakes. The difference is that this information comes from a database and is shown only if the user chooses to show it. The database, for example, may store where the point is located, how long the road is, and even how many square miles a lake occupies. Each piece of information in the map sits on a layer, and the users turn the layers on or off. One layer could be made up of all the roads in an area, another could represent all the lakes in the same area, and yet another layer could represent all the cities.

The old adage "better information leads to better decisions" is true for GIS. A GIS is not just an automated decision-making system but a tool to query, analyze, and map data in support of the decision-making process. The information can be presented succinctly and clearly in the form of a map and accompanying report, allowing decision makers to focus on the real issues rather than trying to understand the data. Because GIS products can be produced quickly, multiple scenarios can be evaluated efficiently and effectively.

Making maps with GIS is more flexible than traditional manual or automated cartography approaches. A GIS creates maps from data imported from databases. Existing paper maps can be digitized and translated into the GIS as well. The GIS-based cartographic database can be both continuous and scale-free. Map products can then be created that center on any location, at any scale, and showing selected information symbolized effectively to highlight specific characteristics. GIS has also been used by utilities on their internet websites so that utility customers can find details of ongoing maintenance activities.

6.7.2 Computerized Maintenance Management System (CMMS)

A comprehensive Computerized Maintenance Management System (CMMS) is a key tool in delivering effective customer service, resolving collection system problems, and providing the basis for developing a proactive maintenance program. By creating work orders and importing or exporting data to other modules in a relational database, the maintenance data within CMMS can be mapped, analyzed, and coordinated with other condition assessment information to yield solutions to stoppages, overflows, and backups.

An effective CMMS is also vital for compliance with the proposed CMOM requirements. The MOM portion of the proposed SSO rule incorporates record-keeping and performance objectives, measures, and self-audits to enable utilities to further reduce SSOs and backups. Elements within the CMMS necessary to comply with the MOM provisions include maintenance scheduling, frequency of cleaning, equipment/staff used, allocation of resources, maintenance histories, SSO record-keeping, and effectiveness in reduction of SSOs.

The CMMS will enable the utility to measure and track performance trends, optimize MOM practices, and enable the utility to move from a reactive to a proactive posture in stabilizing and reducing SSOs and backups. Historical records of emergency maintenance, preventive maintenance, and corrective actions yield the basis for developing proactive strategies to preclude the problem from occurring in the future.

The CMMS will have the ability to import and export text and data so that legacy data islands can be removed and other essential business systems can be populated. Today's systems are easily configured to suit the users' needs and provide the ideal master repository for all engineering information being handed over by the design contractor and the construction teams.

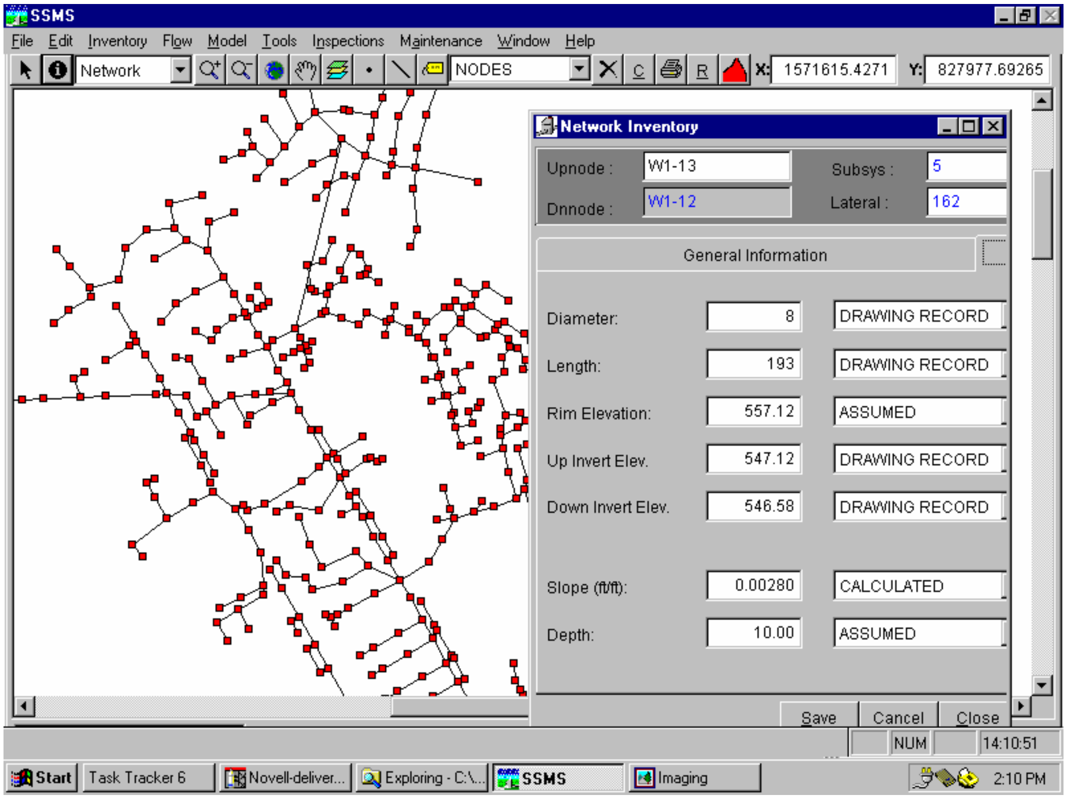


Figure 6-5 Sample CMMS Inventory Screen

Figure 6.5 Sample CMMS Inventory Screen A dedicated staff of technicians and system analysts maintain and continuously expand the capabilities of CMMS. System analysts investigate data anomalies, check data integrity, modify existing applications, and develop new applications.

6.7.2.1 Trend Analysis

A major benefit of CMMS is its ability to analyze data trends. The heart of a planning and monitoring system is prediction and trend analysis based on reliable performance information. The project management professional should monitor the project against its baseline plan and key performance indicators.

Trend analysis can be understood as a search for patterns over time in order to identify the ways in which they change and develop, veer in new directions or shift. It offers a dynamic assessment of the past and present and a means of extrapolating data for the future. Moreover, trend analysis can take different forms. It can be both quantitative and qualitative in nature, providing a basis for precise assessments of change as well as for broad assessments of the direction and impact of change. When trend analysis is done effectively, the analysis can assist in identifying critical trends, including the direction and scope of the changes taking place, whether they are positive or negative in their impact and whether they are qualitative or quantitative in nature. In some cases this can provide a basis for anticipating future behavior and taking precautionary measures to defend against damaging behavior.

Within a trend analysis, it is important to look for patterns in three different meanings of the term:

1) Recurring themes and motifs that are common across a whole range of cases at different times and places,

2) A particular design or a particular distribution of events that is either repeated in regular ways or represents an anomaly or deviation, and

3) A dominant form of activity that shifts over time and is replaced by another dominant form. It is also useful to distinguish between internal patterns that are, in effect, intrinsic to the activity, and external patterns that increasingly characterize a large portion of the activity.

Care should be taken in interpreting the results of the trend analysis. An example is provided to illustrate this point. A spike in the number of SSOs that accompany a rain event could be a direct result of that rainfall, yet it is also possible that what is seen as cause and effect are not in fact linked. An SSO that coincided with a rainfall event, for example, might well have been caused by something which has happened over some time, such as a FOG buildup, and have nothing to do with the rainfall. In other words, it is important to be aware of what can be termed the coincidence problem.

6.7.2.2 Proactive Maintenance Schedules.

A fully-operational CMMS can greatly simplify the scheduling of proactive maintenance activities. Major industries throughout the world have recognized the cost-saving trend toward a maintenance program that targets the root causes of wear and failure. Proactive maintenance methods are currently saving industries of all sizes significant maintenance dollars every year. This concept of saving large amounts on maintenance activities, however, may be difficult to comprehend. According to DuPont, "maintenance is the largest single controllable expenditure [in an organization]." In many industries, it often exceeds annual net profit. The problem of costly maintenance has reached a serious level, but as some companies have found out, and more come to realize every day, their maintenance costs can be cut drastically by establishing a proactive line of defense. While collection system management has some fundamental differences from other commercial enterprises, there are lessons to be learned by the sewer industry.

The accepted methods currently being used to combat sewer degradation are based on either detecting the warning signs of failure once they have already begun (predictive) or regular maintenance according to a schedule rather than the sewer's true condition (preventive). Crucial maintenance activities are often deferred when, in reality, maintenance may be necessary to avoid deterioration of assets or to minimize adverse impact in other areas, such as quality, life-cycle cost, overall utilization of the asset, or overall performance efficiency, over the long term. If this situation prevails for any period of time, the costs of not undertaking the required maintenance begin to appear.

Proactive maintenance addresses sewer degradation by concentrating on the causes of, rather than the symptoms of, wear. Proactive maintenance is being recognized worldwide as the single most important means of achieving savings unsurpassed by conventional maintenance techniques. Low-cost maintenance is a consequence of good maintenance practice.

6.7.3 Internet & Web-Based Systems

Like many other industries, the wastewater collection agencies have discovered the power of internet and web-based technologies for efficient and timely communication and transfer of information. Web-based GIS applications and web-based technologies provide the opportunity to get instant access to a variety of information. An ongoing need for field crews is access to complete and up-to-date information in the field. Plans, as-builts, work orders, maintenance history, and routine information are vital to safe and efficient field operations. For years, many utilities have produced printed sewer atlases that provide plan and scaleable views of the collection system. However, these depend upon a traditional update process that sometimes requires years for the changes or revisions to routinely make it into the paper editions available in the field. The advent of CMMS, GIS, and other computer tools has accelerated the pace at which information and map updates can be completed for office staff. The desire to transfer that capability to the field is realized by utilizing internet and web-based technologies. Several applications of such technologies are mentioned here:

- The field crew responding to an emergency situation can get instant access to a wealth of information residing in the utility's CMMS or GIS. Instant MMS access allows the crews to download the necessary information in the shortest possible time, enabling them to more efficiently respond to emergency situations.

- The field crews with internet access can update the information in the agency's central database in real time and eliminate the need for duplicate efforts which may introduce inaccuracies in the information being entered.

- The web technology is often used as an effective means of communicating with the customer. Communications with the customer is a vital link in exchanging information and building customer goodwill. Effective communication is achieved when the message is targeted, focused, and achieves the desired ends. An example of communication with customer through web technology includes advance posting of scheduled maintenance activities so that customers can take appropriate measures to minimize the disruption to their daily life. Similarly, information about the location of chronic SSOs, public advisories to avoid certain areas due to potential contamination, and other useful information may be posted on the web.

Internet-based technologies for field operations have three major components: database software, a handheld device and operating system, and a wireless system for remote access. Compatibility with existing systems is a key consideration for the database software. Options to consider for the handheld device and the operating system include size and weight, cost, battery life, screen size and resolution, and interface with the software. Wireless options include cellular-based systems using a cell phone and dial-up internet service provider and dedicated systems. Market conditions and costs in a particular service area may influence the selection.

6.8. Financial Management

Short-term financial management is generally concerned with fiscal year planning or budgeting. Long-term financial management is generally strategic, setting goals for a minimum of three to five years. The tools for financial planning are as follows:

- Pro forma income statements,
- Cash flow statements or budgets,
- Ratio analysis, and
- Pricing considerations.

The agency's short-term plan should be prepared on a monthly basis for a year into the future, employing the pro forma income statement and the cash flow budget tools. The long-term or strategic plan focuses on pro forma income statements prepared for annual periods three to five years into the future. Steps in developing effective long-term financial management plans include:

- Determine objectives and how they affect willingness and ability to pursue financial goals. This consideration will help to determine whether or not the business goals fit the business objectives. Long range planning enables the utility to be realistic about the future of its expectations.
- Set goals and objectives and express these goals in specific numbers. Examples of goals may be increases in revenues of 2 to 3 percent each year or a return on investment of not less than 9 to 10 percent each year. These long-range plans can be used to develop forecasts of revenue and compare actual results from operations to these forecasts. If actual performance continuously falls short of target after these goals are established, the agency should reassess the realism of expectations.
- Develop long-range plans that enable the agency to attain its goals and objectives. Focus on the strengths and weaknesses and on internal and external factors that will affect the accomplishment of goals. Develop strategies based upon an analysis of all relevant factors such as pricing strategies, market potential, competition, cost of borrowed and equity capital as compared to using current revenues for expansion to provide direction for the future of the business.
- Focus on the financial, human, and physical requirements necessary to fulfill the business plan by developing forecasts of sales, expenses, and retained earnings over the next three to five years.
- Study methods of operation, product mix, new market opportunities, and other similar factors to help identify ways to improve productivity and profitability.
- Revise the financial management strategy. The most recent financial statements should be used to adjust short- and long-term plans. Compare your agency's financial performance regularly with current industry data to determine how results compare with others in the industry. Learn where the agency may have performance weaknesses. Plans should be modified if expectations have been either too aggressive or too conservative.

6.9. Legal Ordinances

Enforcement of legal ordinances can lead to a reduction in number of SSOs by limiting the discharge of extraneous and non-authorized excess flows into the collection system, and improving construction quality of the sewer system and its components. Legal ordinances may cover a number of areas including:

- Fats, oil and grease (FOG) programs,
- Private property I/I,
- Satellite flows, and
- Construction, design, and inspection codes standards.

6.9.1 FOG Programs

Fats, oils and greases (FOG) are major contributors to wastewater collection system maintenance costs throughout the country. Wastewater agencies should consider developing and implementing proactive FOG programs to reduce the potential of SSOs due to FOG-related stoppages. A proactive FOG program is also a major component of a CMOM program. A successful FOG program would have several components including adequate resources, trained staff, enforcement, and customer education and outreach.

6.9.1.1 FOG Problem

FOG clogs the collection system leading to SSOs, fouls pumping station screens and force mains, and with excessive accumulation at treatment facilities, can lead to bypass of contaminants. FOG has both commercial and residential sources and contributions and both sources need attention for successful resolution of the problem.

Numerous studies have documented the impact of the FOG contribution to the SSO problem. Recent data for the first eight months of calendar year 2002 within Maryland found grease identified as the cause of the stoppage and resulting overflow in nearly 30% (139 reports of 486 total) of all SSOs reported through the 24-hour notifications (Hannan, 2003). FY 2003 reporting for Raleigh, NC similarly identified almost 51% of the SSOs to be grease-related (City of Raleigh, 2003). Statewide in North Carolina, 23-28 percent of all SSOs have been the result of FOG accumulations since 1998 (North Carolina Fog Task Force, 2002).

The problem is not just the grease alone, but the interaction of the FOG with the pipe material and the existing defects within the pipe. Some sewer pipes, such as PVC, are oleophilic, meaning oily substances are naturally attracted to the pipe material. The naturally sticky surface of FOG builds on the pipe wall and upon itself, resulting in increasing masses of FOG material in locations where it gathers and accumulates. Sags or bellies in the horizontal grade of the alignment expose more wetted perimeter of the pipe to the surface-floating FOG material. As the depth of the flow increases within the pipe, grease and oils cling to more of the pipe surface area, including sidewalls and crown. The diurnal flow, the 24-hour wastewater cycle, tends to wash the lower sidewalls. Higher along the pipe walls, however, there is less flow to wash the material away, leading to increased accumulations of FOG and ultimately diminished sewer capacity, stoppages and SSOs.

Grease combined with roots also creates a tenacious maintenance problem that limits relief options for both ills. The roots, in their thirst for water, penetrate the pipe at joints, connections and other infiltration opportunities. Since the roots are typically found above the flow line within the pipe, they occupy the same pipe headspace as surface-floating FOG. The roots themselves pose one problem and also serve as a catalyst for a more significant stoppage potential by providing a surface upon which the grease can cling and build.

The FOG problem can be found throughout the collection system in different forms. Most of the attention is generally focused in commercial areas with significant concentrations of restaurants or other FOG generators. Pre-treatment requirements have led to a variety of different grease interceptor/collector devices installed onsite to capture the FOG material before discharge to the collection system. Restaurant permitting requirements, health inspections and other food service protocols provide the opportunity for administrative regulation and inspection of these of these FOG sources.

Residential sources of FOG include cooking greases, oils, and soap residues commingled with other wastewater discharges to small-diameter pipes within neighborhoods. High-density residential complexes, particularly garden and high-rise apartments, traditionally pose a challenge for grease control. In comparison to the commercial FOG generators, the residential component of the FOG problem is more dispersed spatially, potentially has a higher frequency of occurrence, and may result in more significant O&M impacts to the collection system.

6.9.1.2 CMOM Perspective

Embodied within the management element of CMOM are the legal authorities and other tools necessary to administer programs which preserve and extend the service life of the collection system. The legal authority required to combat FOG discharges to the sewers are generally found within grease ordinances passed by system operators that stipulate the rules for dealing with grease discharges. Proactive authorities also follow up with inspection and enforcement programs to ensure the performance identified in the ordinance is met by the regulated community. Public education or outreach programs are vital to ensure that the program objectives and requirements are communicated to the public in general and to reach residential dischargers in particular.

Region 4 of the EPA has developed the components of grease control guidance as an element of an effective, proactive CMOM program (EPA, 2003). These program elements include:

- Recognized utility characteristics - The program should recognize and incorporate the size and complexity of the collection and transmission system. Local characteristics such as land use and zoning may concentrate FOG sources, which in turn could translate to collection system-specific program needs. The number and location of FOG sources, preferably integrated into GIS or other spatially distributed databases for analysis and easily updated, are also essential.

- Defined purpose and goals - The purpose of the grease control program is to prevent the introduction of the FOG material into the collection system. This is accomplished more effectively by regulating the material at its source before it manifests itself in stoppages and capacity loss in the public sector sewers. Goals include measures of specific program performance in terms of creating inventories of problem areas or sources, frequency and location of FOG-related stoppages, FOG ordinance compliance rates for regulated businesses, levels of FOG public awareness, and other specific and measurable standards.

- Documented activities and procedures - The program should have an ordinance authorizing the FOG program with specific requirements detailed. This may include permits, grease interceptor design requirements, prescribed operation and maintenance of the grease control equipment including the frequency and documentation for servicing the hardware, and the system operator's enforcement response. A series of plans for inspection, monitoring, enforcement, compliance assistance, budget, and staffing are also essential.

- Established performance measures - The program goals are measured and tracked to define levels of success, annual trends and other objectives that identify how well the program is performing.

- Periodic reviews, evaluation and revisions - A periodic review by program and utility managers of the performance measures yields a basis for assessing success. Failings in specific areas provide the basis for improvement and revision in grease control program.

- Adequate staff and training for monitoring and implementing - The activities and procedures defined for compliance translate to staffing and training needs. Active inspection and enforcement requires more staff than passive reporting from the regulated community. Active inspection is also likely to be more successful in gaining compliance. An effective program may blend both elements. The staff is also involved in plan review and outreach and education of the customers that the grease control program serves.

6.9.1.3 Ordinance and Regulation

The federal regulatory structure provides guidance and compliance direction to the state and local authorities. The state further amplifies compliance and can provide an effective role in defining requirements while the legal ordinance implementing the FOG program for wastewater discharge to the collection system is most typically a local instrument.

An example of effective state involvement for FOG program development is found in North Carolina (NC FOG Task Force, 2002). In June 2002, representatives of state agencies, local governments, and industry representatives serving on a FOG task force released a guidance document for developing local FOG programs and exploring the management issues associated with the generation of FOG at the source. The report provides discussion of the technology and design criteria for Fog Control devices, addresses best management practices for the industry, and identifies FOG sampling issues, FOG regulatory considerations, education and outreach programs, and additives for FOG mitigation in the waste stream.

There are a number of regulatory considerations that local utilities must assess before deciding on their approach to the FOG ordinance. All regulations and ordinances must begin with the end in mind. Once an effluent limit is adopted for FOG (e.g. 100 mg/l), a strategy for enforcement must be devised. Sampling of the effluent stream is effective, but requires resources and staffing to implement. A performance-based strategy related to implementation of best technology and proper maintenance of grease separation technology is an alternative.

The North Carolina FOG Task Force recommends these considerations when adopting a strategy (NC FOG Task Force, 2002):

- If effluent limits are adopted, the local government should confirm that such limits are "technically supportable" and take into account the requirements for monitoring and enforcement. For instance, grease devices should have reasonable access for sampling, and the sample results should be used for establishing performance and maintenance frequencies.

- "Action levels" may serve as a more effective enforcement tool rather than a single numerical requirement, as escalating violations may warrant more increasing penalties. Second and third violations may involve additional fines or actions to bring the violator into compliance.

North Carolina issues a collection system permit independently of the wastewater treatment plant. This enabled the state to address issues specific to the collection system separately from the treatment aspects of the traditional National Pollution Discharge Elimination System (NPDES) permit process. This general collection system permit also enabled the state to close a loophole related to satellite collection systems not addressed in treatment-based permits. The first 20% of the new state permits were issued in 2001 and will continue for the next five years to address the entire state. The permit mandates FOG regulation, education and enforcement to ensure proper maintenance and operation of grease separation devices. This is all tied to increasing the performance levels of the collection system operators with respect to SSOs.

Progressive enforcement of grease violations may include a tiered or escalating approach to citations and penalties. Depending upon the severity of the violation and the frequency of occurrence, an appropriate penalty is levied. Penalties increase with both severity and frequency of the violations. Progressive enforcement activity requires dedicated resources to be effective.

6.9.1.4 Industry/Technical Guidance

In formulating the FOG policy, there is consideration given to the effluent limits, whether specific interceptor or trap technologies and sizes are prescribed, and if pumping, cleaning, or maintenance frequencies are identified. In addition to evaluating the administrative issues for implementing and managing the program, industry input should be considered.

The Plumbing & Drainage Institute (PDI) is an association of manufacturers of engineered plumbing products (PDI, 2003). One of the association's functions is standards development. One standard, PDI-G101, promotes certified testing, rating and installation standards for grease interceptors. In the context of the standard, these interceptors are relatively small footprint devices, rated for capacity in gallons per minute (gpm), that achieve grease separation through internal baffling and vented flow control devices. Typical installations are inside, as close as practical to source fixtures, and may be set on the floor or recessed in the floor. There may be multiple devices installed from a variety of fixtures depending on anticipated flow rates. Due to their relatively small size and interior location, these devices are often used in commercial installations in urban downtowns, historic districts, and other sites where outdoor tank options are limited.

An alternative to the interior grease interceptor is the installation of an exterior, large volume, in-ground interceptor. These tanks are large-footprint installations where the typical specification is by capacity or retention times developed from typical flow rates.

These interceptors require large outside pad sites for installation and achieve grease separation by allowing the grease sufficient time to separate from the water emulsion in the large volume tank.

Another engineered product used for FOG control is the grease recovery device (GRD). GRDs typically are timer- or sensor- controlled. Timer-controlled GRDs pass a belt or disc through the grease layer to accumulate the grease on a predetermined schedule, then squeeze or scrape the grease off the collection medium for disposal. Balancing the timer activation to match the diurnal accumulation of grease is one key to effective use of the device. Sensor controlled-GRDs use electronics to identify the presence of grease and initiate the grease removal process on demand. Pumps and/or gravity flow complete the grease removal process.

Reliable, regular maintenance is a sound management practice for any of these devices to be successful in eliminating FOG from the waste stream over extended periods of time. Convenient access to the FOG storage for removal is necessary to facilitate regular maintenance. Review of cleaning frequency records, pumping logs, and manifests from grease haulers are some of the tools that utilities employ to ensure adequate maintenance is in place. These inspections can be active, with routine mailing of records for review, or passive, with records maintained onsite, and can be performed in combination with other health and environmental inspections of the restaurants or other affected commercial properties.

6.9.1.5 Education & Outreach

A comprehensive education and outreach program is vital to achieving success with any regulation, no matter which FOG removal approach is selected. For commercial FOG generators, the information is primarily intended to inform and educate in order to achieve compliance with FOG ordinances. The outreach is specific, targeted and comprehensive. The most effective outreach is performed in coordination with other government agencies (health, environment) and trade associations serving the FOG markets. Direct mailings, workshops, web information and other audio and/or visual presentations can effectively market the message. Active enforcement and promotion of the enforcement penalties are the clinchers to changing the behaviors that contribute to the grease problem in the sewers.

Residential generators of FOG are typically lower concentration but more widespread in the collection system. The different nature of these grease sources merit different tactics using the same mediums. Cartoon characters are often used to get the attention of the homeowner and renters. North Carolina Department of Environment and Natural Resources' Division of Pollution Prevention and Environmental Assistance developed the "Grease Goblin" as the image of the food service Green Plan grease removal program available for use by local governments in that state (NCDENR, 2003). In addition to the traditional education mediums, bill inserts, newspaper articles and community events are also used to reach the customer base. The message can be reinforced in conjunction with reporting of the scope of the grease problem in the collection system, the impact in cost and inconvenience to neighbors affected by backups and overflows, and the level of effort within the utility to control the problem.

Figure 6-6 Sample Grease Control Educational Material

An effective campaign was conceived in Charles County, MD, a suburban community with 230 miles of collection system. They developed and implemented an aggressive, pro-active FOG reduction program after determining grease was responsible for 50% of the SSOs. Although the county requires in-ground grease interceptors for food-handling establishments, several of the larger SSOs were in sewers with no commercial grease dischargers upstream. In pursuing their education and outreach, they targeted third-grade students where the curriculums incorporate the first exposure to water resources. The “Grease Busters” team of superheroes was created to combat the cartoon villain, the “Grease Glob.” The best management practice for the home was crystallized as a simple mnemonic called “**SWAT**;” **S**crape it, **W**ipe it **A**nd **T**rash it. School presentations and pledge signings have been conducted through all the county schools at the target grades. Outreach materials include t-shirts, coloring books, pens and other supplies that will find uses at school and around the house. (Ott, 2002)

Figure 6-7 Charles County's Grease Busters

6.9.2 Private Property Infiltration/Inflow

"It's 50% or more of the problem." There is probably no more quoted I/I statistic as that statement regarding the private property I/I contribution to a collection system. Agencies have borrowed the statistic so often because of the complexity and cost in determining the actual private property leakage rate for any specific collection system. There is tacit understanding that private property I/I is present in all collection systems to some degree. The lack of legal authorities and the private property issues involved in the investigation and elimination of the extraneous flow inhibit widespread pursuit of this element of I/I. Conklin (1981) and others identified the failure to address private property I/I as a primary reason many sewer rehabilitation efforts didn't achieve the level of flow reduction success predicted for system renewal efforts.

During the 1980s, a number of projects focused on the analysis and rehabilitation of private building sewer connections (PBSCs), or sewer laterals. This was due in part to recognition of the significant role that PBSCs play in the collection system. In a typical residential collection system, the length of lateral pipe is roughly equivalent to the length of mainline sewer, or approximately 50% of the total. Not only does the structural deterioration of the lateral pipe and the connection appurtenance play a role in leakiness of the PBSC, the agency's plumbing codes that may have permitted downspouts, foundations drains, areaway drains and other groundwater or stormwater discharges to the sanitary system are significant factors in an agency's overall I/I problem.

Solutions to the PBSC problem are compounded by the inconsistent legal authorities that exist around the country. Many agencies already have a responsibility for the "public" portion of the PBSC, which includes the connection and the building sewer lateral from sewer main to the property line. There may or may not be a cleanout at the property line, but there is generally a shift in legal ownership and resulting responsibilities for the pipe at this location. The "private" portion of the PBSC extends from the property line to the building and includes all the associated piping on private property. Some agencies refer to these same components as the 'lower' and 'upper' laterals. The backyard or sideyard location of the PBSC can increase the complexity of implementing a cost-effective solution. There are also utilities that do not have existing legal responsibility for any portion of the PBSC, leaving the primary responsibility, as well as cost for any solution, to the customer.

The variety of legal responsibilities for the pipe, the resources and costs required to investigate and resolve PBSC problems, and concern over future responsibilities for the pipe have generally paralyzed most agencies from addressing this significant problem. An initial point for meeting the challenge of what to do with this I/I source is a review and assessment of the agency's legal authorities.

6.9.2.1 Codes

Associated with the proper maintenance and operation of a collection system are the legal instruments to provide the basis for achieving compliance and enforcing the rules. Design requirements, construction specifications, plumbing codes and sewer ordinances are just some of the legal authorities that assist in building new PBSCs that are watertight and have a long service life. In order to receive Clean Water Act funds, the agencies must also implement sewer use ordinances that prohibit inflow connections. A National Pollution Discharge Elimination System (NPDES) permit requires the permit holder to properly operate and maintain all facilities and related appurtenances to achieve compliance.

Agencies implement the legal authority to exclude rainwater and stormwater from the collection system through plumbing codes. These legal instruments may reference national, regional, or local codes, or combinations thereof, but must provide explicit language prohibiting private property rainwater, stormwater or groundwater collected by the PBSC. Uniform Plumbing Code (UPC) and National Standard Plumbing Code (NSPC) are two examples of national standards adopted at the state or local level. Variation among the local codes is bound to exist as agencies may have "grandfathered" earlier accepted practices, such as areaway drain connections, or treated issues driven by local climate, such as air conditioning condensate, differently. If those conditions are permitted to exist in older portions of the collection system, then accommodations must be made to transport and treat the extraneous flow that these appurtenances allow in. In general, the adopted code should exclude areaway and foundation drains, roof leaders and downspouts, and other rainwater connections.

6.9.2.2 Permitting, Inspection and Enforcement

Once the code is in place, it is of little or no value if there is no permitting, inspection and enforcement. A survey conducted in conjunction with a Water Environment Federation (WEF, 1999) study into the control of I/I in PBSCs found that 83% of responding agencies had inspection programs in place for new PBSCs, many for 10 years or more. Active inspection of the construction requirements is a key to achieving compliance from the building industry.

Regardless of which department within a city or agency has responsibility for the inspection, a coordinated effort is required to ensure that all agency parties achieve the desired watertight PBSC from the onset so that problems are not constructed into the collection system. Cross-training of staff enables some agencies to meet these needs without additional staff. Building inspectors and code inspectors who typically work for other departments within the organizational structure can add lateral sewer responsibilities to their mix of duties. Inspection of new Pisces and building inspections for existing defects, such as sump pump discharges to sanitary laterals, may be effectively achieved through such a coordinated inspection effort.

As described earlier, the boundary between public and private responsibility for maintenance of the lateral varies among agencies, but is generally either located at the connection to the main or the property line. Agencies that prescribe complete private property ownership and responsibility of the lateral have an additional hurdle in administering an effective source reduction source program. This is due to the inherent difficulties that private citizens face in rehabilitating pipe in public space. Problems with PBSCs in public space are generally not resolvable by private citizens alone without direct involvement from the public agency. The resolution is more focused when there is a defined line of responsibility such as the property line.

Defects within these older PBSCs are often identified in conjunction with condition assessment tools used in the collection system. Once the I/I sources are defined and the solutions developed, there should be a coordinated field inspection to ensure that the repair or replacement is performed in accordance with the current plumbing standards.

6.9.2.3 Solutions

The private property I/I source has long been neglected because of the very nature of the location of the defect. Even when the legal authorities prohibiting the I/I source are well established, the private nature and personal impact to the customer makes for tangled and difficult resolutions. The sheer magnitude of the private property I/I contribution, however, has moved many agencies to devise a solution that works for their situation. This has resulted in a spectrum of solutions from rigid enforcement of the prohibitions to complete renovation of the deficiency, including financing, by the agency.

One size does not fit all when it comes to private property corrections. Different prevailing attitudes of the customer base toward the agency, the respective views of the role of government, legal prohibitions for the expenditure of public money on private property and a host of other issues have led to a patchwork of alternatives that agencies have found to work for them. The issue isn't primarily what to do or how to do it, just to do it. Whatever works for an individual community is generally more successful than doing nothing. Table 6.1 summarizes some of the different approaches being tried in the industry. A sampling of these alternatives as practiced by agencies across the country is presented to illustrate the range of approaches that are possible.

Table 6- 1 Private Property I/I Correction Options

	Financing Options			
Contracting Options	**Customer Financed**	**Agency Financed**	**Agency Rebates**	**Low/No Interest Loans**
Enforcement Only	X			
Customer Contracted	X		X	X
Pre-Qualified Contractors	X	X	X	X
Pre-Qualified, Fixed Price Contractors	X	X		X
Agency Contracted	X	X		
Property Transfer Requirement	X			

- Progressive enforcement- customer contracted/ financed.

Tulsa, OK utilizes a coordinated effort among the Public Works and Building Inspections Departments (WEF, 1999). Public Works identifies the problem and maintains the database of information. Building inspectors are the enforcement mechanism. After a site visit and correspondence directing the customer to repair the defect, the inspector monitors activity for a seven day period. If a permit is secured within seven-days, the inspector tracks the work to completion. No activity after seven days earns the customer a second citation advising them that they have 24 hours to begin corrections. A registered letter stating that the water meter will be pulled and no service provided follows after approximately three days if the work has still not commenced. Approximately 80% compliance is achieved after the first notification.

Dallas, TX also has a dedicated program that relies upon customer-financed repairs (WEF, 1999). A meeting is scheduled with all customers with documented private property defects to identify the problem and discuss appropriate resolutions. The city has achieved high compliance rates, approximately 95%, for the corrections. The other 5% are primarily high-cost, low-benefit repairs that the City ultimately forgives and does not pursue. Service interruption is also an enforcement tool that Dallas can use, but has seldom needed to use it in the decade-long program.

- Progressive enforcement- agency contracted/ no interest loan.

The customer has complete ownership and responsibility for the lateral from house to main in Montgomery, AL (Holmberg, 1999). The City has recognized the difficulty of a private citizen contracting work in public space and offers to perform the work in the lower lateral portion, at customer expense, up to a maximum charge of $1200 to the property owner. A four-year interest-free repayment period is also available for the maximum amount. The customer is provided 60 days to complete the repair or face service termination. A 10-day grace period is afforded when 60 days is insufficient to complete the repairs. Should the customer independently pursue the repairs, the city will perform spot inspections while the work is ongoing and conduct a follow-up smoke test to determine compliance. Any failures of the compliance smoke test result in additional work for the customer.

Extensive public relations, field visits, educational information, and an internet website were all used to implement the program. Sixty-five percent of the customers performed the corrections after the first notice. Overall, 97% of the required corrections were completed by the homeowners, although nearly 250 service terminations had to be implemented to gain compliance.

- Progressive enforcement- shared execution/ financing provided.

Mobile Area Water and Sewer System (MAWSS) of Mobile, AL, provides two options for customers to replace defective laterals from house to property line under their Private Sanitary Sewer Lateral Replacement Program (SSLRP). In Option 1, the customer pays for a MAWSS-secured contractor to perform the replacement. Either the cost is paid in full prior to construction or 15% down with the balanced financed through the city at 10% interest for a maximum five year repayment period. Under Option 2, the customer elects to hire and finance their own replacement with a registered plumber within 90 days of the MAWSS notice. Both options are with a progressive fine attached to the customer's accounts, ultimately escalating to potential service termination after six months (O'Sullivan, 2001).

MAWSS has introduced several twists into their private property process. Point repairs are not permitted on private laterals, as defects warranting the SSLRP are viewed as precursors to further deterioration. The decision is to replace all or nothing. Mini-systems within MAWSS's service area are targeted for the SSLRP where the most benefit will be realized. Testing of the laterals is performed by MAWSS using a different contractor from those that conducted the replacement to eliminate any conflict of interest in the outcome of the pre-and post-testing.

- Voluntary replacement- agency contracted, agency rebates.

San Luis Obispo, CA has adopted a Voluntary Service Lateral Rehabilitation Program (VSRLP) to address the many deteriorating Orangeburg and clay pipe service lines (Hix, 2001). The City has a history of encouraging participation in citywide renewal efforts such as low-flow toilet retrofits, fire sprinklers, and seismic retrofits, by rebating a portion of the customer expense from the city treasury. The VSRLP includes an application form for the customer, a City field visit and video inspection of the lateral, and authorization to perform the work. The customer secures his own contractor and completes the work. The City may be asked to visit the site to confirm additional work. The City performs a post-CCTV inspection after the repairs to confirm compliance. The homeowner may then request reimbursement of 50% of their cost up, to $1,000 maximum.

The VSSRLP is voluntary; no homeowner is forced to make repairs. Only single family dwellings are currently eligible. The program funding is first-come, first-serve for the annual funding of $75,000. Over 200 laterals have been replaced through the program since its inception in 1997. It was also noted that the 200 laterals replaced have not made a measurable impact on the city's rainfall-dependent flows.

- Agency contracted- agency financed

Sarasota, FL implemented a pilot lateral replacement program in a portion of their barrier islands service area where the groundwater table averaged only several feet below the ground surface (Payton, 2002). It arose out of a desire to reduce I/I where the city believed that the lateral was the single largest leakage source. Although these laterals were on private property, the city believed that it was in the best interests of all the ratepayers if all 300+ homes had the laterals replaced collectively.

The City secured the services of a pipe-bursting contractor and installed new polyethylene service laterals and cleanouts. Vacuum excavation was used at the entry pits. The pilot results are being reviewed to determine if there is a benefit to extending the replacements to other portions of the service area. Future responsibility for the cost will be evaluated as well.

A Task Force in Ann Arbor, MI composed of homeowners, city staff, and outside experts investigated I/I alternatives for five neighborhoods in the city (TenBroek, 2002). Detailed I/I findings from these neighborhoods revealed foundation drains connected to the private laterals were responsible for 60%-90% of the wet weather I/I. After evaluating the costs of constructing sewers to transport a 25-year design storm mandated by state design criteria, the City of Ann Arbor opted for private property corrections to relieve severe basement flooding. A comprehensive Footing Drain Disconnection (FDD) program was selected as the lowest cost and best option for the city.

An FDD pilot program, performed at the city's expense, was initiated for 11 houses where the private property work could be performed successfully. The retrofits included foundation drain disconnects, installation of sump pumps for overland flow discharge of the diverted water, vertical and horizontal check valve installations and interior restoration. At costs of $5,000-6,000 per home, the entire program is estimated to cost between $80 and $130 million depending on the final number of homes determined to need the FDD. The program is forecast to last over a 20- to 30-year period.

The City of Auburn Hill, MI (see Appendix II, Auburn Hill Case Study) initiated a similar foundation drain disconnect project to reduce the occurrence of basement flooding problems and to eliminate the effects of storm water inflow on the town's sanitary sewer system. The Bloomfield Orchards subdivision, which includes approximately 500 homes, was selected for implementation of this project. The project includes a "pilot phase" with houses having a history of basement backups selected for the pilot work. A list of owners who have voluntarily agreed to participate was also maintained by the city and was used in chronological order to select additional houses for implementation of the program.

The city hires the contractor to maintain quality control and to simplify the procurement process for the customer. Auburn Hills pays 100% of the cost for the necessary footing drain disconnect and sump pump conversion. The residents are given the option of incorporating other plumbing related work into the project at their own expense. Customers who performed the footing drain disconnect on their own in accordance with the program requirements, did have the opportunity to be reimbursed. The city had also considered a "seller to pay" ordinance that stipulated that those residents who did not voluntarily allow the City to disconnect the drains would have to disconnect the drains at their own expense when they sell their house.

The implementation of the project has progressed very well and is ahead of its original five-year schedule. Of the 500 houses, 491 have been disconnected. Although a flow monitoring assessment of the wet weather flows has not been completed since the last disconnects were made, the flow during rain events in the system has been significantly reduced. Before the disconnect program, it was not unusual for the City to get three to four times the "contracted flow," or the flow capacity purchased by the city, during a two-year storm event. Since substantial completion of the project, the flow has consistently been below the contracted capacity during all wet weather events.

6.9.3 Satellite Flows

Satellite municipal collection systems are those collection systems where the owner or operator is different than the owner or operator of the treatment facility. Nearly 5,000 satellite collection systems will be required to obtain NPDES permit coverage which will include the requirements under the pending EPA CMOM proposal. The current regional NPDES permit holder often has legal agreements with satellite systems which define the conditions under which the satellite system can discharge into their sewer system.

The conditions specified include:

- Applicable municipal code for maintenance and construction requirements,
- Maximum daily discharge,
- Peak flow,
- Duration of agreement and an extension clause,
- Penalties and other measures specified for exceeding capacity limits,
- Advanced notice for termination of agreement by either party,

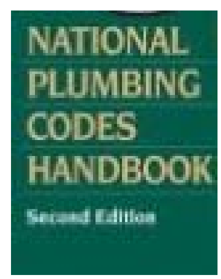
- Locations where discharge is allowed,
- Maintenance requirement,
- Inspection requirements,
- Rehabilitation requirements (including I/I reduction),
- Flow metering requirements at point of discharge, and
- Maintenance of flow meter at point of discharge.

The permit holder is responsible for providing the agreed-upon capacity to safely convey flows. If the satellite system exceeds the agreed-upon capacity allocation, the permit holder may experience SSOs due to limited capacity. It is important that the permit holder and satellite system develop a cooperative relationship and establish regular contacts to foresee such problems and develop strategies to prevent such events. A carefully worded and well-thought agreement can provide the framework for addressing such issues.

6.9.4 Municipal Codes

Municipal codes are legal documents containing requirements on issues such as characteristics of wastewater discharges into the collection system, lawful connections to the collection system, and penalties for illicit connection and discharges into the system. Wastewater agencies can minimize the potential for SSOs by enforcing these codes.

The plumbing code is a powerful tool that sets the circumstances under which a connection can be made to the collection system. The plumbing code makes it illegal to connect private inflow sources to the collection system. The code also specifies enforcement actions that can be taken to disconnect such illicit connections. Wastewater agencies should develop an inspection and enforcement plan to ensure that the requirements of their plumbing codes are met. The provisions of the municipal code should also be included in any agreement made with the satellite systems. This ensures that the satellites' collection systems are built to the same standard.



6.10. Permitting

Through the permitting process, the wastewater agency can determine if its system can convey the flows from a proposed development. This process provides a mechanism to control the growth of urban development so that it does not cause an overloading of the system under existing and future conditions. If the urban development growth is left unchecked, it can lead to an overloading of the collection system and SSOs.

Often, the collection system may be able to handle flows from a proposed development for existing and near term conditions, but may not have adequate capacity for long term conditions. Under such conditions, negotiations can be held with the developers to provide funding for expanding the capacity of the system for future flow.

The permit processing involves the following steps:

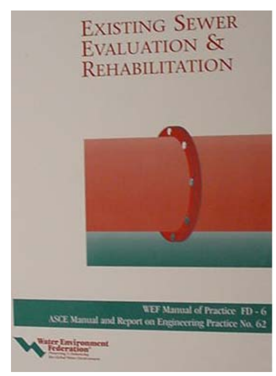
- The developers submit an application to the agency. The application should include, but not be limited to, the layout of development, subdivision plat, grading plans, utility right-of-ways, and storm water management plan.

- The agency reviews the application and performs a feasibility study to identify whether the proposed development is feasible from both technical and economic perspectives. The process includes a field visit to review site conditions. A capacity analysis is also performed to ensure that the collection system downstream from the proposed development has adequate capacity to convey the additional flow. An economic analysis is performed to estimate any upfront funding and other recurring charges which may be necessary. The feasibility study will outline requirements, if any, for approval of the application.

- Once all the requirements identified in the feasibility study are addressed, an authorization is issued to move forward with the detailed design, bidding and construction of the new development.

6.11. Design, Installation, Rehabilitation, Inspection & Testing Standards

Defective designs and installations of sewer lines often lead to future operational and maintenance problems, including SSOs. To avoid such problems, wastewater agencies should develop standards and specifications for the design, installation, rehabilitation, inspection and testing of sewer lines. Such standards not only improve the quality, but also ensure uniformity of the final product no matter who the designer or contractor is.



It is critical that specifications be developed by experienced and qualified staff to ensure their accuracy and completeness. If in-house resources are not available, the agency should consider utilizing outsourcing for development of its standards and specifications. It is also critical to review and update standard specifications regularly to ensure that they are current.

A wide body of knowledge on standards, specifications and design guides has been developed by professional and trade organizations such as ASTM, WEF, ASCE, and NASSCO. The wastewater agencies can either reference these documents or draw upon this body of knowledge to develop their own standards and specifications.

Design standards should cover allowable pipe materials, pipe material selection criteria, and structural, hydraulic, and alignment criteria. Other issues to be covered include the criteria for manhole design, force main design, lateral connections, railway and road crossings, tunnel design, and corrosion control. Design criteria for pumping stations are often prepared on a case-by-case basis but should include pumping capacity and force main velocity.

Construction specifications often follow the format developed by the Construction Specifications Institute (CSI). The general format of such specifications include a general section, followed by a material, execution, and payment section. The execution section covers not only the installation of pipes and its appurtenances but also the inspection, testing and acceptance of work.

Since there are a wide variety of rehabilitation techniques available, one single set of specifications cannot cover them all. A separate set of specifications should be developed for each. It is a common practice for wastewater agencies to make a review of available trenchless rehabilitation technologies and select a few which best suits their conditions. This would limit the need to develop specifications to only those technologies which have been selected. A description of available rehabilitation technologies is provided in Chapter 9.

6.12. Performance Standards

Defining system performance standards is the first step in developing an assessment program which will allow the utility to control cost and ensure the desired level of service. Well-defined system performance standards will serve as critical parameters for optimizing collection system maintenance strategies. Using performance metrics, utilities can evaluate the effectiveness of their maintenance programs.

All performance metrics are not necessarily equal in importance nor are they the same for every utility. The performance metrics enable a utility to quantify and maximize the value contribution of each dollar spent. Performance measures should describe the effectiveness of the collection system in transporting wastewater on the basis of measurable parameters. Thus, the numbers of stoppages, backups and overflows or the number of complaints or service requests are important “level of service” performance measures. Performance measures should not be confused with production indicators or benchmark parameters. Typical production indicators could be ‘miles of sewer televised per year’ or ‘miles of sewer cleaned per year’. If an agency wishes to improve performance by minimizing stoppages or odor complaints, it could study the production efforts of televising and cleaning sewers of similar agencies.

Performance measures can be used to:

- Compare performance with similar agencies and then identify potential areas for improvement,
- Compare performance on an annual basis to identify performance trends within an agency,
- Compare performance of units within an agency, and
- Allocate resources to deficient areas of performance.

If the results from comparisons of performance on an annual basis reveal either an increasing or a decreasing level of performance, the cause of the trend should be identified. Key effectiveness performance measures are shown in Table 6.2. Key efficiency performance measures are shown in Table 6.3.

Table 6- 2 Effectiveness Performance Measures	
Functional Area	**Performance Measure**
Collection Systems	• Full-time employees per 100 miles of sewer • Full-time employees per Mgal • Number of SSOs per 100 miles per year • Number of backups per 100 miles per year • Number of blockages by type (grease, roots, debris) • Number of pipe failures per 100 miles • Flow ratios including peak hourly/average annual daily flow (ADF) and peak monthly/ADF
Customer Service	• Complaint calls per 100 miles per year • Percentage of calls that are repeats or for chronic problems • Percentage of problems cleared per month • Percentage of billings collected per month • Response time to customer, contract, and problem resolution

Table 6- 3 Efficiency Performance Measures	
Functional Area	**Performance Measure**
Collection Systems	• Maintenance cost per mile • Maintenance cost per million gallons/day • Maintenance cost per kilowatt hour used • Percentage of work orders completed per month
Customer Service	• Training expenditure ($) per agent • Customer service costs per day • Customer service costs per customer • Customer service costs per total overhead and maintenance (O&M) cost
Finance, Administration, and Planning	• Overhead costs per total O&M costs • Labor cost per O&M costs • Contract services O&M costs per total O&M costs • Debt service per total budget • Annual materials cost per inventory • Training cost per capita • Fleet costs per total O&M (by function) • Return on assets • Value of main replaced per total value of main • Value of capital additions/net asset value • Replacement value of plant (annual)
Wastewater Operations	• Cost per million gallons • Cost per lab analysis • Cost per customer account • Maintenance costs per million gallons • Overtime costs

6.13. Progress Monitoring & Self Assessment Plan

The wastewater utility should develop and implement a progress monitoring and self assessment program to measure its performance against the performance standards it has established. The plan may include a comparison of the agency's performance with the performance of similar agencies to identify deficiencies or downward trends in specific aspects of its O&M program. Such a comparison allows the agency to analyze target performance levels and adjust them, if necessary. Setting achievable target levels of performance can be a complicated process involving more than just identifying a problem and selecting an appropriate solution. Other factors which usually must be considered include competing work priorities, availability of funds, personnel, and equipment, ratepayers' expectations regarding cost and level of service, and the political impacts of raising utility rates. Many of these factors are local issues and collection system agencies must be responsive to local needs and expectations.

Many agencies have undergone major assessment processes in order to evaluate the effectiveness of their O&M programs. The assessment processes may include internal assessment as well as examining other agencies to determine and define best management practices for managing collection system O&M programs. Assessments typically cover the following areas:

- How the O&M group is organized and staffed in terms of personnel, skills, cross training, and costs,
- How the work is accomplished,
- How efficient the organization is in providing service, and
- How effective the organization is in meeting performance goals and objectives.

Making an assessment of this type requires the organization to examine in detail and break down into subcomponents all work activities that affect the ability to maximize labor performance and minimize demands on material resources.

Efforts of collection system agencies to enhance performance may be focused in the following three areas:

- Regulatory compliance,
- Level of service, and
- Efficiency in managing O&M resources.

Recognizing that O&M is a significant component of an agency's annual budget, the individual components of the O&M program, such as labor and benefits, materials and supplies, contracted services, and utility costs, should be examined in detail. This type of detailed analysis enables most agencies to develop much more efficient methods of managing valuable resources.

6.14. Overflow Response Plan

Every wastewater agency should have an up-to-date Overflow Response Plan (ORP) in place. The ORP is an operational document that describes the procedures to be taken by the wastewater agency in responding to reported sanitary sewer overflows (SSOs). The ORP should outline the steps to be taken when the occurrence of an SSO is confirmed. With an immediate and effective response, the negative effects of the discharge to the surface waters can be minimized with respect to public health, beneficial uses, and water quality.

The primary objective of the ORP is to protect public health and the environment. Additional objectives of the ORP are:

- Provide appropriate customer service,
- Protect wastewater treatment plant and collection system personnel,
- Protect the collection system, wastewater treatment facilities, and all appurtenances, and
- Protect private and public property beyond the collection and treatment facilities.

The ORP should present a strategy for the wastewater agency to mobilize labor, materials, tools and equipment to correct or repair any condition which may cause or contribute to an SSO. The plan should provide guidance that considers a wide range of potential system failures capable of creating a discharge to surface waters, land, or buildings. Solutions to each problem would be expected to be determined on a case-by-case basis as it would be difficult to document each possible response to be taken. The service crews should exercise professional judgment combined with skill and creativity to resolve the diverse problems that are encountered.

6.14.1 Plan Elements

While response plans are tailored to fit the requirements and needs of each collection system, a typical ORP will include the following elements:

- Goals - The ORP should establish operational goals in responding to SSOs. For example, the agency may set a goal of providing initial response within one hour of the SSO report.
- SSO response team - This section of the plan would provide a description of the organizational structure, available crews, equipment and other resources used to respond to SSOs. An organizational chart should be included. This section of the plan should also describe the duties of the response team supervisor and other crews as well as provisions for communication among the crewmembers. Call-out procedures for mobilizing the crews during off-hours and weekends should also be included.
- SSO response procedures - The ORP should describe the dispatch procedures both during business hours and during off-hours. Ordinarily, once the report of an SSO is received by the agency, an inspector is dispatched to the site to assess the situation and confirm the occurrence of an SSO. Following this determination, additional crews are called in to contain the overflow, perform corrective action, and clean-up the site. Initial containment measures shall be taken to contain the overflowing sewage and

recover where possible sewage which has already been discharged, by means such as vacuum trucks or by pumping into downstream sanitary manhole.

- Corrective action - Remedial measures may range from relieving a stoppage in a sewer pipe to repairing or replacing a section of the pipe which may be broken. SSO sites should be thoroughly cleaned after an overflow. Cleaning agents which may negatively impact the environment should not be used.

- Coordination with other agencies - Under varying circumstances, coordination with other agencies may be required. In particular, in emergency conditions, coordination with the Fire and/or Police departments, and/or local Health Department may be necessary. The ORP should include contact information for such coordination activities.

- Reporting requirements – The ORP should include, either directly or by reference to another document, instructions on procedures for reporting SSOs to regulatory agencies. Regulatory agencies require a verbal reporting of SSOs within 24 hours followed by a five-day written report providing additional detail. Individual states may also require additional reporting on a monthly or quarterly basis as well.

- Public advisory & access limitation – The ORP should include provisions for determining under what conditions a public advisory or public access limitation should be issued to warn the citizens of, and minimize the potential negative public health impacts of, an SSO. The plan should describe in detail how the public should be notified. Forms of notification include posting signs, door hangers, flyers, and notification by media such as radio, TV, newspapers, and web sites. Instructions for limiting public access to the site of an SSO should also be enumerated. The criteria to issue a public advisory or declare public access limitation is usually based on a number of factors such as the volume of SSO, the time of year when the SSO has occurred, and the likelihood of human contact with the sewage.

- Water quality sampling - Water quality sampling may be performed to support decision making about public notification and public access issues.

- Training - The ORP should include provisions for annual training on SSO response procedures for all appropriate personnel. Options for training include in-house classroom training, on-the-job training, on-site training by manufacturers and suppliers, and off-site training provided by professional and trade associations and educational centers.

6.15. Monitoring & Reporting Plan

Regulatory agencies often require that wastewater utilities monitor their collection system for occurrence of SSOs and report such occurrences to regulators. Wastewater agencies should develop and maintain an up-to-date Monitoring and Reporting Plan (MRP) which describes the procedures to be taken by the wastewater agency for reporting of all field-verified SSOs, active monitoring of known locations of chronic wet weather-related SSOs, and routine monitoring of the system for identifying unknown locations of chronic SSOs.

The primary objective of a MRP plan would be to document monitoring and reporting procedures to ensure that the wastewater agency provides timely and complete notice of all relevant information regarding SSOs to regulatory agencies. Active monitoring procedures apply to known locations of overflows. These locations are monitored to detect and document the occurrence of SSOs. Routine monitoring activities relate to the entire sewer system. Reporting procedures provide instructions for notifying the regulatory agencies on the timing, location, extent, affected water bodies, and corrective actions to prevent SSOs from occurring.

6.15.1 Plan Elements

Local regulatory agencies may have specific requirements, but most monitoring and reporting plans usually contain the following elements:

- Monitoring Plan- This section of the plan should provide a list of known locations of SSOs. Additionally, routine monitoring procedures, through routine inspection of pump stations, regular inspection of “hot spot” areas, and review of customer complaints and SSO records should be described in this section. Active monitoring of known location of SSOs can be achieved by several methods including electronic level sensors, fluorescent chalk method, wooden float discharge, and visual observation.

- Documentation and Record-Keeping- A record-keeping system should be established to document the occurrences of SSOs. A variety of Maintenance Management Information Systems (MMIS) are available that can be used for record-keeping. Due to the large volume of data and numerous reporting requirements, manual methods of record-keeping should be discouraged.

- Reporting Plan- This section of the plan should describe in detail the reporting requirements of SSOs. Regulatory agencies require 24 hours verbal notification of SSO occurrences followed by a five-day written notification report. Additionally, monthly and quarterly summary reports, as well as an annual report may also be required.

6.15.2 Public Awareness Program

The public can play a significant role in detecting and locating SSOs. To maximize the public participation in minimizing SSOs, the wastewater agency should strive to increase the public awareness through several avenues such as:

- Development and dissemination of educational brochures

- Presentation by wastewater agency staff at community meetings

- Participation in local schools’ and colleges’ environmental awareness programs

- Submission of educational articles to local press

- Posting of educational articles on the wastewater agency’s website

- Issuing of an annual report

6.16. Training

Effective training programs begin with a focus and dedication to frequent, regular and relevant delivery of training materials and presentations. Safety is an everyday concern. While there are different organizational structures that can provide the training and promote a desirable safety climate, many effective training programs often result when those responsibilities are delegated to a group or individual with that sole focus. Traditional and innovative training philosophies including flexible worker programs and cross training are more successful when management is actively involved with the training.

Many of the utilities that report success with their training have either a training office or a training coordinator attached to the unit(s) in need of the training services. The increasing regulatory requirements and safety requirements impact personnel on a daily basis and create a constant demand for recurring training. This training should be designed to keep the staff abreast of ongoing developments and to ensure compliance with regulatory and safety requirements.

Many utilities also take advantage of the training provided by manufacturers and suppliers in the use of their products. This is important to the safe and productive use of large capital investments like combination jet/vacuum cleaning machines.

While industry organizations such as the Water Environment Federation (WEF) and trade associations like the National Association of Sewer Service Companies (NASCCO) have assembled informative instructional material, all sectors are now participating in developing specific, practice-oriented training to maximize the effectiveness of the maintenance staff. From utility trials to equipment manufacturers to third party private companies, specific cleaning procedures are being refined which standardize the approach and methodology to specific tasks such as jetting and combination machines. Together with sound evaluation of the problem and enhanced performance measurement techniques, the training should increase the effectiveness of the hydraulic cleaning.

6.17. Certification

Certification of collection systems personnel is increasingly becoming the norm rather than the exception. The more effective utilities incorporate certification issues into hiring and promotional opportunities for their staff. Certification provides an independent assessment of job skills and experience that is vital in an industry where safety and performance is integral to the daily execution of job-related tasks.

A standard training reference of many certification programs is the two-volume field study training program “Operation & Maintenance of Wastewater Collection Systems” offered by California State University’s Office of Water Programs in Sacramento, CA. These and other trade publications and manuals of practice offered by a variety of trade practitioners are the basis for gaining the knowledge needed for certification that on-the-job training may not satisfy.

In combination with these self-study guides, many states have designated technical training centers. One such organization, the Maryland Center for Environmental Training (MCET), a department within the College of Southern Maryland in La Plata, MD, provides technical assistance and training both onsite and within structured classroom settings around the state (MCET, 2004). Offerings typically include trench and shoring safety, collection system troubleshooting, confined space entry, and open channel flow metering. Local chapters of the WEF and other industry associations often sponsor short courses, specifically tailored to meet the needs of the field staff responsible for the collection system. The Chesapeake Water Environment Association (CWEA) annually sponsors a 40-hour short course where participants come to a local college setting, live in the dormitories for a week and get an intensive burst of collection system training provided by local utility supervisors and industry practioners.

Certification for wastewater collection system operators is generally regulated by a state agency, which defines the necessary requirements. Typically this includes a system classification, generally based on service area population size, and levels of certification based on combinations of education, experience and successful passing of a test.

On a national level, WEF has advocated certification of plant and collection system personnel as necessary to the success of the wastewater program. In 2002, WEF published a new collection systems certification study book to prepare operators for the certification examinations (WEF, 2002). Categories covered include background knowledge, support systems, operation and maintenance, supervision and management, safety procedures, design and construction, electrical pumps and motors and math skills.

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Chapter 7

Operation and Maintenance Solutions

7.1. Introduction

SSOs may happen at all times of day and under all weather conditions. The most frequent types of SSOs, stoppages caused by debris, grease and roots, are often the most direct and the quickest to resolve. The most important element in any agency's response is trained and experienced personnel. Knowing what to do and how to execute the resolution is critical to a successful emergency response.

7.2. Maintenance Strategies

Developing strategies to address the immediate problems and providing a methodology to eliminate the causes of the SSOs are critical for an agency to influence the SSO trend. The following sections discuss the different type of strategies and relative effectiveness of the approach.

7.2.1 Emergency and/or Reactive Maintenance

Emergency maintenance for resolving SSOs involves the application of equipment and personnel resources to stop the overflow in the quickest, safest manner available to the utility. The focus of this section will primarily be pipes and manholes, although emergency power will be related for pumping station applications. Each overflow has the potential to escalate from a nuisance level to a major environmental problem depending on the pipe diameter, flow rate, point of discharge and effectiveness of the emergency actions taken by the agency to relieve or control the SSO.

Effective emergency maintenance requires a rapid response to mitigate damage to the environment and property, and to limit exposure to the population. Since reaction time is a critical element for successful mitigation of SSOs, effective agencies develop emergency plans and maintain staff and equipment on call to deploy on short notice.

Stoppages: Stoppages in sanitary sewers play a major role in SSOs throughout the country. Roots, grease, debris, and other deleterious material all can build to a partial or complete blockage of the pipe. An effective emergency maintenance program must provide rapid responses to those situations. The equipment and staff to respond to these events are typically agency resources rather than contracted which enables control and discretionary direction of those resources to stop the SSO and mitigate the impact to the surrounding environment or receiving waters.

Not all SSOs are caused by stoppages. Other causes include structural defects such as leaks, exfiltration, and force main failures, and loss of power, most frequently during storm events. These types of SSOs are more likely than stoppages to contribute large volumes of wastewater to receiving streams. Being prepared with trained operators and on-call equipment such as backhoes, portable generators, pipe sections, sheeting and shoring, and other necessary tools is vital to timely and effective SSO responses.

Responsiveness: In order to be effective, the primary characteristic of an emergency maintenance response must be timeliness. Lack of a timely or rapid response to an SSO permits an accident to develop into negligence with more severe ramifications for the customer, the environment and the agency. Not only can the volume of the spill be mitigated with quick action by agency crews, but the resulting clean-up and corrective actions may require less cost. Therefore, speed is a critical element of a successful response. Many agencies now establish a goal for responsiveness and track that time as a performance measure for their staff.

Effective and timely responses to SSO emergencies are no accident. They are accomplished through planning and preparation. Planning for emergencies is accomplished with the development of an overflow response plan as described in Chapter 6. Implementing a successful emergency response requires training and practice.

7.2.2 Corrective Maintenance

While emergency maintenance focuses on the short-term solution of containing or minimizing the impacts of a problem, and preventative maintenance is implemented to preclude the conditions that cause SSOs and backups after the problems have been identified, corrective maintenance focuses on the long-term solution of eliminating the cause of the problem. Corrective maintenance is a general term that may include repairing damaged sewer pipes, patching and plugging leaks, re-setting or replacing manhole frames and covers, and other repairs related to the collection system and its appurtenances. Standard Operating Procedures (SOPs) should be developed for corrective maintenance activities, both as guidance for agency staff to properly execute the repairs and as a specification for repairs that are procured.

An important element of a corrective maintenance program is to define the problem so that a corrective solution can be developed. This analysis is typically required to fulfill the requirements for the five-day written notice in the event of an SSO. A good starting point for a corrective maintenance prescription is the monitoring and reporting plan. Many agencies now routinely investigate and inspect pipes and manholes involved in overflows to identify the cause. Analysis of the problem may lead to scheduling of preventive maintenance or corrective maintenance if structural damage or leakage is identified.

Condition assessment programs and sewer system evaluation surveys are also effective programs in identifying needed corrective maintenance. After an evaluation of the infrastructure condition is made, the actual repairs can be implemented. Chapter 9 describes the full spectrum of repairs that can be implemented to resolve the defects. Preventive maintenance work performed in pumping stations and treatment facilities can also flag items for repair or replacement before the part or equipment fails.

7.2.3 Proactive Maintenance

There is increasing recognition of the role played by dry weather stoppage mechanisms such as roots, grease and debris in contributing to overflows and backups. A recent Water Environment Research Foundation (WERF, 2003) study of effective operations and maintenance practices reported that collection system operators ranked cleaning, as the most important maintenance tool utilized (see Figure 7.1). Root removal, including chemical root control, was also highly valued.

A similar survey, conducted as a part of an American Society of Civil Engineers (ASCE, 1999) Optimization of Collection System Maintenance Frequencies and System

Performance study, requested agencies to report an "activity weighting factor as an indicator of the importance of that activity in maintaining their collection system. The combined "cleaning" activities weights, as shown in Table 7.1, resemble the WERF results.

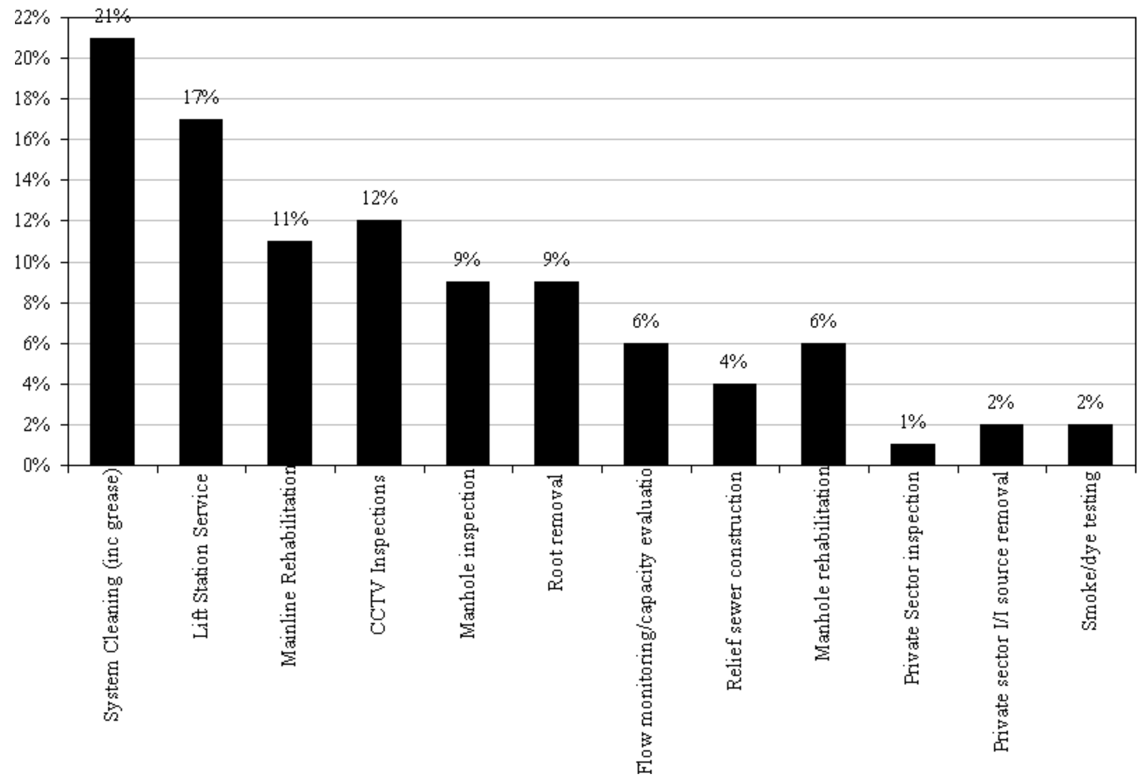


Figure 7-1 Maintenance Activity Weights (WERF, 2003)

Cleaning operations are highly prized by utility operators for a variety of reasons. First, they are able to employ the tool with immediate response to the stoppage problem. Customer service can be delivered within minutes of the identification of the backup or overflow. The ability to be responsive to the most routine collection system concerns with a minimum number of staff necessary is a desirable quality for an SSO solution to possess. In addition, maintaining the ability for instant response to the emergency requirements of the collection system provides an opportunity to make productive use of the equipment and staff in a proactive manner in between the crises. Cleaning skills can be honed and refined while the crews complete the preventive maintenance schedule.

Table 7- 1 Activity Weighting Factors	
Maintenance Activity	**Activity Weighting Factor**
Cleaning (all types)	**26.10%**
Cleaning (17.7%)	
Root Removal (8.4%)	
Collection System Rehabilitation	**24.30%**
Mainline (12.6%)	
Manholes (5.6%)	
Private Sector I/I Removal (6.1%)	
Pump Station Service	**14.10%**
CCTV	**10.50%**
Flow Monitoring	**7.00%**
Manhole Inspection	**6.40%**
Relief Sewer Construction	**6.30%**
Smoke testing	**3.30%**
Private Sector Inspections	**2.00%**
Total	**100.00%**
Source: ASCE, 1999	

Effective proactive cleaning of the collection system is one of the central tenets of a successful "Maintenance" component of the CMOM program. Utilizing the staff and equipment that is available 365 days a year in a proactive cleaning program preempts pipeline conditions before they can culminate in a stoppage leading to an overflow.

7.3. Collection System Maintenance Tools

7.3.1 Hydraulic Cleaning

A WERF survey found that hydraulic cleaning equipment was the most frequently owned and used piece of equipment applied for cleaning sewers less than or equal to 18 inches in diameter (WERF, 2003). Through the targeted application of high pressure water, task-specific nozzles that alter the angle and spray pattern of the water against the pipe walls, cutters, attachments and water tank additives, a wide spectrum of cleaning requirements can be met with one piece of equipment. The equipment's flexibility and the efficient use of labor make hydraulic jet cleaners a favorite among agency operators for both emergency and preventive maintenance applications. A variety of water tank sizes, pressure output, and nozzle configurations are available for both truck and trailer mounted equipment.

Effective hydraulic cleaning is dependent upon a number of factors. A study by the California Collection System Collaborative

Benchmarking Group investigated these factors and developed a consensus of "best practices" for small diameter hydroflushing (CH2MHill, 1998). Some of the more significant findings include:

- Time Management- Effective spatial scheduling of the daily locations of the sewers to be cleaned and selection of equipment that minimizes the onsite set-up time will significantly impact the efficiency of the hydroflush crew. Between 25% and 50% of a day is spent in travel among the jobsites. Another 25%-33% is invested in the jobsite set-up. In total, approximately 50%-75% of the effort involves operations preparatory to the actual cleaning. The scheduling advantage is maximized when performing proactive maintenance, not reactive emergency cleaning, which can minimize travel between jobsites and the jobsite set-up.

- Nozzle Selection- The nozzle can be varied to optimize hydroflush performance in the variety of sewer conditions encountered. The nozzle angle and hole pattern maximize the delivery of the high velocity water for the diameter, pipe slope and nature of the deleterious material to be removed. The benchmarking group recommended a 15-degree nozzle for steep slopes and long runs, a 45-degree nozzle for heavy deposits of grit, and a rotation nozzle for heavy grease. The hydraulic cleaning is completed after using a root saw attachment for roots, a chain flail for roots and hard grease, and a proofing attachment to ensure that the full bore of the pipe has been restored.

- Measure of Results- Standardization of the crew observations was deemed second only to the actual cleaning of the sewers in order of importance. The "clear, moderate, and heavy" standard cleaning conditions are assessed from several factors including the amount and nature of material removed from the sewer, the time to clean, and the number of passes of the jet hose required. Although these factors are both qualitative as well as quantitative, consistency was stressed as a necessary basis for making future maintenance frequency.

There are other jobsite-specific issues that must be monitored as well. In some instances, the pressure used for jetting the mainline may impact the lateral and cause blowback into the dwelling. Once identified, these segments and laterals are documented and either jet procedures modified or alternative mechanical cleaning implemented for future maintenance. Anti-freeze and other daily accommodations must be made if the jet machine is to perform in a winter climate or areas with seasonally freezing temperatures.

Trapping debris in the downstream outlet pipe is critical to the removal of the debris from the sewers. Some utilities advocate a stovepipe, basket or other device at the downstream end of the segment being jetted to facilitate removal from the system. However, the placement of these devices may lead to ineffective removals given the variability of manhole channels and flow patterns. There is also the problem of bringing the trapped material up from the bottom of the manhole. The passing of debris to a downstream pipe segment due to inefficient collection and removal should be avoided as much as possible. Others agencies reported in a WERF study (WERF, 2003) using a root cutter attachment for all jet cleaning applications, even when grease is the culprit, on the theory that the debris is reduced to sizes small enough to move through the system without further problem.

With the advent of more stringent confined space requirements for entering manholes and a desire for more effective removal of the debris cleaned from the sewer, combination hydraulic/vacuum equipment is rapidly increasing in popularity. The vacuum capability provides the mechanism to effectively collect trapped material in the manhole without involving entering a manhole. The expanded capabilities increase the versatility of the truck by providing wet well and catch basin cleaning as well as sanitary sewer operations. Although twice the cost of hydroflush machines or more, many agencies believe that the advantages of the combination machine give them the productive edge in effective sewer maintenance.

7.3.2 Mechanical Cleaning

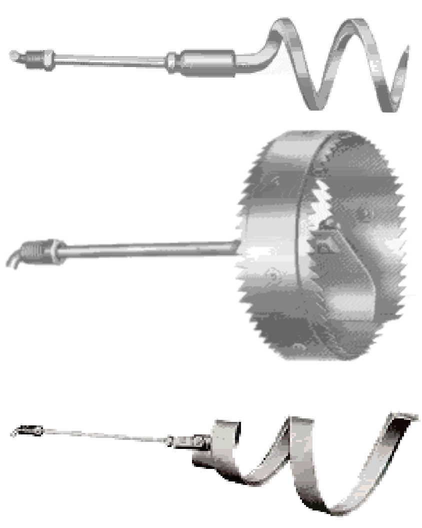
While hydraulic cleaning may currently be the most efficient method of cleaning, it may not be the most effective for selected sewer conditions. Mechanical cleaning techniques include the rodding machine and cable drag machine. Both of these mechanical methods include attachments that enable the device to resolve grease, root, and debris problems through cutting or scraping with existing flow in the line.

Pipe material is more of a factor in the selection of mechanical cleaning rather than hydraulic cleaning. While hydraulic cleaning is more universal with regard to pipe material, mechanical cleaning can only be applied to rigid pipe material such as vitrified clay, concrete, or reinforced concrete pipe. Flexible pipe materials such as polyvinyl chloride (PVC) or HDPE may be gouged, shred or peeled if abrasive or scraping mechanical cleaning techniques are utilized.

Mechanical cleaning does offer some distinct advantages over hydraulic cleaning. While most effective in the same smaller diameters as hydraulic cleaning, mechanical devices do not involve water as the primary cleaning mechanism, so they can be deployed routinely in freezing temperatures. Given their relatively smaller size, mechanical cleaning machines may be a more suitable choice for right-of-way cleaning where the softer footing and more limited access favors smaller and lighter equipment.

7.3.2.1 Sewer Rodding

Rodding a sewer is one of the oldest cleaning methodologies in the industry. Rodding has evolved from the segmental metal or wooden sewer rods that were joined in the manhole and pushed up the line with manpower to the stoppage. Today's rodding machines utilize a continuous steel rod, rotated by a gasoline engine-powered shaft, played out along the length of the sewer with a variety of attachments to match the cleaning requirement and the diameter.



Source:www.wecoind.com

Due to its flexibility in handling many cleaning tasks, it is an important option for emergency cleaning assignments. As a mechanical cleaning tool, it removes roots, grease, and debris through aggressive rotation of the steel rods and the respective attachments. The proper attachments allow the rodder to punch through hard stoppages and enable open channel flow to be quickly established in a surcharge environment.

Attachments include a variety of round stock corkscrews, square stock corkscrews, single and double corkscrews, as well as flat, concave and spiral blade root cutting saws, spears, leaders and porcupine brushes. If a stoppage is the problem encountered, a bullet nose, spear or round stock corkscrew pushed from the downstream manhole will penetrate the blockage and relieve the upstream surcharge. Then, at the upstream manhole, the operator can change the tool to match the sewer conditions (roots, grease, debris) for the pull back downstream. For roots, spring blade cutters, augers or root saws are effective. Porcupines, either alone or in combination with hydraulic action in the pipe, can be effective for grease and loose debris.

Attention to the condition of the attachments is critical to their effectiveness. As mechanical cleaning tools, they experience abrasion and wear and tear of their cutting edges. Porcupines, for example, are sized by the diameter with a minimal tolerance to enable them to pass offset joints and other typically encountered sewer pipe defects. After repeated uses, however, the tines or bristles are eroded away, effectively reducing the cleaning effectiveness for the specified pipe diameter.

7.3.2.2 Cable or Bucket Machines

A more aggressive mechanical cleaning technique is the cable, bucket, or drag machine. These are all the same technique, simply referred to be the different local vernacular for the equipment. These techniques use a steel cable attached to both ends of porcupines, swabs and/or squeegees, and buckets to "drag" the sewer and remove larger or harder deposits than a rodder is capable of addressing.

Source: www.wecoind.com

The cable machine has the ability to clean a greater portion of the collection system than most other cleaning devices due to the larger diameter capability. Buckets are sized for 6-inch through 36-inch diameter and it is in the larger diameters in which the cable machine excels. Through the positive "pull/pull" mechanized winch action possible from both the upstream and downstream manholes, the cable machine can deliver a lot of power to the problem. The porcupine is able to plow through hard deposits, heavy roots, and significant quantities of debris. With the clamshell bucket attachment, the material can be effectively captured in the line segment and delivered to the downstream manhole for removal from the system. The open jaws of the clamshell snag the material into the bucket and are closed upon withdrawal, allowing the material to be winched out. Roller guides keep the cable pull in the centerline of the pipe and eliminate cable "rub" at the crown of the pipe in each manhole

Source: www.wecoind.com

There are some caveats with the use of the cable machine. The cable machine is not the equipment of choice for responding to an emergency situation. A line must be secured through the length of the sewer in order to thread the steel cable from the winch. This line can be floated through the sewer on a tag or parachute line. If there is a stoppage or low flow in the sewer, a hydroflush unit or rodder must be used to traverse the length of the sewer and then the cable can be pulled back with the withdrawal of the jet hose or the sewer rods.

The cable machine also has the most intensive manpower requirements of all the sewer cleaning options. Personnel are required to be at both manholes and the traffic control needs are also likely to be more involved than with other techniques. The buckets and attachments for the cable machine are larger and heavier than attachments for other cleaning techniques. With up to 1,000 feet of ¼-inch to ½-inch diameter steel cable on the mechanical drums, cables and buckets are a lot of weight to maneuver around the job site.

At least two trucks are involved if two point drags are established at both the upstream and downstream manholes.

Since the winch can develop significant pulling power, the cable machine with the bucket attachment has the potential to inflict additional damage on the host sewer if it encounters offset joints, broken pipe, protruding taps or other similar structural defects. Like the power rodder, the cable machine should not be used on flexible pipe sewers.

Diameter and size is another consideration. An 18-inch bucket can fit through a 24-inch diameter manhole frame typically found on a 48-inch diameter manhole. Even on larger diameter manholes, the opening traditionally doesn't exceed 36-inch diameter. There are some occasions when the entire frame and cover and a portion of the corbel may have to be removed in order to insert the appropriate bucket diameter.

Despite the limitations, cable machine cleaning remains one of the most effective cleaning techniques available, particularly for medium- and large-diameter sewers. It provides an effective complement to the more efficient and less labor-intensive hydraulic cleaning techniques.

7.3.3 Hydro-Mechanical Cleaning

Hydro-mechanical cleaning methods utilize historical cleaning techniques that still have application in specific circumstances. In most cases, water supplied from a convenient water source such as a hydrant propels the mechanical device through the sewer, generating water currents, eddys or mechanical force that agitates the debris and sends it down the line.

Sewer balls are one hydro-mechanical technique available in smaller diameters, either as rigid or inflatable balls. The surface of the ball is grooved or ribbed to generate turbulence and agitation when propelled by a head of water behind the ball. The debris and extraneous material is pushed ahead of the ball by the higher velocity jets, keeping the material in suspension in the sewer section. A kite, bag, or scooter is similarly deployed.

Since full pipe flow drives through the sewers behind the hydro-mechanical device, caution must be exercised where there are house connections with below-grade basements in the segment. Care must be taken not to create an SSO when the segment is a steeply sloping sewer with little storage volume available behind the ball. These techniques may be better suited to large diameter sewers where connections are less of an issue.

Specialized applications for these techniques are being developed selectively by a private company in conjunction with its clients to meet unconventional cleaning needs. A patent pending cleaning tool was used in a Fulton County, GA large diameter sewer cleaning application in 1998. This device restricts the existing flow within the sewer, creating turbulences, suspending the material and moving it downstream for removal. Both fluids and wastes were removed in watertight containers downstream for separation of the two components and appropriate disposal of each element. The device is head driven and the speed is controlled by retarding the "inflated" device through an upstream winch cable attachment (Nezat, 2003).

7.3.4 Special Mobile Units

While hydraulic cleaning machines are the preferred equipment by most departments and will relieve most types of stoppages in neighborhood sewers, the size, bulk and weight of most truck-mounted hydro-jets or jet-vacuum combination machines make this style of equipment inappropriate for many right of way or off-road situations. Lighter, transportable equipment will be needed to effectively reach all locations of small diameter sewers most frequently involved in dry weather overflows.

For example, Concord, NC developed and purchased an off-road all terrain vehicle (ATV) constructed to its specifications, equipped to transport personnel and equipment into the most remote locations of its collection system in Cabarrus County. The ATV consists of a six-wheel, amphibious power unit for personnel and a tow-along trailered hydro-jet unit. A small water reserve tank holds water drawn from any nearby water source, including available surface water, and the pump unit is capable of generating high water pressure to the remote stoppage (Hannan, 2002).

Such equipment has been found helpful for utilities in North Carolina where a recent state law requires inspection of all sewers not visible from paved roadway surfaces. It can be used in places where routine cutting and bush-hogging of sewer rights-of-way is difficult. It also can be used in the tributary areas of streams and creeks and their crossings where it is not unusual for many older sewers to be within the 100-year flood plain and in green-space preservations.

7.3.5 Root Control Tools

Wherever there are sewers, roots have been a recurring maintenance problem. Metcalf & Eddy's celebrated treatise, American Sewerage Practice (Volume II, 1915), notes that an "almost capillary opening" is all that is needed for a root seeking moisture to penetrate and grow within the pipe barrel. A survey conducted in Sweden during the mid-1990s found that 99% of the public sewer systems reported disruptions caused by tree roots (Stal, 2001). Nearly all collection systems are universally affected by roots.

Trees are an aesthetic and essential part of the landscape in urban streetscaping and private yards. Trees reduce erosion, help clean the water and the air, provide shade and wildlife habitat, and offer numerous other economic and social benefits. Communities from Ithaca, NY to Washington, DC pride themselves on being "Cities of Trees," adding to the quality of life for citizens in those cities.

Roots are the primary mechanism through which the tree anchors and supports itself and are the conduits to store and transport water and food within the structure to sustain itself. A significant percentage of the tree's roots are found in the top 12 inches of soil, many of those within the top 2 to 6 inches. The availability of water, oxygen and nutrients is critical to the root's survival. With the increasing imperviousness of the urbanized landscape, better drainage to pull surface runoff away, and less organic material available as nutrients, roots must extend their reach.

Roots must continue to grow just as the tree grows or the tree will die. The ongoing cycle of growth and die back of the roots requires constant processing of nutrients to feed the tree, eventually leading the roots to the warmer soil temperatures and moisture- and nutrient-rich environment of the sewer pipe.

In a 1995 report, EPA identifies two primary types of root structures found in sewers: “veil” and “tail” roots. Veil roots grow from the top and sides of pipes with constant flow, creating a curtain effect across the joint or other entry defect. The tips of the veil roots are typically in contact with the flow, enabling grease and other deleterious material to collect that can lead to stoppages. Tail roots grow from all sides of low flow or intermittently dry pipes, such as building lateral sewers, and fill most of the volume of the pipe. Tail roots are elongated root masses that can stretch on for many feet of sewer.

Temporary control is secured by cutting the roots with a variety of sewer cleaning equipment. The problem with clipping the roots is that is does not provide a long-term solution to the problem. Pruning the roots inflicts injury, and injury causes the root structure to produce a hormone which rushes to the cut area to speed re-growth. The “pruning effect” often leads to bigger, bushier roots over time.

Removal of the offending tree is one option for dealing with the problem. In some instances, there may be no other alternative, particularly if the damaged sewer is not renewable by trenchless rehabilitation options. Traditional cut and cover replacement of the sewer may dictate cutting of the roots or cutting of the tree. However, this is not a choice made lightly, owing both to the potential economic value of the tree to the property and landscape and the increasing regulation of urban trees.

In some towns and cities, private trees are inventoried and assigned registration numbers. For example, two Maryland communities, Takoma Park and Chevy Chase Village, require individual permits to prune or remove an existing tree on private property within the city limits. Jurisdiction for trees in public space in Maryland is governed by the Roadside Tree Law. A roadside tree is defined as any tree that grows all or in part within a public road right-of-way, such as tree boxes between the curb and sidewalk. Before undertaking any tree removal, tree trimming, or other remedial care that impacts the health of a roadside tree, an evaluation and permit must be secured from the Department of Natural Resources Forest Service. Tunneling, trenching, and boring are also covered by this regulation. Replacement of a roadside tree is also prescribed if a tree needs to be removed to work on the infrastructure.

7.3.5.1 Chemical Treatment

The use of chemicals, either alone or in conjunction with hydro-mechanical cleaning techniques, are a popular means of root control to retard root growth into the sewers without long-term injury to the tree. Chemical treatment includes use of copper sulfate, metam-sodium formulations and non-metam-sodium formulations. A simple form of chemical root control is the “pour-down” addition of copper sulfate to the lateral or mainline sewer. Manufacturers produce copper sulfate either in liquid form for quicker absorption or crystals that dissolve slowly in water over time.

The performance history and effectiveness of copper sulfate for root control is mixed. Cincinnati, OH, for example, promotes copper sulfate use by homeowners for “do-it-yourself” root control (Cincinnati, OH, 2004). A manufacturer’s recommendation includes introducing two pounds of copper sulfate into the toilet bowl ½ cup at a time with the toilet flushed after each incremental addition. Continue until the final ½ cup is added. This last portion should remain in the bowl overnight before flushing. However, just north of Cincinnati in Fairfield, OH, copper sulfate is identified as harmful to the environment and the natural bacteria that decomposes dead roots and its use is prohibited (Fairfield, OH, 2004).

Reinforcing the environmental concern over copper sulfate is a 1995 ban in the San Francisco Bay area by the California Environmental Protection Agency (Cal/EPA, 1995). The shallow estuaries of the bay were found to be vulnerable to contamination from copper and related products. While copper sulfate is added in relatively small quantities, its application directly to the sewer has potentially significant impacts to the treatment process.

Metam-sodium (Vapam™) is a chemical used to control roots in sewers and is classified as a pesticide resulting in restricted use. This requires applicators to be state certified in the handling and use of this chemical. Metam-sodium is often used in combination with dichlobenil tree root control where the former is the quick acting fumigant and the latter is the long-term impact agent. Initially applied by soaking or the spraying the roots with this chemical solution, the current recommended application involves using a foaming agent to achieve contact with the roots growing from the crown and above the flowline of the sewer. Dichlobenil has also been incorporated into chemical grout mix (acrylamide and acrylate formulas) to enhance the resistance of soil stabilizing grouts to root penetration.

Preparatory mechanical cleaning of the sewer may or may not be performed prior to the chemical application. The hose insertion method is often used for placing the foam within the sewer pipe. The hose is inserted through the pipe to be treated and the foaming action initiated while the hose is slowly withdrawn from the pipe. The amount of contact time and the degree of FOG material that may be built up on the roots will impact the effectiveness of this chemical root control application.

A third variant in the chemical control arena is the non-metam-sodium formulation. This does not require state licensed applicators and is dispensed to the sewer community through authorized agents, such as plumbers and contractors. Homeowners wishing to treat their sewer lateral for roots must employ one of these vendors to add the chemical to the toilet or the building sewer cleanout. Water activates the foaming process of the chemical.

In 2002, the Los Angeles Board of Public Works authorized a pilot chemical root control program for 20 miles of the city's sewers at a cost of $86,000 (City of Los Angeles, CA, 2002). This was a first step for a city that has more than 680,000 street trees along more than 6,500 miles of public roads. The program was projected to grow into a $1.25 million effort through the end of the following fiscal year, targeting more than 150 miles of 6-inch to 10-inch diameter sewers, 12 to 15 feet deep, where roots are identified as major causes of sewer stoppages.

A major factor to consider in using any of the chemical root control agents is effectiveness. While each of these chemicals has a manufacturer's warranty and has demonstrated proficiency in killing roots under a variety of conditions, the sewer is a difficult environment for effective chemical control. Anecdotal evidence from collection system operators indicates that effectiveness of chemical control may be spotty and inconsistent. Utilities should implement a program that evaluates the effectiveness of the chemical root control application and proceed accordingly.

7.3.5.2. Bio-Filters and Barriers

One approach to root control involves creating barriers to uncontrolled root growth. These barriers have been used in tree boxes between the curb and sidewalk to deter roots from lifting or damaging these adjacent concrete structures. This approach involves limiting or directing root growth in a direction away from the sewer pipe to be protected or creating gaskets and joint materials that are resistant to root penetration. These techniques are pro-active deterrents to future root impacts and are developed during the design and construction phase.

Bio-fabrics are porous geotextiles with root inhibitor chemicals sewn into the fabric. These bio-barriers leach the chemical into the soil, where it remains as a long-term deterrent to roots. The chemical, trifuralin, limits root growth in the direction of the sewer when the fabric is installed vertically along the wall of a pipe trench or wrapped around the pipe envelope. The spatial relationship of the future roadside tree, the public utility corridor containing the sewer, and the bio-fabric are critical to achieving success with this technique. Future structural integrity of the fabric must be maintained as well. Root-inhibiting chemicals may also be added to the gasket material of flexible pipe joints as a further safeguard. In many respects, this is more practical because it is a benign deterrent. After installation, no further attention is required (Coder, 1998) (Van Voris, 1988).

7.3.5.3. Tree Species Selection

A significant amount of study has been developed in urban forestry relative to species selection to ensure survivability of the tree in the urban landscape. Height, diameter, root impacts to the sidewalk, paving, underground utility installation, soil and water conditions are all factors affecting the lifespan of trees in our communities. An additional pro-active technique to minimize future pipe damage from roots is to actively participate in the selection of the species to go into curb boxes and along roadways.

Many collection professionals recognize that the thirsty roots of the willow and poplar trees make them trees to be avoided in proximity to any underground pipes. Beyond these genuses, several characteristics may yield longer term success. Generally, smaller and slower growing species cause fewer problems. However, all is not absolute. Even “good” trees can go “bad” when roots seek out the sewers.

7.3.6 Grease Removal Tools

As discussed in Section 6.9.1, the elements comprising a good FOG program include adopting a strategy suitable to the nature of the problem and providing the resources to administer it. Adequate enforcement mechanisms are essential, including action levels for penalties and escalating fines for persistent or chronic violators. Effective FOG programs recognize that the proactive solution to grease is to not allow it into the collection system in the first place.

The complexity of a FOG program for any particular jurisdiction is sometimes determined by the nature of the collection system. In several suburban collection systems in the Mid-Atlantic region, where new or recent development dominates the commercial market, many suburban restaurants are built on “pad” sites where there is the opportunity for the construction of large-volume, in-ground grease interceptors. Larger tank volumes and longer residence times should contribute to more effective retention of the FOG material in the tank. Anecdotal evidence from those collection system operators indicate that FOG is effectively managed in the private sector through the active use of these large-volume interceptors. Proper maintenance of the interceptors, including scheduled removal of the accumulated fats and greases, is essential to the separation efficiency of the tank.

Some communities tend to have a more isolated problem in older portions of the collection system where “grandfathering” of earlier rules or technology retrofit of existing businesses is more of an issue. In 1994, Wichita, KS implemented grease requirements that required all new food service establishments to install a grease interceptor and with a corresponding inspection and maintenance program (City of Wichita City Code, 2002). To address the "grandfathering" issue of existing food service facilities, Wichita mandated a monthly service fee for existing restaurants to cover city costs for removing grease in the collection system. If, over time, documented significant amounts of grease were found from the facility, a retrofit would be ordered.

In 2001, the City of Los Angeles passed legislation to address the grease problem from over 10,000 food service establishments, estimated to be responsible for nearly 50% of the sewage spills in the city (City of Los Angeles, 2001) at an annual cost of approximately $1.5 million to clear sewers choked with grease (Tong, 2001). This analysis resulted from a GIS assessment of the locations of their grease stoppages which found that over 75% of the restaurants creating grease problems did not require an industrial waste permit. The ordinance provides for annual inspection fees of $244 to $356, application of best management practices (BMPs) for all establishments, and mandatory grease interceptors for all new restaurants and in restaurants with remodeling project values exceeding $100,000. It also includes retrofit requirements for those establishments documented to cause grease-related sewage spills or failing to effectively implement BMPs.

In 2002, St. Petersburg, FL passed a comprehensive grease ordinance to establish uniform permitting, maintenance and monitoring requirements for controlling grease discharges (St. Petersburg, FL, 2004). In addition to mandatory grease interceptors for all new food service establishments, new grease interceptors could be required in existing restaurants when one or more of these conditions were met:

- Documented grease discharges contributing to stoppages or requiring additional collection system maintenance,
- No existing grease interceptor or trap,
- Existing interceptor is undersized or defective,
- Plumbing permit is issued for remodeling of the food preparation waste plumbing system, or
- Facility is sold or undergoes change of ownership.

Grease traps were prohibited for new food service facilities except where it could be documented that inadequate space was available for a grease interceptor, which has a minimum size of 750 gallons. Grease traps that are allowed must conform to Plumbing and Drainage Institute (PDI) Standards G101.

FOG programs have led to numerous reviews of existing plumbing codes and development of BMPs that will continue to progress toward less grease discharge to the collection system. One practice review includes the re-assessment of commercial food grinders, such as garbage disposals, in food service establishments. While the Uniform Plumbing Code (UPC) prohibits food grinder discharges to grease interceptors, grinders in many communities are permitted to connect to the sewer lateral directly. One BMP suggests eliminating food grinders from all restaurants entirely with fine mesh screens installed in kitchen and mop sinks to trap solids for removal to the trash.

BMPs are intended to address the human behavior component of the FOG problem. In this role, many BMPs are designed for employee training and to elevate awareness. Posting of signs directing the proper disposal of FOG material, in languages commonly spoken by the employees, is important. “Dry” clean-up is a major recommendation within most practices. This includes using methods that scrape or wipe food or grease residue before using a wet cleaning method. Rubber scrapers are used to remove food residue from dishes and utensils with disposal to the trash. Disposable paper towels or food-grade paper can be employed to soak up oil and grease or wipe down areas. “Wet” method BMPS include pre-washing with hot water only so as not to emulsify the grease, hindering the interceptor’s ability to remove the FOG material. Spill prevention, recycling, exhaust hood cleaning, routine maintenance frequencies for traps and interceptors consistent with their use and collection of grease are other examples of BMPs routinely being adopted within the industry.

7.3.6.1. Bioremediation

In addition to trapping grease and removing it through physical and mechanical means, products have been developed to reduce the grease blanket thickness and volume within the interceptors. Bioremediation, sometimes referred to as “bioaugmentation” or “bio-treatment,” in this context is the controlled application of biological products containing microorganisms and enzymes selected for their ability to digest food service facility fats and oils and other interceptor waste stream discharges naturally.

The advantages of bioremediation in a grease interceptor application include digesting organic wastes within the drain line and promoting the naturally-occurring bacteria population in the interceptor, which in turn reduces the grease volume, the biochemical oxygen demand (BOD) and total suspended solids (TSS) of the effluent. In turn, this reduces the frequency of pumping of the grease interceptor and may eliminate any sewer fee surcharges that a utility may impose to treat higher strength wastewater typical from food service establishments.

In 1999, a Virginia county reported on a controlled test of a bioremediation product in 10 food service establishments including fast food, a supermarket and sit-down restaurants (Envirogenesis, 1999). Each had an outside, large volume interceptor ranging from 1,000-1,250 gallons in capacity. Composite samples of the interceptor grease volume, BOD and TSS performed over a 24-hour period, both before and after the controlled addition of the biological additive, were collected and analyzed at the utility laboratory over a 20-week study period. All ten of the interceptors showed measurable reductions in the grease blanket thickness from the end of baseline evaluation to the end of the treatment period. On average, the floating blanket of oils and grease went from 18 inches thick to three inches and the sludge depth at the bottoms of the tanks from 20 inches to two inches. In eight of the 10 interceptors, the average BOD improvement was 18% and the TSS improvement nearly 36%. Where improvements were not found, significant defects in the interceptor baffling or effluent piping were noted.

For nearly 20 years, New Castle County, DE has conducted a bio-treatment program involving the application of bacteria to sewers and wet wells for the reduction of grease (Appendix II, Case Study, 2004). The earliest program began with a modest four gallon mix of dry bacteria cultures and four manhole sites where a one gallon mix was discharged. The initial program achieved demonstrated results, gaining management support for increased dosing capacities of 40 gallons, then 90 gallons and 180 gallons. The program has culminated in the current “bug truck” with a maximum capacity of 360 gallons.

The “bug truck” is an insulated, closed-body utility truck designed exclusively for bio-treatment application of sewers. The truck contains four 100-gallon tanks where the bacteria are fed and cultivated. Each of the tanks contains ports for the addition of water, dry bacteria cultures, and food to sustain the growth. Connections are available at the garage for hot and cold running water and compressed air for aerating the mix. A small space heater is operated during the winter months to sustain the bacteria. Discharge of the bacteria to the sewer or wet well is by gravity from a hose at the base of each of the tanks.

New Castle has used three manufacturers of dry bacteria cultures over the years. The current mix includes approximately five grams, or about one tablespoon, of dry bacteria added to 90 gallons of water with 500 ml, or about one cup of dry dog food added as food medium for the bacteria. The water blend of approximately 30 gallons of hot water to 60 gallons of cold water yields the optimal temperature of 60 degrees Fahrenheit. for bacteria growth. The mix is also aerated using an onsite compressor in the garage. While in transit, the truck movement and baffling inside the tank are sufficient to keep the mix aerated. The mix material cost is approximately $2000 annually.

New Castle County currently has 29 collection system sites and 12 wet wells receiving the bacteria dosings. The current sites have been identified from maintenance records where recurring grease stoppages have been relieved. Once the location has been identified, the targeted manhole is selected, generally 400 feet upstream of the grease concentration. Approximately five gallons per manhole for pipes and 90 gallons per wet well is the nominal bio-treatment application. The empirical evidence suggests that the five gallons applied to the pipe will treat approximately one mile downstream of 8-inch, 10-inch, and 12-inch diameter sewer. The bio-treatment is applied by pouring the bacteria solution into an upstream manhole three to four times per week per manhole application and two times per week per wet well.

As a result of a cost and resource allocation review, New Castle has very recently moved to a third-party applicator to enhance the results (Hannan, 2004). Rather than the bug truck applying the bacteria solution on a scheduled frequency, the contract applicator doses the bacteria solutions through distributed injectors located at selected manholes and pump station wet wells.

Bioremediation has also been developed as an application directly to the waste and drain lines in the kitchen footprint. Drain lines accumulate organic slime that slows waste flow through the pipe, eventually clogging if untreated. Rather than emulsify the grease and oils through chemical or detergents, the controlled dosing of biological additives to the drain pipe applies grease-degrading bacteria to the problem area. Digestive reduction of the grease is supported through the regular dosing of waste stream with the bacteria cultures. Considerations in selecting the products for use include knowledge of the waste stream temperature, the pH, and the typical detergents and other solvents used in the kitchen for cleaning that may have a deleterious effect on the bacteria.

7.3.6.2 De-greasers

Sewer pipes made from plastics and vitrified clay are described as oleophilic because grease is attracted to the pipe surface. Grease and oils are both hydrophobic and lighter than water and want to move away from the waste stream. These natural forces create the attraction of grease and oils to the pipe wall and is the same reason why removing grease from these pipe materials is so difficult.

A study reported by County Sanitation District No.1 (CSD-1) in Sacramento County, CA found that grease was more likely to accumulate in small-diameter sewers with low flows or slow flows, described as one to two feet per second. Minimum-slope sewers, those with sags or bellies, and sewers with offsets or protruding laterals can contribute to grease accumulations (Hassey, 2001).

Attachments are available for both hydraulic and mechanical cleaning equipment targeted to the removal of grease. Care must be taken with some of the more aggressive methods, such as brushes or porcupines, so as not to damage the walls of the flexible, PVC pipes. Durham, NC reported using sand traps in downstream manholes to retain the grease removed through jetting and then vacuuming the residuals out of the manhole. Internal inspection observations of cleaned sewer pipes following grease stoppages, however, often reveal that stubborn grease coatings remain, attesting to the difficulty of removing this particular material.

Degreasing agents have been developed for the market place in the last several years. Typically, these are added to the water tanks of hydraulic cleaners to form one- to two-percent solutions and sprayed at high pressure onto the grease accumulations on the pipe wall. The combination of the penetration achieved by the water jet and the degreasing agent works to loosen and flush away the grease. These additives are solvents and emulsifiers that “liquify” the grease and move it downstream.

Anecdotal evidence resulting from discussions with collection system operators indicates that these additives do improve the efficiency of grease removal from the pipe walls. Re-coagulation of the liquefied grease is a potential concern. Empirical performance evidence and documented metrics are not as readily available within the industry.

Other products aid the rapid metabolization or microbial digestion of grease fats, proteins and carbohydrates by the existing bacteria in the wastewater stream. These bioaccelerators help prevent grease buildup in wet wells, and sewer pipes and may be introduced at a rate proportional to the flow in both liquid form and in blocks of bacteria that dissolve over time.

7.3.6.3 Program Effectiveness

In order to evaluate any program, performance measures must be developed. For example, the County Sanitation District No.1 (CSD-1) in Sacramento, CA developed the following performance measures:

- Reduce the number of stoppages and overflows due to grease (and the resulting non-compliances), and
- Reduce the claim costs associated with cleanup costs due to grease stoppages from businesses
- Reduce the cleaning frequency in sewers tributary to FOG discharges.

CSD-1 performed a grease assessment pilot project involving monitored locations. One area where no grease control was practiced served as a control (Hassey, 2001). Three other collection system areas were also monitored to evaluate the impact of active grease control, sewer rehabilitation to improve wastewater hydraulics, and the use of a pumping station wet well as a regional 'grease interceptor' for several upstream restaurants. The pilot work confirmed the benefit of active grease control.

7.3.7 Sewer Interceptor Maintenance Tools

Sewer interceptors are the backbone of the collection system. Some wastewater agencies rely on the self-cleansing capability and conservative capacity design of sewer interceptors to pass the peak flow without overflows. However, occasional cleaning of interceptors is sometimes necessary. Interceptors are often the final repository of debris and material collected from the neighborhood.

There are several factors inherent to the form and function of the interceptors that make selection and application of the cleaning tools critical. The diameter of the pipe brings selected cleaning tools into the mix and limits the effectiveness of others. Interceptor sewers are typically classified as 15-inch diameter and larger. This size often defines and separates the interceptor or "capital" size sewer from the rest of the smaller collection system. Perhaps the most flexible cleaning method employed in smaller sewer diameters, hydraulic jet cleaning, is most challenged by the larger capacities of the interceptor. Increasing the diameter of the sewer just two diameters from 18-inch to 24-inch adds 78% more cross-sectional area for the hose to move through and 33% more circumferential pipe surface to clean. This adds substantially to water requirements for hydraulic cleaning and the larger interior space limits the effectiveness of pressure washing. Larger pipes also mean heavier and bulkier debris may be trapped or laying on the interceptor invert, which may not be amenable to hydraulic cleaning.

Most interceptors are located along creeks, rivers and wetlands to take advantage of the grade that the topography presents. Access to these sewers may be a challenge which makes the use of conventional cleaning equipment very difficult. Cleaning tools for these sewers need to be transportable over rough terrain and able to cross the streams and water bodies that the pipes are following.

One class of cleaning tools employs hydro-mechanical cleaning methods. Water head propels the mechanical device through the sewer which generates water currents, eddies or mechanical force, agitating the debris, suspending it in the flow and washing it down the sewer. A patented product utilizing this principle, Jigawon, has been developed by a private company which allows effective cleaning of large interceptors. This tool consists of a flow restricting device that uses the existing sewer flow to create turbulence within the pipe, causing the material to be put in suspension and move downstream. Both fluids and wastes are removed in watertight containers downstream for separation and appropriate disposal of each component. The device is water head driven and the speed is controlled by retarding the "inflated" device through an upstream winch cable attachment. A case study of the use of this device in Fulton County, GA was presented at the ASCE Pipelines2003 Conference (Nezat, 2003). A total of 14,760 feet of the sewer line, with access every 2,000 to 3,000 feet, was cleaned. Approximately 150 tons of debris was removed from the interceptor using this device. Confirmation of the cleanliness of the interceptor was provided by sonar and CCTV inspection.

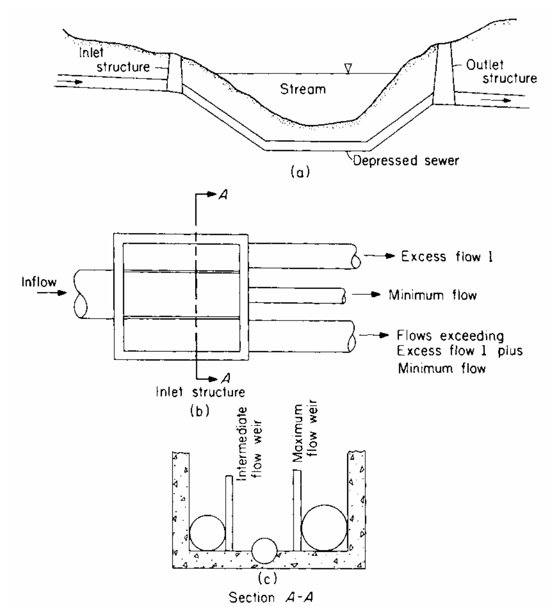
Sewer cleaning "balls" are available in larger diameters, either as rigid or inflatable balls. The surface is grooved and ribbed to generate turbulence and agitation when propelled by a head of water behind the ball. The debris and extraneous material is pushed ahead of the ball in the sewer section.

Kites, bags, or scooters are other hydro-mechanical devices appropriate for larger diameters. Since full pipe flow drives through the sewers, caution must be exercised where there are house connections in the segment with below-grade basements. Most connections are limited in trunk sewers, enabling the application of these tools with some degree of success.

Mechanical cleaning is one of the most practiced methods for large diameter sewers. Cable machines using engine-powered winches pull or drag a clamshell or bucket through the sewer by means of steel cables and drum rollers and capture rocks, gravel and other debris at the bottom of the pipe and retrieve them to the downstream manhole for removal. The mechanical bucket machines are ideal for urban interceptor locations where road access is available. They are more difficult to tow into rights-of-way where penetration of inaccessible landscapes are more routine. Additional details of mechanical cleaning tools are presented in earlier sections of Chapter 7.

7.3.8 Inverted Siphon Maintenance Tools

Inverted siphons, or depressed sewers, are gravity sewers with special needs. These sewers cross natural or man-made obstacles, such as stream or pipe crossings, which prevent a constant or uniform slope pipe design and construction. While the upstream manhole pipe invert is always higher than the lower, the sewer profile is depressed to pass under the structure or obstruction, creating an intentional low spot in the pipe. In order to accommodate the variety of diurnal and peak flows, siphons often are constructed with multiple barrels of several diameters. Elevations are established to maximize the utilization of the appropriate-sized pipe barrel to achieve the maximum velocity for the flow regime.



Due to their nature, debris often settles at the bottom of the siphon with grease accumulating near the top, requiring frequent cleaning. Inverted siphons should be designed with attention to convenient flushing and maintenance. Many utilities consider the use of inverted siphons as a last resort when no other feasible options are available. For example, the City of Fairfax, VA considers siphons only after all alternate designs have been determined to be impracticable. The city also requires an inverted siphon to be at least six inches, with a minimum of two barrels. The siphons should not serve a population of less than 3,000 in order to maintain minimum flow through the pipe barrels. (City of Fairfax, VA, 2004).

Mechanical devices such as balls or bucket machines are effective tools for cleaning inverted siphons. Care should be taken that the crown of the pipe barrel is not damaged from the steel cables that propel the bucket machine. Proper shoe and pulley arrangements should be used to ensure that the cable does not put undue pressure on the crown of the pipe barrel.

Hydraulic cleaning has been found to be effective for both small and large diameter siphons. Jet machines with the appropriate nozzles can be used to “nibble” at the debris in the siphon. The selection of the nozzle and the angle of the spray flushing action are important features in the effectiveness of this technique. Greater depths of the belly of the inverted pipe combined with steeper slope requires the hydraulic cleaning action to work harder to pull the debris “up the hill” for removal. This may limit the applicability of this technique for siphon cleaning.

A strategy to minimize the need for frequent cleaning of inverted siphons is the installation of automated flushing systems. For example, the East London City Council (UK) is planning to use such a device for a 600-millimeter (23.6 inches) diameter inverted siphon from Leaches Bay to the Grand Prix Circuit. Since the wastewater flow and resulting velocities through the inverted siphon will be low during the beginning cycles of development, the plan is to supplement the wastewater flow with seawater on the upstream end of the siphons. It is planned to pump seawater to an "off-line" reinforced concrete storage reservoir and use that water to flush the system approximately once every four hours. The frequency and amounts of flushing will be scheduled so that the siphon will be cleared at least twice a day. As the wastewater flow increases, the quantity of seawater used for flushing will be decreased and the flushing system would potentially be eliminated in 15 to 20 years (Entech, 2003).

Siphons have also been employed in combined sewers where a dedicated mechanical flushing system can be built directly into the sewer structure. The City of Richmond, VA described the application of such a cleaning device in their twin 66-inch diameter siphons under the James River (McConico, 2001). The city has found that wet weather events contribute significant quantities of sand and grit to the combined sewers, particularly following winter application of sand for road traction. Using an existing combined sewer overflow (CSO) junction chamber, the city performed a trial application by temporarily storing 4.6 million gallons of water behind a crest dam. A low head (1 foot) rapid release of the water proved successful at moving 40 tons of material to the treatment plant grit channels at the downstream side of the siphon. Following the successful demonstration, tilting weirs were designed and constructed to store and release up to 11.2 million gallons of water for flushing of the twin siphons. The stored head increased scouring velocities to an average of 6.5 feet per second for 20 minutes.

7.4. Collection System Maintenance Frequency & Rates

Regardless of the cleaning technique employed, there are several important variables that utilities must assess based upon their own system characteristics. These variables also help define the labor and equipment requirements needed for an effective maintenance program. Establishing a cleaning frequency for specific portions of the collection system is one of those variables. Maintenance histories, nature of the stoppages, and age of the system are factors used in determining an appropriate frequency of cleaning.

Many agencies have annual cycles for sewers with a history of problems. Emergency problems typically transition into a preventive maintenance schedule which can become a basis for a proactive program. The frequency of cleaning and the quantity of the collection system to clean is a key decision for agencies. This decision has a direct role in the effectiveness of the program and shapes the budget and staffing requirements. The choices for an effective program include preventive maintenance cleaning of sewers that have exhibited a problem in the past, the rote process of cleaning the entire system on a prescribed basis or targeting proactive maintenance to those portions where the most benefit is received for the cleaning investment. The former approach has been advocated by many regulatory agencies while the latter approach is gaining popularity be with wastewater agencies. The proactive process also requires a thorough understanding of the nature of the overflow problem and the historical performance of the pipe in the collection system in that regard.

The North Carolina Clean Water Act of 1999 initiated a series of requirements for collection system operators in the spirit of the draft SSO rules proposed at the federal level (General Assembly of North Carolina, 1999). Among other stipulations, this law required the permitting of collection systems with permits issued over a five year roll-out period beginning July 1, 2000. The law also established SSO reporting rules, annual wastewater performance reporting requirements and operation and maintenance guidance. The O&M requirements are discussed in this section.

The NC permit program is taking a “holistic” approach to the collection system and will include the state’s determination of what proper sewer operation and maintenance should include. Frequency of O&M is addressed in several specific areas. The permit prescribes an assessment of cleaning needs for the collection system and implementation of a program to clean, through hydraulic or mechanical means, all sewer mains. By permit requirement, at least 10% of the collection system sewers should be cleaned annually. The state does not direct which 10%, leaving the selection to the discretion of the operator in Responsible Charge.

Another frequency stipulation is directed toward those sewers that are subject to routine environmental impacts. Semi-annual inspections are required of all aerial lines, sub-waterway crossings, siphons, and sewers parallel to stream banks, regardless of diameter, that are subject to erosion that may threaten the structural integrity of the sewers.

The Maintenance & Operations Collection System Benchmarking Study, performed for the County Sanitation District No.1, Sacramento, CA, resulted in an interesting perspective for agencies to consider (CH2MHill, 1998). The benchmarking effort included seven California utilities seeking to improve their performance through the use of metric and process benchmarking. Several agencies in the study reported having practiced proactive maintenance and have completed the five- to 10-year cycles of cleaning their entire systems. “Although these agencies have consistently been top performers, they now question whether system-wide proactive maintenance is necessary or if focused proactive maintenance would be as effective.”

Focused proactive maintenance utilizes previous system performance and inventory characteristics to project where problems may develop. Universal cleaning includes those sewers that don’t need attention, such as a three-year old sewer, as well as those in dire need. The triage approach to proactive maintenance attempts to identify those sewers or classes of sewers that exhibit performance histories of problems amenable to cleaning.

7.5. Facilities Maintenance Plan

7.5.1 Pump Station Maintenance

One of many areas where wastewater professionals "agree to disagree" is whether management and functional responsibility of pumping systems belong with treatment or collection system units. There are certainly good arguments on both sides of the issue. Although the pumping system is clearly a transport mechanism, the treatment side of the discussion presents the electrical/mechanical (E/M) components integral to the pumping station as similar functions to existing systems maintained at the plant. Power, pumps, Supervisory Control and Data Acquisition (SCADA), lock out/tag out, and other requirements of the pumping system involve skills typically found in treatment personnel. Pumps are at the headworks of many treatment systems and have been integrated into the management philosophy of agencies due to these relationships.

However, satellite systems do not have treatment works. Pump stations are also dispersed throughout the service area, providing the "lift" that the wastewater needs to continue its journey by gravity to a destination sometimes many miles away. The length of travel, location of the stations, routine need for preventive maintenance and station visits, and lack of treatment works all present an alternative case for custodianship within the collection systems groups.

Regardless of the management approach, pumping systems are a major source of SSOs for agencies. Although pipe stoppages are responsible for the greater frequency of overflows, pumping systems and their failure under the stress of peak flows and stormy weather have the greater potential for high profile, major quantity discharges of wastewater. Loss of power, pump failures, insufficient capacity, force main leaks, and a host of other maladies all can lead to the type of overflows that routinely bring emergency response plans into action. Health Department and media notifications, potential for watershed sampling, advisory postings, and the attendant clean-up and restoration should provide additional incentive beyond the enforcement ramifications to take the proactive measures necessary to keep the pumping systems operating efficiently and effectively.

7.5.1.1 Preventive Maintenance

The most critical component of any pumping system is the care and attention received through a comprehensive preventive maintenance program. The goal is to have the pumping system operate reliably under stress to keep the wastewater in the collection system. The implementation of "best practices" from the industry can take an agency's preventive maintenance to a higher level of effectiveness and efficiency.

Components of an appropriate preventive maintenance program for pumping facilities include:

- Routine lubrication of mechanical components, and
- Routine housekeeping of the station, and

- Thermal scans of electrical circuits, and
- Vibration analysis of pump shafts, and
- Wet well cleaning, and
- Operating at the pump's best efficiency point, and
- Computerized Maintenance Management System (CMMS) for record keeping

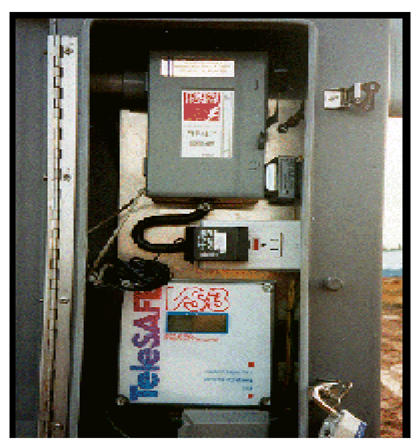
7.5.1.2 Screening

With the continued development of non-clogging impellers capable of passing larger-size solids, there is a movement in the industry exploring the elimination of traveling screens ahead of the pumps. Screens are a major operation and maintenance cost, requiring frequent attention. The failure of the screen drives can result in clogging and flow restrictions upstream of the wet well, leading to potential overflows that are independent of the station capacity.

More stations are being designed or operated as unmanned facilities, regardless of their size. Programmable logic controllers (PLCs) and SCADA permit even the largest pumping facilities to operate without the benefit of onsite staff. Screens simply become one more moving part that needs to be maintained. The selection or retrofit with non-clogging pumps, and attention to the pumping parameters necessary to contribute to a non-clogging operation, may enable the agency to eliminate the screens. There is an inherent risk that a pump may jam without the solids screening ahead of the intake. However, the occasional repair may be less costly than the ongoing O&M associated with the screens. Appropriate station controls must enable the lag pump to take the flow should the lead pump jam.

7.5.1.3 Power Reliability

Wet weather overflows at pump stations are more likely to be caused by loss of power than any other factor. Lightning strikes, toppled trees and other power grid problems routinely interrupt power to many stations during inclement weather. Unlike treatment facilities where secondary power grid feeds and large standby generators are common features, many pumping stations were not designed with backup power provisions. Bypass or overflow points were designed in the station to protect upstream property and the overflow was tolerated, particularly in smaller stations.



Redundant power supplies have become one of the most cost-effective enhancements that can be performed to increase reliability and eliminate SSOs at pumping stations. The proliferation of the self-contained, standby generator packages, or "generpacks," enables the cost-effective retrofit of many stations with a secondary power source. These "generpacks" register the primary power interruption and have auto-ignition features that allow them to cycle on for continuous power supply. SCADA controls enable the operators to know when the generator has cycled so that a crew can be dispatched to re-establish the primary power feed or re-fuel the generator for additional operating time. The use of enclosures or housings around the engine components help keep operating decibels to acceptable norms and keep the station "neighborhood-friendly."

If the station capacity is very small, flows are limited, the station has an unusually large wet well capacity for the current flows, or any other capacity reason that enables a window of opportunity for response from an agency crew, a portable generator may be a more cost-effective solution. The simple retrofit of the station to accept a quick-disconnect plug for rapid hook-up allows for one or more portable generators to provide back-up power for multiple pumping stations.

7.5.1.4 SCADA

Remote control of pump station operations through a SCADA (Supervisory Control And Data Acquisition) system significantly improves the ability of the operators to monitor and take appropriate action to ensure optimal operation of the pump station. The SCADA system can provide a variety of information, such as:

- Overflow reports and/or alarms
- On/off pump status
- Malfunctioning pump status
- Water level in the wet well
- Pumped flow rate
- Electric power status
- Standby generator status

SCADA technology has been advancing at a rapid pace. The new technology allows the traditional pump station hardware, such as pumps, valves, and motor controls, to be in constant communication with remote hardware and software. Advances over traditional hardwired connections through other cabling technologies are also increasing the flexibility of the SCADA network. Daisy chain, bus and star are the major network topologies. The open bus topologies utilize remote terminal unit (RTU) and programmable logic controllers (PLCs) for control of variable frequency drives for pumps, switchgears, motor controls, power monitors, workstations and valve actuators.

The communication technology has also expanded. The traditional leased or dial-up line is being replaced by radio signals, fiber optic and internet communication devices. The internet access allows the option of mobile computing from the field through a wireless protocol and near real time access to the pump station hardware. A limitation with some SCADA controls has been storage of the data. High capacity storage devices are needed to store the sheer volume of data that is possible from the monitoring and control functions of the hardware. The lower costs, faster speeds of the network and increased computing power available all keep driving SCADA to be more affordable and attractive for agencies.

The real advantage of SCADA systems is the efficiency and cost-effectiveness of unattended operation. Different levels of control can be designed, from "local manual," meaning interface with pump station crews that use the SCADA for maintenance and logging preventive maintenance visits, to full SCADA automatic mode, requiring reduced staff interface in the field. The more completely the unit processes that occur at pump stations, such as screening, pumping, flow measurement and power, can be monitored and controlled, the more proactive an agency can be to anticipate or react to equipment failure and wastewater overflows.

7.5.2 Wastewater Treatment Plant Maintenance

Wastewater treatment plants include complex structures, equipment and physical, chemical and biological processes that need to be monitored and maintained on a continuous basis. These functions are performed by skilled personnel who have acquired the training and knowledge required to perform them. It is critical that written Standard Operating Procedures be available for the maintenance of treatment plant components and that scheduled preventive maintenance occur in accordance with industry standards.

Some utilities have gone beyond the hard copy O&M manuals and have developed electronic versions of such manuals that can be accessed by all plant personnel through their computer terminal. For example, the District of Columbia Water and Sewer Authority (DC WASA) has developed a Plantwide Interactive Electronic Reference System (PIERS) that is not only used in daily operations but is also used for training purposes (Foster, 2003).

The PIERS System, which operates on the DC WASA intranet site, allows DC WASA Operations and Maintenance staff to access an electronic version of the O&M manual, check on plant equipment status from a process perspective, facilitate in-plant communication through a bulletin board for each process area, and use it for other purposes such as maintenance, safety, and training. It provides 24-hour access to technical information on standard operating procedures, construction drawings, equipment service manuals, and the process safety management plan.

DC WASA has benefited from this project in several ways:

- Availability of information that is accurate, up-to-date, and easy to access.
- Improved communications between operations and maintenance; as well as between shift operators, and between staff and management.
- An information distribution system that is reliable.
- Lower cost to update operations and maintenance manuals.

An additional feature provided by PIERS and other treatment plant software is the ability to develop a critical equipment list, a tool that helps to operate the plant. By providing a dynamic list of essential equipment with a real-time status, plant staff is more informed of potential process problems and what backup equipment is available. The listing can be made by process, equipment type and service status to facilitate ease of operational review. A list of out-of-service equipment and the timeline for the status provides a routine basis for O&M by the plant staff. Summary reports by application and process simplify the communication of the plant's overall status and its ability to deal with pending wet weather flows or toxic shocks that may lead in one manner or another to permit violations and overflows.

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Chapter 8 Condition Assessment Solutions

8.1. Introduction

Condition assessment is a critical component of an effective program to resolve SSOs. Decisions regarding the maintenance, operation, and rehabilitation of the collection system to eliminate SSOs can be based on the results of a condition assessment of the system. Condition assessment may address the structural and/or infiltration/inflow conditions.

The condition assessment is typically based on inspections by closed circuit television (CCTV), Sewer Scanning Evaluation Technology (SSET), manhole inspections, smoke testing, dyed water flooding or other evaluation means as appropriate. For structural assessment, particular attention is made to defects such as pipe breaks, cracks, displaced joints, missing pipe pieces, sags, corrosion activity and manhole structural defects.

I/I condition assessment is performed by utilizing a combination of methods such as manhole inspection, CCTV inspection of sewer lines, and flow monitoring. An analysis of the data is performed to estimate the amount of infiltration and inflow.

8.2. Protocols for Identifying Location of SSOs

The identification of the likely location of SSOs and evaluation of the causes of SSOs should be a part of a comprehensive preventative maintenance program and capital expenditure plan. Cities, sewerage authorities and agencies need established and proven guidance for identifying and evaluating the causes of SSOs. Such guidance material should cover both wet weather and dry weather SSOs.

Several techniques for identifying the locations where SSOs may occur include:

- Sewer inspections by CCTV monitoring;
- Analyzing sewage indicators in nearby streams and storm drains;
- Flow monitoring and hydraulic modeling;
- System inspections including manholes, pumping stations, private sector sources, and smoke and dye testing;
- Review of customer complaints and/or maintenance records; and
- Engineering analysis of the structural integrity of the sewer system.

The USEPA has developed two SSO management flow charts which capture the key elements of a sound SSO program, including the protocols for identifying SSOs. Figures 8.1 and 8.2 are charts that can be used by agencies in planning SSO management and in discussions among operators, agencies and with regulators. Figure 8.1 presents the general flow of a suggested SSO Management Program, identifying each decision point and associated activity. Figure 8.2 provides additional details for key elements listed in Figure 8.1. These are helpful guides for implementing an SSO program. Further details on protocols for identifying location of SSOs may be found in the ASCE (2000) report entitled, “Protocols for Identifying Sanitary Sewer Overflows”.

8.3. Sanitary Sewer Evaluation Survey Activities

Sanitary Sewer Evaluation Survey (SSES) activities include those activities to quantify flows including I/I and to assess the structural and I/I condition of the system pipes, manholes, and other structures and facilities.

8.3.1 Flow & Rainfall Monitoring

Flow monitoring is used to quantify wastewater production (base) and infiltration and inflow (I/I) in the collection system. The data collected can be used for hydraulic evaluation of the sewer system, calibration of hydraulic models, assessment of I/I, and assessment of effectiveness of rehabilitation measures in eliminating I/I. Flow monitors are installed at strategic locations in the sewer system and the flow is measured at frequent intervals, typically 15 minutes.

Flow meters may be installed as “permanent” or “temporary.” Permanent open channel flow meters include:

- Flumes such as Parshall flumes and Palmer-Bowlus flumes,
- Weirs, such as V-notch, rectangular, and trapezoidal,
- Velocity measuring devices, both doppler and ultrasonic, and
- Depth measuring devices, including ultrasonic, bubbler, static pressure devices, and transducers.
- Various combinations of all of the above

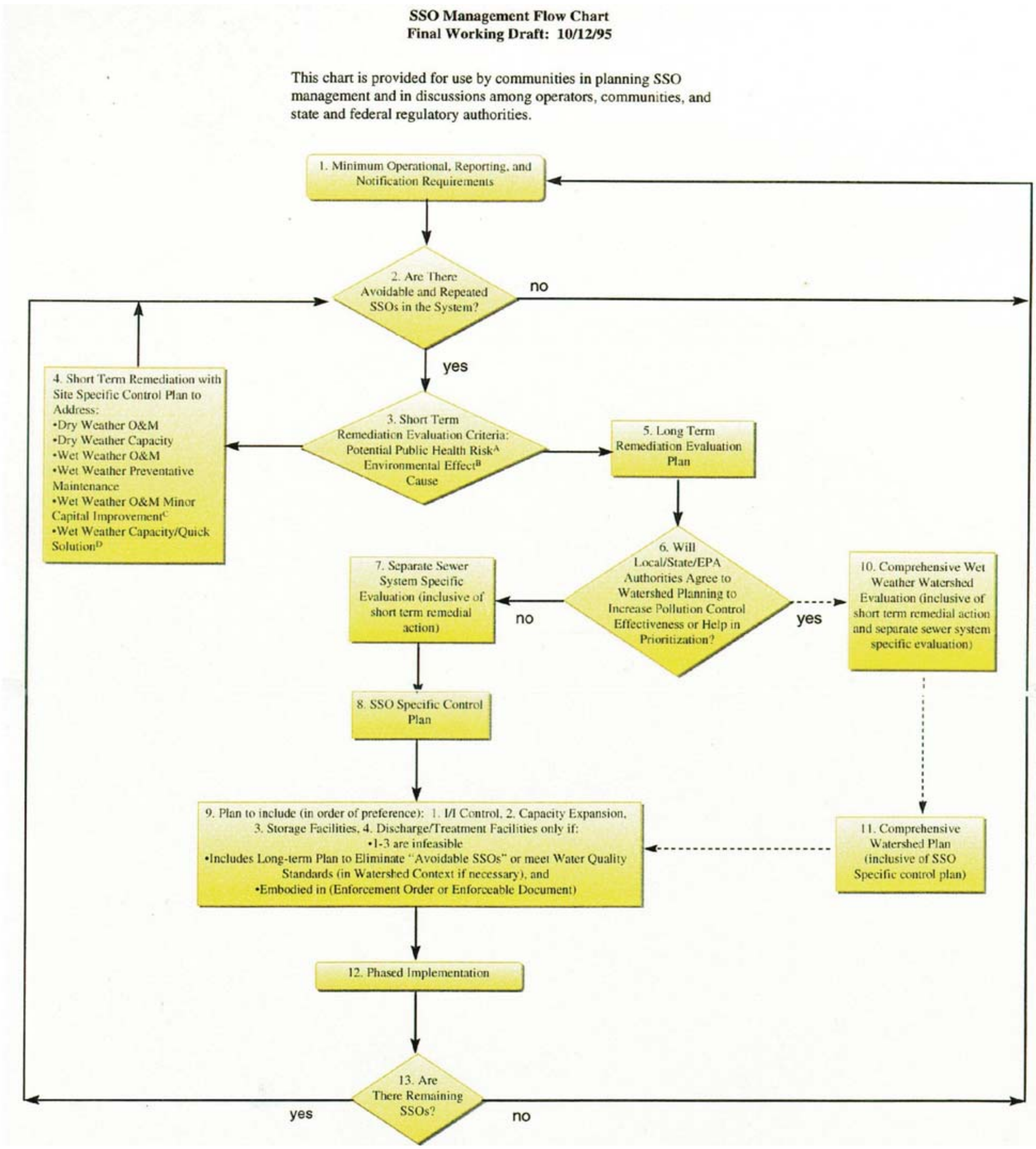
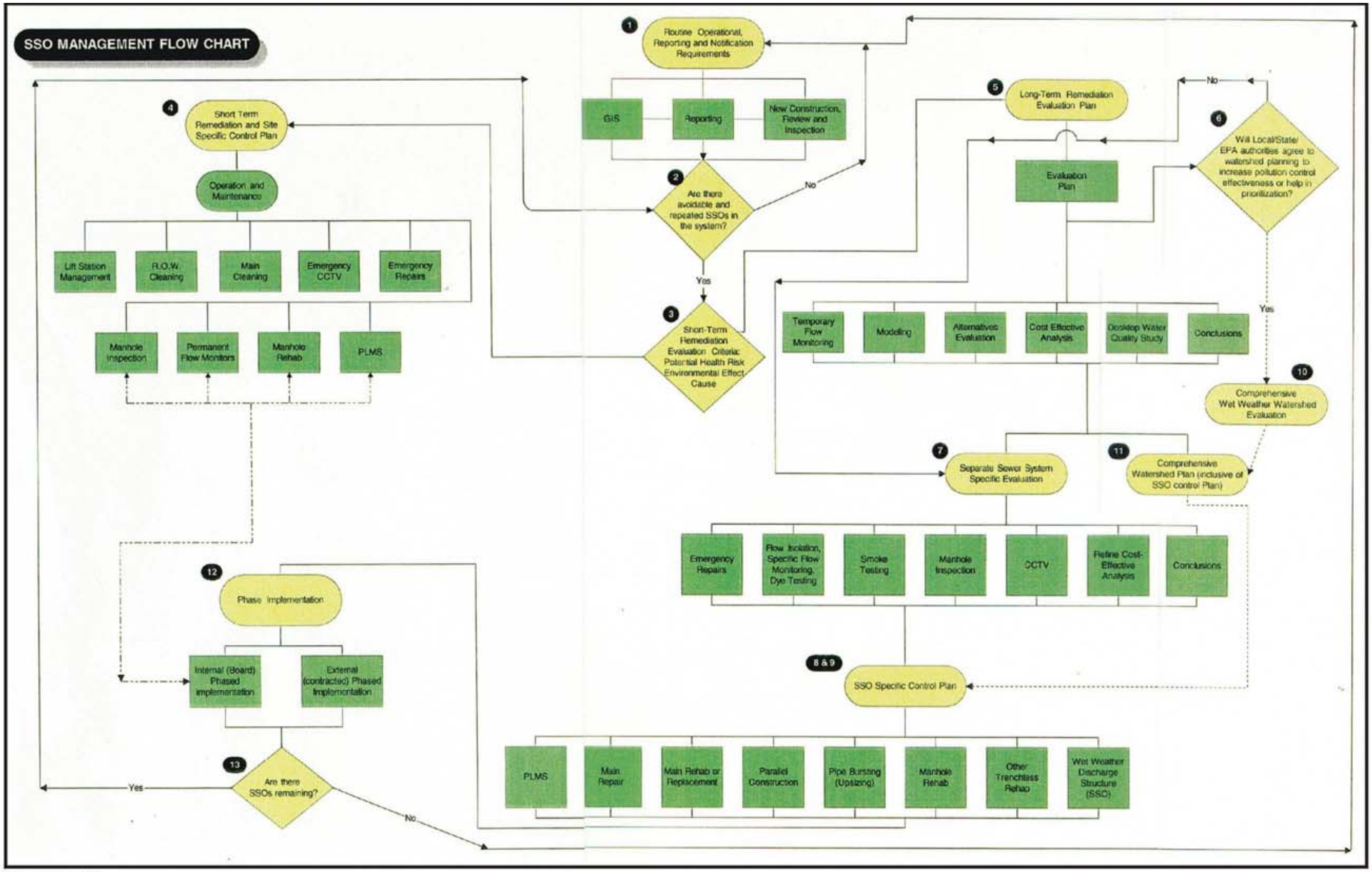


Figure 8-1 SSO Management Flow Chart (General)



Source: EPA

Figure 8-2 SSO Management Flow Chart (Detail)

Temporary flow metering devices include ultrasonic, doppler, or bubbler devices for flow measurement. The instrument is often installed in the upstream reach of the access manhole. The monitoring device has the capability of storing the data, which can be downloaded to a laptop computer in the field or transferred to the office via a phone line or over the internet. Specialized software is also available which can help analyze the data. In addition to monitoring flow meters at strategic open channel locations in the sewer system, flow meters can also be installed at pumping stations and the wastewater treatment plant. Both short-term monitoring, typically 60 to 120 days, and long-term monitoring, one year or longer, may be performed to capture data under various weather and loading conditions.

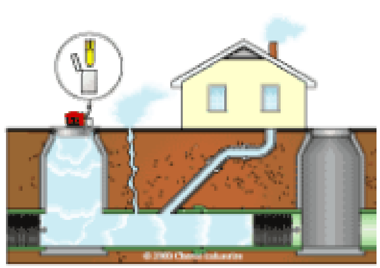
For areas concerned with wet weather flows, rain gauges should also be installed and monitored. Alternatively, rainfall data may be obtained by utilizing remote sensing radar technology, known as Next Generation Weather Radar System (NEXRAD). This system has approximately 138 Weather Surveillance Radar Doppler sites throughout the United States. NEXRAD provides greater accuracy in both rainfall intensity and its spatial distribution. The rain gauge data is used to determine the spatial distribution of rainfall and its impact on system flows. A ground rain gauge network is important to properly calibrate the NEXRAD data (Seremet, 2002).

The number of flow meters required for adequate characterization of the wastewater flow and the level of infiltration/inflow depends on a number of factors such as the objective of the flow monitoring program, sewer system configuration and size, the number of sewersheds or drainage basins, and budget and time constraints.

8.3.2 Flow Isolation

Flow isolation and measurements (I&M) are used to quantify localized infiltration levels into the sewer system. This typically involves isolating one or more sewer segments and measuring the flow manually during the early morning hours of low domestic activity, such as midnight through 5 am. Night I&M usually is performed during high groundwater conditions. During the flow isolation, the upstream sewer line is plugged and flow is measured with a v-notch weir in a manhole downstream of the plugged sewer section. Portable pre-calibrated weirs or flow depth and velocity measuring devices are used for flow measurement. This flow quantification procedure allows for more precise measurements of leakage and confirmation of infiltration values obtained from a flow monitoring program.

8.3.3 Smoke Testing



Source:www.cherneind.com

The purpose of smoke testing is to locate rainfall-dependent I/I sources, which could lead to an SSO during a storm event. Specific sources detected include roof, yard and area drain connections, catch basins, area drains, and broken main and service lines. A non-toxic, non-staining low-pressure smoke is pumped through a manhole into the sewer pipe for distances up to 600 feet. Smoke emissions from manholes and from the ground indicate defects in manholes, sewer lines, and sewer laterals through which I/I may enter the sewer. Both single blower and dual blower techniques have been used. The dual blower technique uses a blower on both the upstream and downstream test section manholes. The smoke emissions from sources such as roof leaders, stairwell drains, and around building foundations indicate possible surface connection to the sanitary sewer. The absence of observed smoke emission from a potential source does not prove that problems do not exist. Surface water connections indicated by smoke testing can be tested with dye tracing, to confirm or rule out the connection.

All potential sources identified by smoke testing should be photographed and documented. A schematic drawing, giving explicit directions for locating the observed smoke, should be included for each observed smoke emission. Observations of smoke emissions and the appropriate manhole identification number shown on the agency's map should be recorded appropriately on each smoke testing form. An assessment of the quantity of I/I should be made based on the area and type of ground cover of the catch basin.

Public notification is an important part of a smoke testing program because of the potential for smoke appearing in and around buildings. Adequate notice of the impending smoke testing should be made to every building served by the sewers to be tested. Also, to reduce the possibility of fire alarms, the Fire Department should be kept informed of the areas to be tested each day. Smoke testing should not be done when the ground is saturated; the pipe is flowing full, or during rainy or windy days.

8.3.4 Dyed Water Testing

Dyed water testing includes dye tracing or flooding, and is done to determine possible sources of inflow such as area drains or catch basins suspected of being connected to the sewer line, or sources of rainfall-induced infiltration/inflow which indirectly contribute to the flow in the sewer line through the soil and pipe cracks. The dye testing is normally used to complement smoke testing of suspect areas. A manhole downstream of the test area is monitored to see if the dye water injected in an outside source such as a downspout has found its way into the sewer system. Color CCTV may also be used for locating problem areas after the dye penetrates the pipeline from the surrounding soil. Verification for major sources (such as storm water catch basins) is achieved by comparing flows at the downstream manhole before and during testing.

Dyed water is made by mixing a nontoxic indicator dye with water. The test methods include:

- Pouring the dyed water into the suspect source,
- Flooding storm sewer catch basins or ditches with dyed water
- Injecting dyed water in the area of underground suspect sources.

All test results should be appropriately recorded on a dye testing form. A schematic drawing, giving explicit directions for locating the observed dye, should be included for each positive dye test. All positive dye tests should be quantified by giving consideration to the surrounding area contributing to the problem, and the amount or intensity of dye observed.

8.3.5 Closed Circuit Television Inspection (CCTV)

Since 95 percent of the collection system is non-man entry due to small diameters, it can only be inspected by CCTV. CCTV is often performed on selected defective sewer lines identified through other less costly preliminary inspection techniques such as lamping, smoke testing, and dye water testing. CCTV inspection is performed by pulling the camera through the sewer line. Alternatively, the camera may be installed on a tractor transporter which advances in the sewer line by motorized tracks or tires. The CCTV unit can traverse up to 1,800 feet each way from a given access point. Most CCTV equipment on the market has color cameras with tilt and pan capabilities. Some CCTV units have also been combined with a sonar unit on partially surcharged sewers to give a complete picture of the sewer both above and below the flow surface.

During inspection, the images from the camera are observed on a monitor. If the camera becomes obstructed and cannot continue, a reverse setup is usually used to enter the camera from the downstream manhole. If flow depth is above the camera lens, bypass pumping may be necessary. It is important to clean the line prior to CCTV inspection.

The CCTV images are stored on videotape, CD or DVD. Encoding the images in MPEG format will allow searching for a particular section of sewer in a few seconds instead of several minutes.

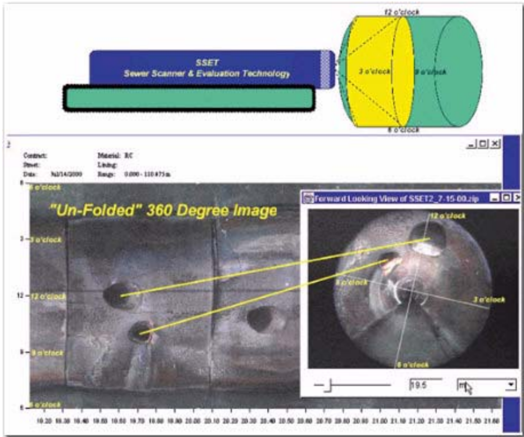
Observations are summarized in field logs which are prepared and narrated by an operator. Still photographs of defects and other features of interest are also taken. The videotape provides a visual and audio record of problem areas of the sewer line. The evaluation of the CCTV records will help identify structural problems of the sewer line, locate leaking joints and non-structural cracks, blockages, dropped joints, and identify areas of root intrusion.

The analysis and interpretation of the CCTV data is as important as its collection. A standard should be selected and applied for characterizing the defects. National Association of Sewer Service Companies (NASSCO), a non profit organization, has recently implemented a Pipeline Condition Assessment and Certification Program (PACP) to provide standardization and consistency in the way sewer pipe conditions are evaluated. NASSCO is utilizing a revised version of the Water Research Center (WRC) CCTV codes. All the information should be organized in a database for further analysis. A number of proprietary software packages are available which may be used for this purpose.

Although CCTV is a very useful tool for evaluating inflow/infiltration (I/I), its use is very limited in evaluating exfiltration as it relies totally on the visual record. While it is easy to visually identify defects which may leak, defective joints are more difficult to identify. It is also very difficult to survey the parts of the sewer below the flow surface, unless the effluent is very clear.

8.3.6 Sewer Scanner and Evaluation Technology Surveys

SSET is a new inspection pipeline technology developed in Japan. It can be an effective tool in performing condition assessment of sewer systems. The removal or repair of defects discovered during the inspection can reduce the level of infiltration/inflow and/or



enhance the structural integrity of the sewer line, thereby decreasing the potential for SSOs. An important feature of this technology is the possibility of measuring the rate of deterioration of the sewer system. This can be achieved by comparing the SSET images taken at a certain time and compare them with images taken at a later date. Since the images are digital, it is possible to develop software which can compare these images and detect any deterioration which may have occurred since the last inspection. This will allow for the calculation of a deterioration rate. Such information is critical in estimating the remaining service life of the sewer line and will allow the wastewater utility managers to plan for rehabilitation or replacement of sewer system assets in a timely manner.

The SSET system consists of a scanner, a CCTV, and three axis mechanical gyroscopes. The gyroscope is used to measure inclination and meander. The mechanics of placing the SSET in the sewer line are similar to the CCTV inspection. The images of SSET are of higher quality than CCTV images. The high-angle “fish eye” lens provides simultaneous 360-degree side scan and forward-looking images. An array of high density LED light provides the lighting for the camera. The digital data of images are stored on CD-ROM for rapid access and easy archival. Interpretation of the results is conducted in the office by an engineer rather than in the field by a technician. This increases the speed of field operations and reduces the cost.

The scanned image is digitized and a color-coded computer image is produced. Statistical data on defects can be generated. Since the data is in digitized form, it is possible to develop software programs to automatically interpret the images and diagnose the defects. Research is underway to develop such diagnostic tools using neural network and fuzzy logic techniques.

The Civil Engineering Research Foundation (CERF) performed an evaluation of this technology. A technical evaluation panel, which consisted of representatives from 13 municipal agencies throughout North America, oversaw the evaluation. The evaluation was initiated in the fall of 1997 and lasted approximately two years. It was conducted in two phases: an extensive field-testing program that required approximately 10,000 feet of sewer pipeline to be scanned in each participating municipality, and a comprehensive analysis of the collected data (CERF, 2003).

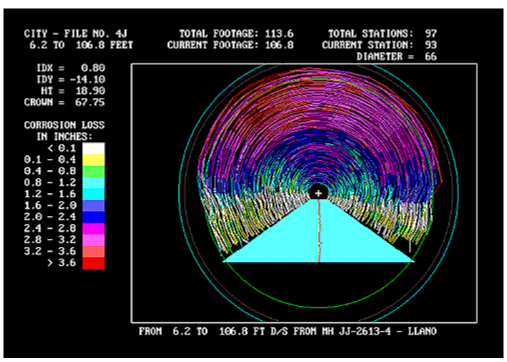
The evaluation report noted the SSET's abilities to produce a digital record of the sewer pipe, to identify vertical deflection in pipes, and to deliver easily comprehensible and manageable results. SSET output provides an excellent format of data presentation and is superior to CCTV standard log sheets and report tables. Images produced by SSET can be screened relatively quickly and offer the ability to easily recognize and locate significant problems in pipelines. Various defects in sewer pipes are generally shown accurately, with the image resolution being adequate to clearly indicate their type and size in most cases. SSET is applicable in pipes ranging from eight to 24 inches in diameter and is appropriate for all pipe types except dark-colored HDPE and iron pipes. In terms of the difficulty of field operation, SSET is comparable to CCTV and is relatively easy to use. The most notable weakness of SSET is that it does not identify all types of problems or defects that exist in sewer pipelines equally well.

As a result of the field operations and the subsequent analyses of the collected data, the panel concluded that, compared to CCTV, SSET provides significant improvement over traditional technologies through additional features, but cannot provide all of the features of CCTV that can be important in sewer inspection.

Since the completion of CERF's evaluation, significant improvements have been made to the technology in terms of the lighting system and the design of the camera lens. In addition, special software has been developed to facilitate interpretation of the images. Research is underway to develop a pattern-recognition software that can detect common defects such as cracks, broken joints and protruding taps. In addition, several software packages that were primarily developed for the capture and analysis of CCTV images have been upgraded to be able to handle SSET images as well. SSET developers have also worked with NASSCO and software providers to develop the ability of adopting standard PACP defect codes for analysis of SSET data.

8.3.7 Sonar Technology

Pipe profiling sonar (PPS) was developed in Europe and is now in use in North America (WRc, 1984). The technology can provide information on structural damage, blockages, sediment, large cracks, and the location of incoming lateral lines. PPS can be used for inspecting pipes from three-inch through 144-inch diameter and has a maximum cable length of 2,500 feet. Underwater sonar equipment combined with enhanced CCTV provides an ideal engineering tool to inspect and assess large diameter sewers with high flow conditions, providing comprehensive structural and hydraulic condition assessment.



Source:www.sonexhome.com

The scanning unit is housed in sealed stainless steel pressure housing (Radio Detection Website, 2003). The sonar unit transmits an acoustic signal radially toward the pipe walls, using a rotating transducer. The time delay between transmission and reception of reflected pulse echo is used to determine the distance from the transducer to the surface which reflected the pulse. Determination of the acoustic frequency to be used is influenced by two competing factors - background 'noise,' which decreases as pulse frequency increases, and signal loss, which increases as frequency increases. The frequency chosen will also affect image sensitivity and power requirements. At low frequencies, less than 200kHz, the pulses emitted can penetrate sewer walls, thereby providing an assessment of structural condition and pipe wall thickness. However, the accuracy of readings decreases for sewers of 72 inches or more in diameter. The device communicates via cable with an acoustic processor unit fitted with a CD read-writer for storing still-frame images from the display screen at full resolution. The stored images can be loaded back into the system, cursors positioned, and measurements taken of pipe diameter, objects, and large defects. A video output connection allows the entire survey to be recorded onto VHS or S-VHS tapes. As the scanner moves through the pipe, an indication of the distance traveled is shown on-screen to an accuracy of four inches, allowing accurate location of flaws in the pipe relative to the initial point of sonar deployment. Pitch and roll indicators display the orientation of the scanning unit in the pipe in analog and digital form.

The precision of the sonar results are a function of several factors, including the speed of longitudinal movement through the sewer, the quantity of suspended solids in the effluent, and the degree of turbulence. Under ideal conditions in a 96-inch diameter sewer using extremely slow forward advancement, the device can indicate openings or cracks of about 0.2-inches (Andrews, 2000). Under normal use, the sonar image will identify those defects that clearly require action. Several factors influence the quality and clarity of sonar images:

Flow from laterals causes considerable air entrainment in the main sewer line downstream of the connection. The entrained air tends to interfere with the sonar image, making it unclear.

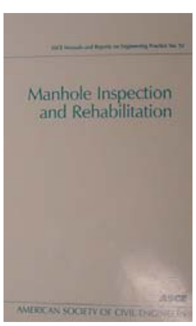
Heavy suspended solids and debris can also interfere with the sonar signal. This can cause partial distortion of the sonar image.

8.3.8 Man-Entry Inspection

Man-entry inspections may be performed on large-diameter sewer lines and tunnels. During inspection, the crew should observe the appearance of the sewer line walls, signs of flow disturbances, extent of corrosion, and the structural condition of the sewer line. Sounding tests may be performed by striking the crown, sidewalls, and invert of the sewer line with a hammer and noting whether the generated sound is dull or solid. Photographs should be taken of any observed defects. A hand-held video camera should also be used to videotape the internal surface of the sewer line. To assess the extent of corrosion activity, field measurements of pH, dissolved oxygen, ambient hydrogen sulfide, and dissolved hydrogen sulfide should be taken.

Due to hazardous conditions in the sewer line and confined space requirements, safety precautions are of paramount importance. If the flow of wastewater cannot be diverted, inspections should be performed at night and during dry weather conditions so that the wastewater flow is minimal. Ventilation fans should be used to ensure that the crew inside the sewer line has good ventilation. Harnesses must be used for entry and exit structures. Gas detectors, escape capsules, flashlights, emergency air-horns, and life-vests should also be available for use. The inspection should be performed by at least two persons and they should have constant communication with the personnel outside the sewer line.

8.3.9 Manhole Inspection



Manhole inspections are performed to confirm the physical layout and mapping of the sewer system, determine the physical condition of the sanitary sewer manholes and to locate sources of I/I. During inspection, evidence of surcharging may be observed in the form of high water marks on the walls of manholes. The manhole inspections identify defects that can be used to estimate the I/I flows attributable to each manhole. Such data can also be used to establish manhole maintenance and rehabilitation needs.

The American Society of Civil Engineers Manual of Practice No. 92 on "Manhole Inspection and Rehabilitation" provides further guidance on implementing a successful manhole inspection and rehabilitation program (ASCE, 1997).

It is very critical to have a standardized manhole inspection process in place. Manholes can be a significant source of I/I into a system. The standardization of manhole inspection and rehabilitation has greatly reduced the effort required to verify the condition data for each manhole for proper rehabilitation design and implementation.

8.3.10 Line Lamping (Visual Inspection)

Source: www.envirosight.com

Line lamping or pipeline visual inspection is performed in conjunction with manhole inspection. Lamping consists of visually inspecting the interior of the sewer lines connected to the manhole by using a powerful flashlight and mirror while standing above or in the manhole.

Line lamping is used to obtain information on pipe condition and to determine if a section of pipe is straight and clean. Line lamping is also used to determine the size and flow characteristics through the manhole. The data generated from lamping is also used to identify sewer pipe defects and provides a basis for selecting sewers for television inspection. Data from line lamping includes observations of the pipe, flow, depth, and deposition or debris present. Each of these observations should be recorded appropriately on the line lamping inspection form.

Line lamping is not an effective method for man-entry-size sewers where a walk through of the line can be performed. However, it can be an effective tool for mid-size sewer lines where man entry is not possible and adequate illumination can be achieved.

The practice of lamping is becoming high-tech with the introduction of pole-mounted digital cameras into the market. The camera is lowered into the manhole and digital pictures of the sewer line are taken. The advantages of this system over traditional lamping are that no man-entry is required, the images are very clear, and the pictures can be stored for future reference.

8.3.11 Stream Crossing Inspection

The stream crossing of sewer lines is often a vulnerable point for SSOs. If the sewer is buried under the streambed, the scouring of the stream bed will expose it over time and the pipe will lose its soil support. The pipe segments may move due to the water pressure and joints may open. Such openings will introduce significant amounts of flow into the sewer system, which may exceed the capacity of the sewer line.

Stream crossings using inverted siphons often get clogged due to the accumulation of silt and debris at the bottom of the invert. This clogging may cause an overflow upstream. The foundation of aerial stream crossing piers is also subject to scouring and may lead to a foundation failure of the sewer line.

The sewer lines crossing a stream should be inspected to ensure that they are not broken or cracked. In addition, the manholes on each side of the stream should be checked to see that no excess flow is taking place, which would indicate a leaking sewer under the stream. Since these sewers are in remote areas, they are susceptible to vandalism and can overflow for long periods of time without detection. Stream stabilization and sewer relocation would require long-range planning, design, permitting and construction periods, so it is important to identify these problems as early as possible. Additionally, inter jurisdictional issues need to be resolved. For example, while the sewer agency owns the sewer line and the right-of-way to cross the stream, the stream itself is owned by another entity. The sewer agency has to negotiate with such entities to come to an agreement about what portion of the stream stabilization cost, if any, should be borne by the sewer agency.

8.3.12 Internal Corrosion Monitoring

The environment of a sanitary sewer line is conducive to the generation of hydrogen sulfide, which can cause various problems such as undesirable odors, potentially lethal toxic conditions, and corrosion of unprotected sewer pipes. The inside pipe wall above the wastewater flow line will be the principal area of corrosion. At points of high turbulence, such as drops, manholes, junctions and other structures, hydrogen sulfide is released very rapidly and can result in severe corrosion, leading to loss of structural integrity and subsequent collapse of the sewer line.

Typical locations to investigate for the presence of corrosion involve areas where wastewater has had the opportunity to go septic or anaerobic. This can occur in interceptors or where there are lengthy travel times, or time of concentration, where there are few “fresh” contributions of wastewater to supply new oxygen sources. Force mains are prime locations where residence time and the circumvented slime layer promote the generation of hydrogen sulfide.

Internal corrosion monitoring involves field measurement of parameters such as ambient and dissolved oxygen, ambient and dissolved hydrogen sulfide, pH, and temperature. The results of these tests are analyzed to assess the potential corrosivity of the wastewater flow. Direct measurements of wall thickness loss and review of CCTV images also provide additional information.

Changes in wastewater characteristics can either accelerate or inhibit the rate of corrosion. In Los Angeles, it was reported that industrial pretreatment programs successfully reduced metals concentrations over time in the sewers. Without the metals, bacterial activity increased, resulting in more dissolved sulfides being available to migrate into the sewer atmosphere, generating crown and headspace corrosion (Shand, 2003). In FY 2000, the Sanitation Districts of Los Angeles County reported spending $6.9 million on chemicals and contracts to reduce the rate of sulfide production and control corrosion in the collection system (LACSD, 2001).

The East Bay Municipal Utility District (EBMUD) reported that the 105-inch diameter Wood Street Interceptor had experienced severe corrosion (Girma, 2001). The Wood Street Interceptor is approximately 9,000 feet long and was constructed of cast-in-place reinforced concrete in a thumbnail shape. Extensive field investigations, including man-entry manhole inspection, concrete corings, wastewater sampling, CCTV inspection, and walk-through inspections, were conducted. Corrosion modeling was also performed to estimate the remaining useful life of the interceptor system. The results of the corrosion modeling indicated that the Wood Street Interceptor should be rehabilitated within 10 years.

8.3.13 External Corrosion Monitoring

The environment in which the sewer line is installed can affect its long-term performance. The critical factors include pipeline materials, soil type, moisture and free oxygen levels. Vitrified clay and PVC pipes are almost inert to the environment and do not corrode.

However, cast iron pipe, ductile iron pipe, and steel rebars in the reinforced concrete pipe can corrode.

Generally speaking, fine grained soils, such as silt and clay, are more corrosive than coarse grained soils, such as sand and gravel. If the groundwater table is always either above or below the pipe, the potential of corrosion is minimal. However, when the groundwater table fluctuates in the pipe region, the wetting and drying cycles may result in high chloride concentration and a supply of free oxygen in the mortar coating of concrete pipe. This leads to a breakdown of the passivating film of the steel rebars in the concrete pipe and acceleration of the corrosion process.

A number of methods are available for external corrosion monitoring. Some of these methods are:

- Measurement of the acidity of the environment,
- Measurement of the electrical resistivity of the pipeline ,
- Measurement of stray currents,
- Measurements of potentials between pipeline and environment (potential survey),
- Measurement of the effective electrical resistance of coating, and
- Determination of conditions suitable for anaerobic bacteria.
- According to Marshall (2000), the most common method of determining the cathodic protection system adequacy of metallic pipes, such as force mains, is performing a Close-Interval Survey, which measures the pipe-to-soil potential and provides results that will detail the effectiveness of the cathodic protection.

8.3.14 Pumping Station Inspection

The failure of a pump station can lead to significant SSO problems. The pump station should therefore be inspected frequently to ensure that it is operating as intended. The frequency of the inspection may vary from once a day to once a month and depends on such factors as size of the station, criticality of the station, and reliance on real-time monitoring of the station using SCADA systems. The agency should have an emergency response plan in place to respond to pump station failure. Such a plan would incorporate the use of generators, pumps, tank trucks, and other equipment. Inspection trips can be performed in conjunction with routine maintenance activities such as lubricating equipment.

When performing a pumping station inspection, special attention should be given to safety precautions. Animal infestation, toxic odors and, slippery floors are examples of potential hazards to be mindful about. The inspection should cover the following items, the frequency of which is determined by its criticality.

- Standby generator,
- Pump and motor condition ,
- Compressor condition,

- Valves condition,
- Belt condition,
- Oil level,
- Bearing condition,
- Wet well condition,
- Back flow preventor,
- Lighting and heating,
- Phone line,
- SCADA system,
- Fire extinguisher,
- Condition of the building, vents, and louvers,
- Security of the pumping station and alarms,
- Electrical switches, circuit boards, and wiring conditions,
- Evidence of grease or oil leaking, and
- Evidence of equipment heating

8.3.15 Force Main Inspection & Evaluation

Visual inspection conducted along the alignment of the force main is a common method to detect force main problems. Such problems include construction-related damages, malfunctioning of air release and vacuum relief valves, damage to blow-off valves, and exposed force mains at stream crossings. Routine monitoring of pressure and flow at pump stations also can provide clues to potential problems in force mains.

Cast and ductile iron and steel force mains are susceptible to corrosion. The potential for external corrosion can be assessed by conducting potential surveys. Such surveys measure the pipe-to-soil potential. Any anomalies in the results can be a sign of corrosion activity, which can be confirmed by test pitting and inspecting the outside surface of the force main.

The failure of a force main can lead to the release of a large quantity of wastewater into the environment. It is therefore very critical that the condition of force mains be fully assessed and proactive measures taken to prevent failure. In the event of an unfortunate force main failure, the failed pipe section provides an opportunity to make an assessment of the condition of the force main. The cause of the failure should be fully investigated and additional investigative and/or remedial plans developed and implemented to minimize the potential for recurrence of failure. For example, the evaluation may include taking the force main out of service and inspecting it internally by CCTV, ultrasonic or magnetic devices to determine the general condition as well as the structural integrity of the force main.

Additional investigation such as transient analysis or vibration analysis may be deemed necessary to identify the cause of failure.

Experience has shown that pipe break history provides the best clues as to future performance. It is critical to track the performance of force mains over time and use that as a basis for prioritizing which force mains should be scheduled for comprehensive inspection and potential remedial measures that may be needed.

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Chapter 9 Rehabilitation Solutions

9.1 Introduction

The need for collection system rehabilitation arises from several factors:

- Deterioration of the structural integrity of the aging sewer systems,
- Excessive infiltration/inflow due to defects in the system,
- Increasing regulatory control of wet weather overflows from sewer systems, and
- Additional hydraulic capacity needs for the sewer system.

A prerequisite for system rehabilitation is a comprehensive condition assessment of the system. The results of the condition assessment form the basis for characterizing the defects, identifying deficiencies, and prioritizing the system rehabilitation needs. Prioritization considers both cost and non-cost factors. Generally, both short term and long term plans are developed for system renewal. Short-term plans include repair of critical defects needing immediate repair. Long-term plans include projected needs and less immediate needs, which will be implemented over a number of years.

When infiltration/inflow (I/I) reduction is the objective of rehabilitation, a “total rehabilitation by mini-basin” solution should be adopted. Otherwise, it is unlikely that the target I/I reduction would be achieved. For example, if all the sewer lines in a mini-basin are rehabilitated by lining, but other components such as manholes, laterals, and connections are not addressed, it is likely that the groundwater would migrate along the path of the rehabilitated pipe until it finds an opportunity through a defect, such as a weak pipe-to-manhole joint, to enter the system. As such, minimal I/I reduction would be achieved. As mentioned in Chapter 3, both the City of Rockwood, TN, and Clean Water Services, OR (see Appendix-II, Case Studies) reported utilizing the rehabilitation by “mini-basin” concept.

9.2 Sewer Line Rehabilitation

The deterioration of the physical condition of the aging sewer systems along with increasing regulatory control of wet weather overflows from sewer systems has resulted in a significant need for rehabilitation of existing collection systems. The rehabilitation of the sewer system can minimize sanitary sewer overflows (SSOs) by improving the hydraulic capacity of the sewer system and eliminating or reducing the occurrence of infiltration and inflows. The structural integrity of the sewer pipe can also be improved by rehabilitation.

An assessment of the condition of the pipe and hydraulic capacity requirements will provide an indication about whether a pipeline should be rehabilitated or replaced. When additional hydraulic capacity is required, the replacement option often prevails. When the structural integrity of the pipe is compromised, full replacement or structural rehabilitation options should be considered. If the existing pipe is structurally sound, rehabilitation is often the preferred alternative to extend the service life of the pipe. When the pipe is in a generally good condition with the exception of a few short sections, then point repairs of the deficient sections is the preferred alternative.

While open cut is always an option, rehabilitation of sewer pipes is increasingly being accomplished with trenchless methods. Depending on project-specific situations, trenchless pipe rehabilitation techniques may offer a variety of potential advantages over traditional open-cut pipeline replacement techniques, such as:

- Generally more cost-effective than open cut,
- Avoidance of many surface constraints,
- Disruption of other services minimized (e.g., power lines),
- Surface reinstatement needs minimized,
- Surface disruption including traffic disruption kept to a minimum,
- Reduced surface settlement, particularly important in sensitive areas, such as under railways, motor ways, services and adjacent to buildings,
- Environmental disturbance minimized, and
- Installation of services at greater depths than would normally be considered cost effective for trenching.

The following are some of the trenchless techniques available for rehabilitation of sewer lines:

- Sliplining
- Cured-in-place-pipe,
- Fold and form lining,
- Spirally wound pipe,
- Segmental lining, and
- On-line replacement.

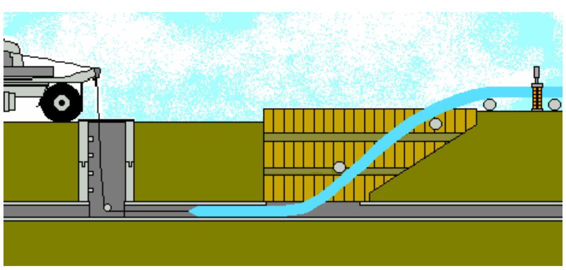
An engineering analysis should be performed to determine the most feasible options for a particular situation. Factors to consider include:

- Cost (both capital and operational and maintenance),
- Pipe size,
- Pipe length,
- Pipe depth,
- Existing pipe condition,
- Gravity versus pressure applications,

- Degree and/or volume of capacity enhancement required,
- Access conditions,
- Right-of-way requirements,
- Availability of alternative corridors,
- Soil conditions,
- Groundwater conditions,
- Ground cover,
- Location (urban versus rural),
- Traffic conditions,
- Environmental impacts,
- Social and economic impacts,
- Schedule, and
- Availability of qualified contractors.

9.2.1 Sliplining

Sliplining is used to rehabilitate damaged sewer pipes by placing a smaller diameter conduit inside the damaged section. HDPE is a widely used pipe material for sliplining; however, other pipe materials, such as PVC or polymer concrete, have also been used successfully. This method is commonly used where the new, smaller diameter sewer pipe, and the resulting lower friction coefficient for the new pipe, is sufficient for the system capacity needs. Sliplining is a fully structural solution.



With sliplining, the liner is inserted into the existing pipe at an access pit location and is then pulled through the existing pipe by a winch or similar equipment. The inserted pipe is not deformed or cured. The existing line must be cleaned, if necessary, to insert the new line. In a typical application, the new line has the largest possible diameter that can fit inside the existing pipe. Therefore, cleaning and flushing is necessary if there is buildup within the old pipe. Grouting the annulus provides additional strength to the composite structure and further protects the new pipe from collapsing due to soil pressure.

As an example, sliplining was used in St. Thomas, U.S. Virgins Islands (Dorman, 1999) to rehabilitate a 24-inch force main. The force main conveyed wastewater from a wastewater pumping station with an average daily flow of 2.2 million gallons per day (mgd). The force main was 3,560 feet long and was made of ductile iron. Overflows were occurring at the top of a hill, when the pumping station was operating with more than one pump. The overflows were caused by corrosion of the force main and hydraulic inefficiencies in a junction chamber. The pump station could not be put out of service for more than eight hours. Sliplining with HDPE was used to solve the problem.

9.2.2 Cured-In-Place-Pipe (CIPP)

CIPP liners can be used both for structural and semi-structural rehabilitation of sewer lines. The CIPP liner consists of a tubular felt-like material saturated with an epoxy resin that after curing turns into a rigid liner for the pipe. Before the process is initiated, pipes must be thoroughly cleaned and dried. A CCTV camera is run through the pipe to ensure the pipe wall is clean and ready for installation of the liner. In addition, the location of service lines will be documented during the CCTV operation. After preparing the pipe interior, the CIPP liner is installed by the inversion process using air and/or water pressure to turn the resin impregnated jacket inside out while propelling it through the pipe and pressing the resin coated face against the host pipe wall. The resin is then cured using either steam or hot water at any temperature from ambient to 180 degrees Fahrenheit. The curing time decreases from several days at ambient temperature to three to four hours at 180 degrees Fahrenheit. The curing process is non-reversible so the final product will retain its characteristics. The thickness of the CIPP liner is determined by both internal pressure and external hydrostatic pressure. The liner will slightly reduce the inside diameter of the pipe, however, this reduction may be offset by the smoother surface of the material. After the lining is installed and cured, a CCTV camera should be run through the pipe to inspect the condition of the liner and open the lateral connections by a robotic machine.

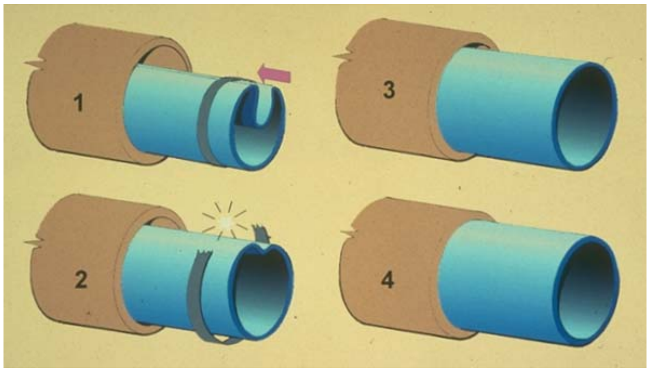
ASTM Standard F-1216, "Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube" describes the procedures for reconstruction of pipelines and conduits. The standard also provides the inspection requirements such as sampling and testing, leakage and pressure testing, visual and CCTV inspection, and delamination tests. Design guidelines are provided in Appendix X1 of the Standard. The design guidelines cover both gravity and pressure sewers under partially or fully deteriorated conditions.

The City of Boca Raton, FL 14,000 linear feet force main was failing in many areas due to sulfide attack at the pipe crown and was rehabilitated by CIPP (Tingberg, 1999). The contract was awarded for this work at $985,000. The estimate for doing this work using traditional open cut methods was $2,000,000.

Another 6,000 linear feet cast iron pipe run was corroding and causing the City to spend about $30,000 per month in random open cut emergency repairs. CIPP was used to rehabilitate this line as well. The cost of the contract was $480,000. The liner segments used ranged in length from 200 linear feet to 1,800 linear feet. Six projects totaling over 30,000 linear feet were completed.

9.2.3 Fold and Form

Fold & form is a technology for rehabilitation of sewer lines by inserting a folded liner into the existing pipe and expanding it through pressure, heat or mechanical means to restore its original circular shape. The fold and form liners consist of polyvinyl chloride (PVC) or high density polyethylene (HDPE) material folded into a cross section that is significantly



smaller than that of the pipe to be rehabilitated. The “folding” allows easy installation of the liner throughout the length of the pipe. Because of this initial shape, these liners are also called “deformed pipe liners”.

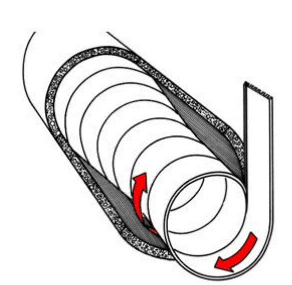
Before the liner is installed, the pipe must be brushed or scraped and cleaned of all debris and build-up, so that the liner can fit tightly against the pipe wall. After the folded liner is pulled into the pipe, it is heated, expanded and reformed to fit against the pipe wall. The installed liner is cooled using circulated air that stiffens the liner. After installation, laterals are reinstated by robotic machines. The fold and form method is generally limited to smaller diameters (up to 15 inches), and generally does not negotiate bends as well.

The applications of fold and form technology for pipe rehabilitation is well documented in the literature. For example, Aguiar (1996) reported that the Miami-Dade Water and Sewer Authority, FL, utilized fold and form liners to rehabilitate approximately 10% of the sewer lines which had been identified to be in need of rehabilitation. Fold and form liners were used to repair defects in line segments which were no deeper than eight feet and experienced infiltration leakage only. It was not used on line segments which had broken or collapsed section.

9.2.4 Spirally Wound Pipe

This technique is based on forming a pipe in-situ by using PVC-ribbed profiles with interlocking edges. The ribs enhance the hoop strength of the liner. This method is applicable to sewer lines smaller than 30 inches in diameter. The process involves the fabrication of the liner in the manhole by helically winding a continuous PVC fabric. The installation process consists of six steps:

- Bypassing of flow, if necessary,
- Cleaning of the line and removal of tree roots,
- Plugging of laterals,
- Lowering the winding machine into the manhole and feeding it with PVC strips from the surface,



- Grouting of the liner; and
- Reinstatement of laterals by local excavation or by a remote-controlled cutter.

This method can be used for either structural or nonstructural purposes. One option to provide structural strength is to inject grout behind the spirally wound pipe. Another option is to include steel reinforcing in the spirally wound pipe. If the grouting option is utilized, consideration should be given to the buckling strength of the liner so that it does not buckle during the grouting process.

The rehabilitation of sewer lines by this method increases the hydraulic capacity. Although the cross-sectional area decreases slightly, the relatively smooth surface of PVC liner reduces the friction to flow and more than offsets the effect of diameter reduction. The applications of spirally-wound pipe technology are numerous. For example, Chusid (2000) reported that the City of Santa Monica utilized spirally wound pipe for rehabilitation of 110,000 feet of sewer lines. This was part of a five year comprehensive program that the City of Santa Monica embarked on to rehabilitate the sewer lines which had been damaged during the Northridge earthquake.

9.2.5 Segmental Lining

This technique, which is used for man entry sewers (30 inches in diameter or larger), is based on forming a pipe in-situ by using PVC-ribbed panels with interlocking edges. The panels are placed inside the sewer line and locked together on the edges to form a continuous liner. The PVC panels incorporate male and corresponding female double locking edges. The edges form a circumferential joint, which is simply snapped together by a smaller joiner strip. The joiner strip utilizes a flexible polymer co-extrusion to make the joints water tight. The panels and joiner strip are light and easily handled and can be passed through a narrow opening or manhole eliminating any need for excavation.

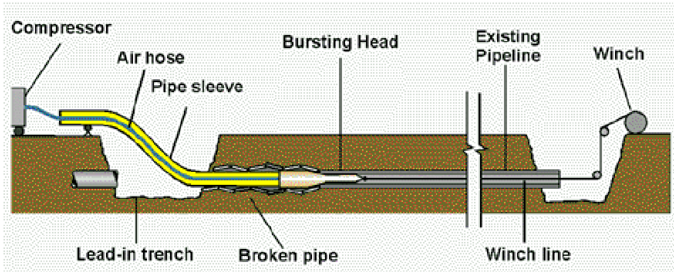
The annulus between the liner and the sewer pipe is filled with grout. The grout improves the structural integrity of the liner. The ribs which impart a hoop strength to the liner, also provide a mechanical anchor for the PVC liner as the annular gap is filled with grout. Consideration should be given to the buckling strength of the liner so that it does not buckle during the grouting process.

The hydraulic performance of the pipe may be significantly improved as the PVC panels generally can be placed close to the existing surface resulting in a minimum loss of diameter while providing a smoother surface to the flow.

Several applications of segmental lining have been reported. For example, the Hampton Road Sanitation District in Hampton, VA (www.danbyrehab.com/projects.htm) used this method for rehabilitation of approximately 2,000 feet of a 42-inch reinforced concrete pipe which had been severely damaged due to hydrogen sulfide crown corrosion. The City of San Jose, CA also has utilized this method for rehabilitating approximately 3,000 feet of its sewer interceptors ranging in size from 36-inches to 72-inches. In addition, the City of San Jose used this technique for rehabilitation of 6,300 feet of a 54-inch x 36-inch elliptical shape brick sewer line (www.danbyrehab.com/projects.htm).

9.2.6 On-line Replacement

On-line replacement was initially established in related utility industries, notably the gas and water sectors. Flows in these pressure pipes were not inherently dependent on gravity for delivery of the product, enabling a greater margin of success for the early projects. The technology was adapted to the wastewater industry when additional precision and control was introduced for minimizing sags or depressions and maintaining final grades and elevations.



While on-line replacement is ideally matched to applications with in-situ needs for additional capacity for new development or wet-weather flows, this technology is also a viable alternative for small diameter sewers. Structural problems and extensive root infestations may also provide a basis for recommending this renovation technique.

Line and grade are essentially as designed in the original sewer. These technologies make use of the original investment in the pipe and trench as a guide for the new, larger capacity sewer.

Although the manufacturers and contractors differ in their approach, the fundamental distinction that separates on-line replacement from other sewer renovation technologies is the crushing or bursting of the host pipe to increase the envelope to receive the larger diameter pipe. Pre-design issues necessary to evaluate the application of on-line replacement vary according to the technology applied, but generally include:

- Depth of sewer,
- Trench conditions,
- Existing sewer grade,
- Desired final diameter,
- Existing pipe material,
- Existing sewer house connections,
- Surface cover, and
- Bursting technologies.

Shallow sewer mains have caused more concern than those found at traditional gravity sewer depths, such as 8 to 12 feet, due to the tendency of the bursting head to walk. Less overburden may allow the expanded sewer to “ride up” in the trench. Many older sewers were laid in trenches excavated in the native soil with bell holes dug out to maintain consistent grade. The slope was achieved primarily through the trench cut with minimal bedding and the backfill was often native soil material. The most consolidated portion of the entire trench is under the invert of the host pipe and often this was undisturbed soil. Expansive soils trenches or trenches cut in rock may create unsatisfactory final pipe conditions, in part dependent on the diameter increase desired.

Another existing site condition to avoid has been concrete encasements or cradles. Many agencies have design details that require sanitary sewer crossings of water bodies, such as creeks, streams, storm ditches or culverts, to be encased in concrete. Existing soil conditions may also dictate the use of concrete cradles to the springline of the pipe to support the sewer main. Both conditions may eliminate the sewer from on-line replacement consideration or at a minimum require an alternative for the encased portion of the host sewer.

The slope of the existing sewer may be a significant factor in the candidacy of the sewer for bursting, particularly if connections to the existing sewer enter at the springline of the pipe or lower. Early applications of bursting in 6-inch diameter sewers with less than one percent grade and 6- inch by 6- inch wye connections, where there were matching inverts of the connection and the main, required the new taps to be relocated downstream on the new 8-inch diameter burst sewer due to higher invert of the new pipe. Newer bursting technologies can successfully negotiate the flatter grades typically found in larger diameter sewers; however, it is a factor worth noting in the pre-evaluation.

Early on-line replacement was constrained by both the ultimate final diameter and the increased diameter differential as compared to the original pipe. The industry speaks of increasing one diameter, such as 6-inch to 8-inch or 10-inch to 12-inch, or two diameters, 8-inch to 12-inch or 12-inch to 18-inch. The technology has now developed to the point of handling even three and four diameter increases where the economics of the alternatives make on-line replacement attractive.

Some sewer pipe materials can increase the problems associated with the execution of on-line replacement in the field. Vitrified clay pipe (VCP), cast iron, asbestos cement and plain concrete are ideal pipe materials for on-line replacement. Reinforced concrete pipe may hamper some types of bursting technologies due to the steel reinforcing wire. Bursting PVC sewer mains, or pipes rehabilitated with HDPE fold and form or CIPP liners, requires attention to splitting the thinner pipe wall in addition to bursting the rigid material of any original host pipe. This is because the flexible pipe tends to fold and “accordion” in front of the bursting head, fouling the progress for that segment.

Replacement pipe materials traditionally were butt welded high density polyethylene, but new advances in the insertion technology have also allowed hubless PVC pipe with restrained joints and high strength VCP pipe jacking pipe to be used as well.

The ideal sewer for on-line replacement does not have any sewer house connections/taps. Although some on-line replacement technologies can be applied from existing access points such as manholes, the primary launching point for the larger diameter pipe is from an excavation. If taps occur at densities greater than one per every 50 linear feet of sewer, the number of excavations will create increased cost and restoration.

Sewer house connections require several strategies that enable taps to be dealt with successfully. If limited taps are encountered, the launch pits may be sited at the location of the connection(s) since the tap has to be dug up and disconnected prior to upsizing the host sewer. Vacuum excavating or “daylighting” of connections may enable even frequent taps to be uncovered economically. Roadway fees and restoration requirements, such as permanent patches and mill and overlay, will influence the final cost and ultimate applicability of this technology.

Surface cover is a significant factor in the cost assessment when considering the economic viability of bursting. Turf and other right-of-way surface covers are more favorable to lower cost bursting applications. Not only are initial excavation costs lower, but restoration costs are lower as well. The excavations to expose frequent taps may also lead to paving restoration requirements (mill and overlay) from the roadway owner that will create an undesirable economic impact for this alternative. If the road is a primary or arterial route, extensive traffic control requirements will also be required from the roadway owner.

On-line pipe replacement technology has developed from a few pioneers in the field to multiple manufacturers plying a variety of methods and tools to meet different scales of pipe upsizing challenges. For sewer replacement, pipe bursting, pipe eating and pipe reaming are the three primary methodologies specified.

Pipe bursting technologies come in a variety of styles. Pneumatic moles, hydraulic systems, chain drive pullers, and rod drives are just a few of the variations available. Each system possesses advantages given specific field conditions. Some negotiate bends, others help to straighten existing sewers that have lost minor line or grade, however, the objective of each is to increase the size of the existing sewer.

The pneumatic bursting system is an air driven mole with a bursting head at the lead of the new pipe train. A constant tension winch moves the bursting head forward with the percussive head fracturing the host pipe, pushing the pipe fragments into the surrounding soil. Hydraulic operated systems expand the bursting head with minimal vibration and transfer of energy into the surrounding soil and adjacent utilities. Typically a pipe splitter precedes the hydraulic head which then compresses the split and expanded pipe fragments into the surrounding trench. With both systems, an annular space is created. The diameter of the new sewer determines the size of the bursting head and the power necessary to ensure the bursting train completes the entire length of the pipe run.

”Pipe eating” is a microtunneling derivative technology employing a set of cutting tools at the face of the unit. The unit is of a larger diameter than the host pipeline, enabling the crushed sewer to be removed in a bentonite slurry through a pressurized new pipe. Units can follow the line and grade of the existing sewer or have some steering capability.

Pipe reaming uses directional drill technology to power tools that grind and reduce the existing pipe into small pieces, enabling a replacement pipe to be pulled into its place. The existing pipe is replaced by use of modified “back reaming” technology traditionally used in directional drilling. The directional drilling rods are routed through the host pipe, backreaming cutting head and pipe string attached, and the entire assembly pulled back to the drilling rig. Two diameter upsizing has been reported.

The successful application of pipe bursting for renewal of existing sewers has been reported in many communities. Several capacity-enhancement applications were described in Chapter 5. The application of pipe bursting at West Valley Sanitation District, Santa Clara County, CA (Kalkman, 1999) for non-capacity related purposes is cited here as an additional example. Following condition assessment of 38,000 linear feet of collection system in the Los Gatos area of the District, the existing defects were prioritized for renovation and replacement. The District elected to proceed with a mix of renovation options including structural lining, open-trench replacement and pipe bursting. Nearly two thirds of the rehabilitation was pipe bursting due to the lower cost compared to open cut. Any incremental capacity was an additional bonus.

9.3 Manhole Rehabilitation

It is estimated that there are now over 20 million manholes in municipal wastewater systems throughout the United States which provide the principal means of access for inspection and repair of our collection systems. These manholes frequently provide disproportionate sources of costly inflow and infiltration which lead to SSOs. With the deterioration of the aging collection systems due to increasingly aggressive sewer environments, late stages of design life and, sometimes, poor construction, more attention has been paid to inspection and rehabilitation of manholes.

Inflow into a manhole generally originates from the cover, frame or frame seal. Typical defects may include open vent or pick holes in the cover which are subject to ponding; bearing surface may be worn or deteriorated; it may not fit properly; or the cover may be cracked, broken or missing. The frame may also be cracked, worn or deteriorated. The gasket may be missing, or the frame may be offset from the chimney causing leakage between the frame and chimney joint.

Infiltration generally occurs due to cracked, loose or missing mortar or at joints between precast sections and pipe joints. Deterioration due to corrosive sanitary sewer gases and microbiological growth can literally eat through the original cementitious walls and mortar causing leaks, erosion and ultimately structural deterioration. Infiltration caused by corrosion is becoming more prevalent due to evolving environmental controls in wastewater treatment.

Removal of I/I sources is a major reason for rehabilitating manholes to reduce the potential for SSOs. In addition to open cut replacement for fully deteriorated manholes, the following methods are available for manhole rehabilitation:

- Chemical grouting,
- Coating systems,
- Structural linings, and
- Frame, cover & chimney rehabilitation.

It is very important to have a standardized process for selecting manhole rehabilitation methods. For example, the Sewerage and Water Board of New Orleans (S&WB) has developed a standardized process for selection of rehabilitation method for manholes (Kelly, 2000). The S&WB currently utilizes the following rehabilitation methods:

- Full depth lining,
- Partial depth lining,
- Install inflow pan,
- Elastomeric frame seal
- Frame and cover casting adjustment, including replacement or resetting
- Manhole replacement, and
- Grouting.

Experience shows that 95% of manhole rehabilitation failures are due to weak specifications, improper application, and inexperienced installers. If these three factors are addressed, most manhole rehabilitation projects would be successful.

9.3.1 Open Cut Replacement

Open cut removal and replacement is a proven method for renewing deteriorated manholes. To the extent practical, manholes should be rehabilitated to minimize sewer service downtime, disturbance to the surrounding environment, traffic flow, business and community activities, and avoid a large volume of debris to be disposed of. Often times, rehabilitation is a less costly option than full replacement. However, if a manhole is severely deteriorated, open cut replacement may become a preferred option. Manhole replacement may also be needed if the sewer line is either replaced with a larger pipe or is installed at a lower elevation necessitating the need for a larger or deeper manhole. Open cut may also be utilized if manhole relocation is dictated by hydraulic or access requirements.

9.3.2 Chemical Grouting

Chemical grouting is used to reduce I/I in manhole structures. Since chemical grouts do not add to the structural integrity of manholes, they only should be used when the overall structural integrity of the manhole is sound. Grouts give best results in cohesive soils. They may be used to fill voids and stabilize soils behind manhole walls. Grouts are normally applied under pressure through grout holes drilled into the manhole walls.

A wide range of chemical grouts are available. They can be divided into four broad categories: acrylamide, acrylate, urethane foam, and urethane gel. Acrylamide grouts are reported to be carcinogens and should be handled with care. Urethane foams are normally used in the upper five feet of the manhole, with the urethane gel and acrylate grout used in the lower sections.

Careful observation and monitoring of the grouting operation is necessary to ensure success. The service life of grouting solutions is reported from as low as five years to as high as 25 years. If done properly, a grouting application should last between 10 to 15 years (Romans, 2001).

The Miami-Dade Water and Sewer Department (MDWASD) utilizes chemical grouting in conjunction with lining or coating systems such as prefabricated fiberglass, polyurethane, and cementitious manhole liners (Larsen, 1999). Chemical grouting is used to seal the pipe entrances. The municipalities of Susquehanna Township and Lower Paxton Township in Harrisburg, PA (Hilderhoff, 2001) reported using urethane grout and brushed on mortar for the rehabilitation of manholes. Post-project appraisal showed that the rehabilitated manholes did not perform well. As a result, the 1/2-inch thick mortar coating was selected resulting in 98% passing of a vacuum test.

9.3.3 Coating Systems

Coating systems may be used as a corrosion protection barrier and/or to enhance structural integrity of manhole structures. Coatings can be applied by spraying, or hand-applied. When using a coating system, it is essential that the surfaces be properly cleaned and prepared. High pressure water blasting of 2,000 to 5,000 psi may be used to remove loose mortar, grease and oil residues, and prepare the surface to ensure that reliable mechanical bonding occurs when the coating system is applied.

Coating systems may be cementitious, epoxy, or polymer base. Cementitious-based coating systems have low corrosion resistance. The corrosion resistance can be improved by using calcium aluminate cement. Epoxy and polymer (polyurea and polyurethane) have excellent corrosion protection properties. The keys to achieving effective coating systems are proper surface preparation, adequate inspection, and thorough specifications.

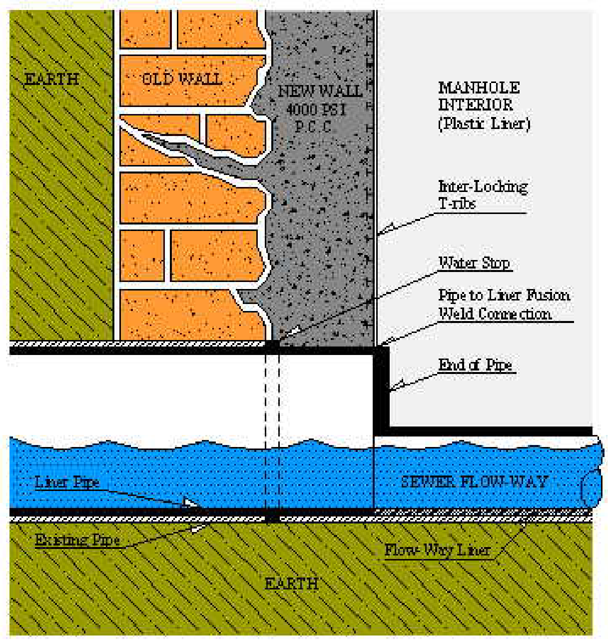
The application of coating systems for manhole rehabilitation is well documented in the literature. For example, the Warren Township Sewerage Authority (WTSA) in Warren Township, NJ (McGregor, 1999) reported using coating systems for manhole rehabilitation.

The municipalities of Susquehanna Township and Lower Paxton Township in Harrisburg, PA (Hilderhoff, 2001) utilized 1/2-inch thick cement mortar coating for manhole rehabilitation after experiencing poor results with a thinner coat. This utility achieved a 98% success rate in passing a vacuum test.

9.3.4 Structural Lining

Structural linings restore the structural integrity of manhole structures. Several structural ling methods are available. These include:

- Poured-in-place concrete liner,
- Cured-in-place (CIP) liner,
- Formed-in-place (FIP) liner,
- Prefabricated fiberglass, and
- Spray-applied systems.



The poured-in-place concrete liner is often combined with epoxy coating or a PVC liner for corrosion protection. The PVC liner has T-lock ribs which get embedded in the concrete liner. Alternatively, the concrete liner may be sprayed over with a thin layer of epoxy coating. The thickness of the concrete liner is based on the external hydrostatic and active soil pressure around the manhole, as well as the traffic loading. In addition, if no corrosion protection barrier is installed, a corrosion allowance should be added to the concrete thickness required to resist external loading.

Cured-in-place liners are a variation of the cured-in-place pipe (CIPP) technique used extensively for rehabilitation of sewer lines. However, this technique has been used on a limited basis for manhole rehabilitation due to mobilization and cost factors. The formed-in-place liner, a variation of formed-in-place pipe (FIPP) used extensively in Europe for rehabilitation of sewer lines, consists of two concentric thin layers of HDPE liners which is filled in with a specially formulated grout. While FIPP liners have been used in Europe for rehabilitation of manholes, it has not been used in the United States as yet. This technology has been introduced into the US market in the past three years.

Prefabricated fiberglass is a one-piece monolithic unit which is corrosion resistant, and provides adequate structural strength. The disadvantage is that, the top and the chimney part of the manhole should be removed for the fiberglass liner to be installed.

Spray-applied systems include cement mortar, epoxy, polyurethane, and polyurea linings. The success of such lining systems depends on degree of surface preparation, quality of inspection, and applicator's experience.

The City of Pensacola, FL (Shook, 1995) has utilized poured-in-place concrete with a T-lock PVC lining for structural rehabilitation of several of its severely deteriorated manholes. No bypass pumping was necessary. The cost of rehabilitating the manholes was 50% of the cost of full replacement.

The Metropolitan Water Reclamation District of Chicago (Nance, 1998) utilized spray-applied fiber reinforced cement mortar lining with epoxy coating for rehabilitation of a severely deteriorated 30-feet deep brick manhole. The cement mortar lining was applied by spraying in two layers, each layer having a thickness of 1.5 inches. The first layer was allowed to set for eight hours before the second layer was applied. The second layer was allowed to cure for 16 minutes, which was then coated with a 125 mil high-build 100% solid epoxy for corrosion protection.

The polyurea lining has the advantage of curing very fast. As such, the manholes can be placed back in service shortly after the liner is applied. Bouley (1993), for example, reported that the Bensenville, IL. used a polyurea liner for structural rehabilitation of its brick manholes. While the polyurea sets completely in 24 hours, it dries to the touch in less than a minute.

9.3.5 Frame, Cover & Chimney

Most inflow into a sewer system occurs through the defects in the upper components of the manholes. The inflow can significantly be reduced by rehabilitating or replacing these components.

The manhole covers with pick holes or cracks can either be replaced with watertight covers, or be sealed with mastic compounds and pick hole plugs. Alternatively, watertight inserts may be installed under the manhole cover.

A common defect observed in manholes is the deterioration of frame-chimney joint (frame seal) due to such factors as ground movement, thermal expansion and contraction, and traffic loading. The frame-chimney joint can be repaired internally without excavation when frame alignment and chimney conditions permit. When excavation is required to replace the frame or to reconstruct the chimney and/or the cone, the frame-chimney joint can be sealed both internally or externally. This can be achieved by either installing a flexible manufactured seal, or by applying a flexible material to the joint area.

The effectiveness of manhole rehabilitation in reducing I/I has been well documented. For example, the Plainfield Area Regional Sewerage Authority (PARSA) had a history of overflow problems in wet weather (Villee, 1999). After multiple SSOs in early 1997, it developed a manhole rehabilitation program with the following elements:

- Install inflow inserts on 45 manholes with covers that had eight vent holes in them,
- Reset castings of 50 manhole frames were reset with a flexible sealant and mortar,
- Repair open joints on 25 manholes and chambers with cement mortar, and
- Reinstate the integrity of 100 manholes by installing new gaskets, and cleaning of the lockdown bars and inner covers.

As a result of this program, the number of SSOs dropped from more than 20 in 1997 to none in 1998, even though 1988 was even a wetter year than 1997.

The municipalities of Susquehanna Township and Lower Paxton Township in Harrisburg, PA (Hilderhoff, 2001) utilized either a urethane seal or a fabricated rubber seal, installed between frame and corbel, to rehabilitate the chimneys. The success rate of rubber chimney seals was 60% while flexible urethane seals had a success rate of 90-100%.

9.4 Lateral Rehabilitation

Laterals are a major source of infiltration/ inflows (I/I) to the collection system. For example, Hannan et al. (1996) reported that the Washington Suburban Sanitary Commission (WSSC) determined that 43% of I/I originated from sources other than the sewer main. In addition, for I/I attributable to laterals, 76% entered through the connection at the sewer main and 24% came through the lateral. Wastewater utilities have found that an effective lateral rehabilitation program can significantly reduce the level of I/I. In addition to an effective rehabilitation program, I/I can be reduced by disconnecting the inflow sources, such as sump pumps and roof leaders. For example, Johnson County, KS (WERF, 2003)reported a successful program of disconnection of inflow sources. Additionally, by enhancing and enforcing the plumbing code, the potential for development of future sources of inflow is minimized. Elimination of sources of I/I will reduce the volume of extraneous flow into the sewer system and will reduce the potential for SSOs to occur.

The following methods are available for lateral rehabilitation:

- Removal and replacement
- Cured-in-place pipe (CIPP) lining,
- Chemical grouting, and
- Pipe bursting.

9.4.1 Removal & Replacement

Open cut removal and replacement of sewer laterals is a proven method for renewing sewer laterals. The old service line may either be abandoned in place or removed. This technique is cost-effective when dealing with relatively shallow services, and where there is no elaborate landscaping or obstacles such as fences, paved driveways or sidewalks. A key factor to a collection system owner using the removal and replacement method is obtaining the property owners' consent to access the property for construction.

The initial concern of the property owner will likely be whether the property can be restored to pre-construction condition, especially when mature vegetation may be affected. If necessary, the alignment of the new service line should be revised to minimize the extent of ground restoration or avoid structures and other obstacles. The location of cleanouts is also a critical issue from the property owner point of view. While cleanout location is dictated by local building codes, consideration should be given to revising the alignment to address the property owner's concerns. Finally, a warranty will have to be extended for materials and workmanship. Sod and other landscaping material often will suffer, resulting in claims for warranty service. Pre- and post-construction conditions should be documented by either photos or videotapes.

Case histories of lateral removal and replacement are abundant. For example, the Susquehanna Township Authority, PA (Hilderhoff, 2001) implemented a pilot program to determine if public funding of lateral repairs would benefit all system users. As a result of the pilot, the Authority revised its regulations which indicated the property owner was responsible for the service lateral repair, and established a permanent policy of funding private sewer pipe renewal or replacement if determined to "be in the best interest of all system users." This criterion is applied at a mini-basin level where a total rehabilitation of the mini basin sewer system is undertaken. The authority established a procedure for assessment and repair or replacement of sewer laterals. Each lateral in the designated drainage area would be air tested. All service laterals and building sewers that fail would be handled by either open cut repair or replacement or with a cured-in-place liner. As part of the sewer lateral repair process, a cleanout was installed by open cut. The Authority reported a replacement cost of $1,200 - $2,300 for each lateral.

Another example of lateral removal and replacement is reported by the Mobile Area Water and Sewer System (MAWSS), Mobile, AL (Sullivan, 2001). It's severely deteriorated sanitary sewer laterals make up about 65 percent of the collection system piping. These laterals were estimated to be responsible for up to 70 percent of the I/I measured in theses areas. Since approximately 60 percent of the sanitary sewer laterals lie on private property, MAWSS initiated a Private Sanitary Sewer Lateral Replacement Program (SSLRP) in January 2000. This program requires property owners to replace defective sanitary sewer laterals on private property outside of easements or public right-of-ways.

To date, about 20,500 linear feet of laterals have been removed and replaced. Assuming that an average of 50 linear feet of lateral has been replaced for each property and assuming that each remaining property will require PSSL replacement, a total of more that 30,500 linear feet of lateral pipe should ultimately be replaced in these areas.

9.4.2 Cured-In-Place-Pipe (CIPP) Lateral Lining

The most common type of liner used for lateral rehabilitation is CIPP (cured-in-place-pipe). Access to the service lateral may be from either the sewer line or from the cleanout. If a cleanout is not available, a small entry point outside the building can be made to install one. The process of liner installation in the service lateral is very similar to the CIPP lining of sewer lines. The lateral should be cleaned of all debris and roots. The liner is saturated with resin and is pulled through the service lateral by either the inversion or winching method. The liner is then inflated and cured by either water or air. Since the junction

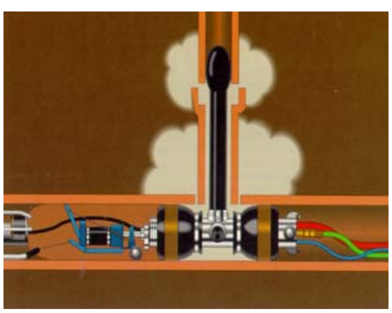
between the service lateral and the sewer line is the weakest point, special measures should be taken after the liner is installed so that the junction becomes water-tight. Proprietary systems are available which rehabilitate the lateral/sewer line junctions at the same time that the lateral is rehabilitated. If both the sewer line and the lateral are planned to be rehabilitated, the lateral should be rehabilitated first followed by the rehabilitation of the lateral. This will minimize any damage to the liner in the sewer line.

The Susquehanna Township Authority, PA (Hilderhoff, 2001) reported utilizing CIPP liners for rehabilitation of sewer laterals during a pilot program and in a subsequent permanent service lateral rehabilitation program. The authority reported a unit cost of \$18-\$22 per foot for lining of service laterals.

The Boston Water & Sewer Commission (BWSC), MA (McSweeney, 2000) observed infiltration increased significantly during high tides as part of a project to remove infiltration from the Charleston Navy Yard. BWSC rehabilitated 45 service laterals by a proprietary product which rehabilitated service laterals and the junction of the laterals and sewer line at the same time.

In another application, Fundich (1999) reported that the South Palos Township Sanitary District (SPTSD), IL, used CIPP lining for rehabilitation of 117 clay pipe service laterals. A proprietary product was used to line the service laterals and the junction of the laterals and sewer line at the same time. The rehabilitated lateral and junction passed an air pressure test of 5 psi for 10 minutes. SPTSD was able to reduce the level of infiltration by approximately 60% through rehabilitation of 43% of its sewer lines and 27% of its service laterals.

9.4.3 Chemical Grouting



Chemical grouting is frequently used to reduce infiltration/inflow (I/I) in laterals. Chemical grouting is less costly than other alternatives such as removal and replacement, or cured-in-place lining. However, since chemical grouts do not add to the structural integrity of laterals, they should only be used when the overall structural integrity of the laterals is sound. Grouts give best results in cohesive soils. They may be used to fill voids and stabilize soils around the lateral. Grouting is often used to seal the junction of the lateral and sewer pipe. A section of the sewer line containing the lateral is isolated by bladders. Very-low-viscosity chemical grout is then pumped into the isolated area under pressure. The grout penetrates through the cracks into the surrounding soil and seals off the cracks and other defects. Careful observation and monitoring of the grouting operation is necessary to ensure success. All laterals rehabilitated by grout should be air tested. If the lateral does not pass the test, additional grouting should be performed until the lateral passes the air test.

Larsen, et. Al, (1996) reported on the extensive use of chemical grout in southern Florida where high ground water conditions exist. A one-year warranty inspection on approximately 1,300 chemical grouting applications for lateral rehabilitation in Broward and Miami-Dade counties indicated that less than 2% of the laterals were leaking at the junction of the service lateral and sewer line.

9.4.4 Lateral Bursting

Lateral bursting is very similar to pipe bursting. Access pits are excavated at both the upstream and downstream ends of the service lateral. One entry is for the insertion of the replacement pipe led by a bursting head, while the other end is for access to pull the head through the lateral by cable or rods. The existing service line is burst into pieces and pushed into the surrounding soil. The new pipe is pulled in place behind the bursting head. An advantage of lateral bursting is its capability to upsize the lateral size by one or two pipe diameters.

A lateral bursting equipment has only recently been introduced into the market and there is not a long track record of its use. However, it appears to be a promising tool and its use is expected to increase significantly in the coming years as utilities become aware of its potential. One application has been done in Jacksonville, FL (www.tttechnologies.com/stories/gcrack/26/index.html). It involved bursting six laterals, approximately eight to nine feet deep, and with an average length of 30 feet. The four inch VCP laterals were replaced with six inch HDPE. After each burst, the HDPE service lateral was tied into the existing sewer line by a saddle-T with steel clamps.

9.5 Spot Repair

Spot repairs may be used to correct isolated or severe problems in a pipeline segment. They are most commonly used to correct individual defects within a pipeline segment, and can be an initial step in the use of other rehabilitation methods. Spot repairs are usually limited to the rehabilitation or replacement of only a short portion of the sewer line. The following techniques are available for spot repairs of short deficient sections of a pipeline which is otherwise in a generally good condition:

- Open cut repair/replacement,
- CIPP,
- Internal grouting,
- External grouting, and
- Rubber Seals with stainless mechanical bands.

9.5.1 Open-Cut Repair/Replacement

Open cut has been the traditional method for spot repair. With the advent of trenchless technologies, collection system utilities prefer to avoid open cut repairs to minimize surface disruption, and traffic impact. For emergency repairs or in cases when they are only a few spot repairs to be made, open-cut may become a more cost-effective and desirable option. The severity of the condition requiring repair may also necessitate the use of an open-cut option. For example, the trenchless repair of a collapsed short section of an eight inch sewer pipe may not be feasible and the only viable option may be the open-cut method. Site conditions, such as soil type, may limit the options to open-cut only. Additionally, when the depth of the sewer line is shallow, the soils are stable, and no ground water is present, open cut may be more cost effective than trenchless options. The advantage of open cut is that it does not need sophisticated equipment and extra skilled personnel. There is also the opportunity to inspect the repaired pipe fully and ensure it is constructed according to the specifications. As a general rule, open cut should not be considered the first choice, if trenchless options are feasible and cost-effective.

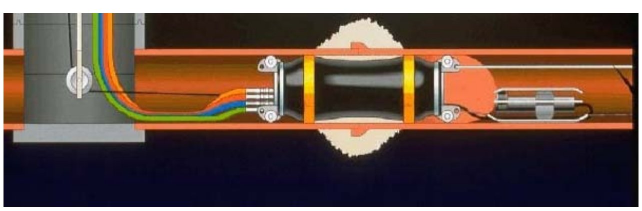
9.5.2 Cured-In-Place-Pipe (CIPP) Lining

CIPP liners for spot repair can vary from 3 feet to 60 feet in length. A composite section consisting of a polyester wearing surface and a resin soaked fabric is pulled to the desired repair location. A chemical reaction that cures within a few hours creates a pipe within a pipe repair. The sleeve must be pulled into place within a short period of time, approximately 30 minutes, to avoid hardening before the repair site is reached. A CCTV camera is used to position the repair sleeves.

The City of Portland, OR (Caufield, 2002) has used this process for spot repairs in locations with extremely poor access. One case dealt with a service branch that had been missed during a fold-and-form repair project. The patch was positioned over the problem connection, cured and then reestablished with a robotic cutter. Another case involved a service branch that passed under an electrical vault and two light rail tracks. A grounding rod had penetrated through the sewer which provided a perfect place for sewage to buildup and backup. After the owner of the electrical vault removed the grounding rod, the sewer repair could begin. A small excavation over the service branch was required for access and the patch was pushed into place to affect the repair. Rail service was not interrupted.

The Regional Municipality of Hamilton-Wentworth (Gunn, 1999) has evaluated the structural capabilities of cured-in-place pipe (CIPP) spot repair systems by asking contractors to install a sample of their spot repair systems in a section of existing clay sewer. The spot repairs were tested according to ASTM D 2412-93 "Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading." The external loading capabilities of CIPP spot repair were found to be well within the accepted values for PVC pipe.

9.5.3 Internal Chemical Grouting



Internal chemical grouting may be used for spot repairs of defective pipe joints. Grouting is also used to seal the junction of the sewer pipe and manholes. Experience has shown that chemical grouting of isolated joint often does not provide a satisfactory solution to a reduction of inflow/infiltration (I/I). This is due to the migration phenomenon whereby groundwater migrates from a grouted joint to the adjacent joints and enters into the sewer system. However, if an entire reach is grouted, a reduction in I/I is often realized. Chemical grouts can be used to fill voids and stabilize the soil around the sewer pipe. However, since chemical grouts do not add to the structural integrity of the pipes, they should only be used when the overall structural integrity of the sewer pipe is sound.

During the grouting process, the area selected for grouting treatment is isolated by bladders. Very-low-viscosity chemical grout is then pumped into the isolated area under pressure. The grout penetrates through the cracks into the surrounding soil and seals off the cracks and other defects. Careful observation and monitoring of the grouting operation is necessary to ensure success. All sections rehabilitated by grout should be air tested. If the treated section does not pass the test, additional grouting should be performed until it passes the air test.

The application of grouting for spot repair is well documented. For example, the Denver Metro Wastewater Reclamation District (District), CO (see Appendix II – Case studies) has reported extensive use of chemical grouting. Most of the I/I in Denver's system is considered to be from infiltration. Therefore the city has a sewer inspection and joint sealing program. Sealing involves the injection of chemical grout into the voids of a defective pipe joint or crack to seal the area and prevent infiltration from entering the sewer. To measure the reduction in I/I achieved by the sealing program, WMD chose four test reaches for pre-and post-sealing flow monitoring. The cost effectiveness of the grouting program was also analyzed. It was found that the program was cost-effective when the entire sewer reach or sub-basin was tested and sealed. However, the program was not cost effective when only a portion of the sewer reach was sealed. The infiltration removed from sealed joints simply migrated to other locations along the sewer that were not rehabilitated.

Another example provided is from the McCandless Township Sanitary Authority (MTSA), PA, (Balkley, 2001) which reported success in line joint grouting of eight to ten inch diameter lines. Grouting was especially found to be more cost effective in well-developed areas where excavation was a limiting factor. MTSA has found line grouting to be 90 percent effective using "spot" air tests over a seven year period.

9.5.4 External Grouting

When access to the inside of the pipe is not practical, external grouting may be used from above the ground surface. Both cementitious and chemical grouts may be used. External grouting may be used to address issues such as soil movement, pipe settlement, soil voids, and groundwater.

Portland cement grouts can be used to form impermeable subsurface barriers; however, its use is limited to medium sand or coarser material. Micro-fine cement may be used in fine sands. Compaction grouting may be used for remediating or preventing pipeline and manhole structural settlements. Compaction grouting is achieved by injecting low-slump cement-based grout into granular soils, forming grout bulbs that displace and densify the surrounding loose soils.

A wide range of chemical grouts are available. They can be divided into four broad categories: acrylamide, acrylate, urethane foam, and urethane gel. Acrylamide grouts are reported to be carcinogens and should be handled with care.

The application of external grouting is often limited to large size interceptors. For example, The City of Niagara Falls, NY utilized external grouting to reduce infiltration into the Fall Street Tunnel (FST), a three-mile long tunnel crossing from east to west. This tunnel was constructed between 1894 and 1923, and ranges from a six feet by seven feet section 30 feet below ground level, to an eight feet by eight feet section 70 feet below groundwater level (Roll, 2001). Of the roughly 10 mgd of dry weather infiltration into the FST, approximately six mgd was in a 200 foot stretch of tunnel from a power conduit crossing. External grouting was selected to eliminate the infiltration. A series of grouting holes drilled along each side of the tunnel allowed the creation of a concrete cocoon around the tunnel. Over the course of the three month construction duration, about 150 tons of grout was pumped into 81 holes. The Fall 2000 leakage rate of 5.8 mgd was reduced to a Spring 2001 rate of 1.6 mgd, a difference of about 4.2 mgd.

9.5.5 Rubber Seals

Rubber seals are used to repair leaky joints. The rubber seal is secured in place by two stainless expansion steel bands. The stainless steel band straddles a problem joint and inflatable rubber gaskets seal both ends of the band. Grout ports can be supplied on the bands to provide a redundant repair. These products can be used in systems ranging from 16 inch to138 inch in diameter. It is necessary to prepare the joint to be sealed by removing any grease and scale before the seal is positioned. The advantage of these products is that a problem joint can be repaired without excavation, which can be expensive and disruptive at the depths that these problems often become apparent. The disadvantage of these products is that high ground water pressures may eventually overwhelm the seal. Monitoring of the seal over a full year will likely be required to indicate whether or nor the seal is effective. A bulge at the seal may occur with failure being a distinct possibility.

The City of Portland, OR (Caufield, 2002) has used rubber seals for man-entry sized sewers (72-inch diameter) and has injected grout at joints that either leaked or failed air tests during construction inspection.

Kane (1999) reported that the Monterey Bay, CA pipe which had been damaged during the Loma Prieta earthquake was repaired by rubber seals. The 11,260 foot long outfall carries effluent from a 29.6 mgd secondary wastewater treatment plant and ends up in 110 feet of water in Monterey Bay. The pipe is a 60-inch reinforced concrete pipe. Each area that was suspect was inspected with exact measurements of the joint gap. In addition, an electronic level was used to determine the slope of the pipe. The divers were able to make a 2000-foot penetration to the last leak area. Divers used 20 mechanical seals which were expanded and pressed to fit. The installation process utilized a rubber band around the inside of the pipe with metal straps and a portable power jack to install the seals. Divers alternated between working in teams of two and one. The single diver was responsible for setting up the work site with seals and tools and video recording some of the completed work. The two diver teams did the bulk of the repair work. The repair work took approximately six weeks.

9.6 Disconnecting Inflow Sources

The inflows to the collection system through service laterals cannot always be eliminated by rehabilitation. A case in point is when extraneous inflow sources such as downspouts or foundation drains are directly connected to the sewer system through service laterals. In such cases, the inflow source should be disconnected. In Johnson County, KS, a successful private lateral disconnection program was shown to account for almost 40% of the total I/I reduction achieved, or 110 million gallons per day (mgd) during the 10-year storm event (WERF, 2003). This program, together with a collection system rehabilitation, reduced I/I by as much as 280 mgd during the 10-year storm and has led to significant reductions in the number and severity of sanitary sewer overflows (SSOs).

There are several primary sources of inflows which may be disconnected:

- Foundation drains,
- Basement entry drains,
- Sump pumps,
- Downspouts,
- Outdoor drains,
- Damaged or open cleanouts, and
- Stormwater cross connections.

In addition to disconnecting the existing inflow sources, wastewater utilities can minimize the potential for development of future sources of inflow by enhancing and enforcing their plumbing codes.

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Chapter 10

Concluding Remarks

10.1 Summary

The Clean Water Act of 1972 established the standard that all collection systems covered by the National Pollution Discharge Elimination System (NPDES) must attain no unpermitted discharges or overflows from the collection system. While the law created the benchmark for collection systems, the initial regulatory focus was bringing treatment plant performance and plant discharges into compliance to achieve the fishable and swimmable goals of the federal law. Grant-funds and then loan programs were provided to eliminate cost-effective, excessive infiltration/inflow from the collection system, primarily to reduce peak wet weather flows at the plant that could cause non-compliance.

While combined sewer problems dominated the industry's attention in the early 1990's, separate sanitary sewer issues came to the forefront with the formation of the SSO Subcommittee of the Urban Wet Weather Flows Federal Advisory Committee. Beginning in 1994 and continuing today, the emphasis has been to improve the EPA's and the permit holders' effectiveness in addressing wet weather pollutant sources. As the problem emerged in more clarity, not only was capacity identified as a critical parameter to contain peak wet weather flows, but operation, maintenance and management concerns were enumerated that also contribute to the frequency and magnitude of sewer overflows.

The culmination of the proposed actions by the federal government resulted in the initial publishing and subsequent withdrawal of the proposed SSO Rulemaking Efforts in January, 2001. The SSO regulatory emphasis was temporarily distracted for several years while other supporting issues, such as "blending", received attention. The Clean Water Act, however, already provided EPA the tool necessary to pursue enforcement actions against overflow violators. Continuing federal and state consent decrees and administrative orders to address SSOs have generated overwhelming industry attention to collection system performance.

This Guidance Manual is the third in a series of documents produced by ASCE over the last five years that are responsive to the issue of sanitary sewer overflows in the collection system. The first, "Optimization of Collection System Maintenance Frequencies and System Performance (1999)," identified and developed parameters for evaluating the effectiveness of maintenance programs, reviewed how maintenance and rehabilitation funds were being spent, provided and overview of selected values for maintenance frequencies, and created a process for utilities to measure their own performance against others. Based on the data collected from wastewater utilities, cleaning of the collection system and pump station maintenance were the two most important activities to precluding SSOs. Not surprisingly, a strong relationship was found between the performance rating and the reinvestment rate. It was recommended that an agency find the balance necessary to maximize performance, minimize SSOs and achieve both with the most cost-effective level of reinvestment.

"Protocols for Identifying Sanitary Sewer Overflows (2000)" was the next in the series, bringing attention to the hydraulic, maintenance and inspection and structural protocols used to recognize SSOs to enable more effective response and to build a basis for proactive actions to preclude SSOs. The Hydraulic protocols involve modeling and techniques incorporating the use of flow monitoring data from the collection system. Maintenance and Inspection protocols include the use of scheduled inspections, maintenance reviews, monitoring of receiving stream, customer observations, and event system notifications. Structural protocols are related to assessments of the pipe integrity through visual, physical sampling, and analytical methods.

The “Protocols” study included a data collection task that provided the responding utilities an opportunity to expand upon the statistical responses with narratives regarding their approach to identifying and responding to SSOs. High awareness of SSOs and their impact has translated into a series of programs that they consider important for SSO effectiveness. Consider that all the respondents have an ongoing I/I program and all consider SSOs in their rehabilitation program. Nearly every responding agency has written SSO protocols and two-thirds of these plan additional protocols in response to new findings and information. The majority have identified design deficiencies which contribute to SSOs and have modified those requirements and criteria. Over half of the agencies have a corrosion control program and a grease abatement program.

Many of these program elements are the building blocks for a good Capacity, Management, Operation, and Maintenance (CMOM) program. That leads to the current Guidance Manual in the series, “Solutions for Sanitary Sewer Overflows,” which is a compendium of solutions to SSOs. The objective was to identify and evaluate existing solutions for resolving both dry and wet weather SSOs and develop a compendium of the effective solutions.

The collection system industry is rich in shared experiences. Practioners have never been more active in publishing and making their results and opinions. While there are individual and unique facets to each collection system, there are also success stories that agencies have written that will benefit other operators with similar problems. So many stories, in fact, they all can’t be documented here. This Guidance Manual should be viewed in the context of other outreach material available from EPA, WEF, WERF, ASCE, NASTT, NASSCO, industry vendors, contractors and engineering consultants. Materials are more available than ever through the internet and other technology transfer mediums.

EPA’s goal of zero overflows may not be attainable. However, reasonable efforts need to be made to reduce the current incidence of SSOs. Every dollar effectively reinvested in the collection system enhances performance, reduces overflows, and diminishes the impact of backups and other customer and environmental impacts. This Guidance Manual identifies some of the good investments to make to begin that process of improving the capacity, management, maintenance and operations of the nation’s collection systems.

10.2 Research Needs

While many of the traditional SSO solutions presented in this Guidance Manual have been extensively implemented by wastewater utilities across the nation, some of the more innovative SSO solutions have been implemented on a limited basis. As such, a thorough evaluation of the full potential of such solutions was neither possible nor was part of the scope of the present study. As these solutions gain more acceptance and are implemented by wastewater utilities at a more frequent rate, it would be prudent to evaluate the effectiveness of such solutions through conducting in-depth studies of case studies specific to each solution. Since this would be a monumental task, it is logical to group the solutions into the major categories used in the organization of this Guidance Manual and tackle each area separately.

- The following major areas are recommended for future studies:
- Evaluation of innovative capacity solutions
- Evaluation of innovative management solutions
- Evaluation of innovative operation and maintenance solutions
- Evaluation of innovative condition assessment solutions, and
- Evaluation of innovative rehabilitation solutions.

In addition, it is recommended that a clearinghouse or website be considered to provide an opportunity for wastewater agencies to update and build on SSO solution success stories. The information collected in this manner can be used to develop an updated version of the current Guidance Manual every five or ten years.

January 2001
AMERICAN SOCIETY OF CIVIL ENGINEERS (ASCE) PROJECT TO DEVELOP SOLUTIONS FOR SANITARY SEWER OVERFLOWS (SSOs)

LITERATURE SEARCH

The following sources were used for the literature search:

- ASCE Online Database
- EPA Website
- World Wide Web Search Engine Alta Vista
- Civil Engineering Database
- Water Online Website
- Public Works Online Website
- Construction Industry Research Information Association (CIRIA) Website (UK)
- Institution of Civil Engineers Website (UK)
- Wastewater Planning Users Group (WaPUG) Website (UK)
- Water Environment Federation (WEF) Website
- Water & Environment Technology Magazine
- Public Works Magazine
- Proceedings of the WEF Collection Systems Specialty Conferences (1998-2001)
- Proceedings of WEFTEC 98, 99, 00, 01
- Proceedings of WEF Conference on Advances in Urban Wet Weather Pollution Reduction, July 1998, Cleveland, OH
- Proceedings of ASCE Pipeline Conference, Phoenix, AZ
- Proceedings of the North American Society of Trenchless Technology No-Dig Conferences (1998-2001)
- Proceedings of ASCE Pipeline Conference, Convergence 2000, Kansas City, Kansas 2000
- ASCE Conference, Building Partnerships (2000 Joint Conference on Water Resources Engineering and Water Resources Planning & Management, Minneapolis, Minnesota, August, 2000)
- State of the Practice - Proceedings of the World Water and Environmental Resources Congress, Orlando, Florida, May 2001
- Proceedings of the Eighth International Conference in Computing in Civil and Building Engineering, Stanford, California, August, 2000
- Proceedings of the Fifth ASCE Materials Engineering Congress, Cincinnati, Ohio, May, 1999
- Proceedings of the 26th Annual Water Resources Planning and Management Conference, Tempe, Arizona, June, 1999

A summary of the literature search follows. This information will be used in developing solutions for sanitary sewer overflows (SSOs.)

1. Jones, Douglas T., Short, T.J.; "A Comprehensive Wet Weather Management Program for the City of Bloomington, Indiana," 2001 A Collections Systems Odyssey: Integrating O&M and Wet Weather Solutions, WEF Specialty Conference Paper, July 2001

This paper documents the aggressive preventative maintenance program adopted by the City of Bloomington Utilities (CBU). CBU regularly cleans all sanitary sewers within its service area each year. The televising (CCTV) of sanitary sewers is accomplished on a five-year turnaround cycle. Lift stations are maintained at least once per week and all lift stations are telemetered. This has resulted in a minimal number of sanitary sewer overflows (SSOs) or basement backups that are attributable to mechanical failure, or blocked sewers. The collection system is made up of 250 miles of sewer, ranging from 8-inch to 60-inch diameter pipe, and just over 40 lift stations.

2. Dent, S., et al; "A Watershed Approach to SSO Management," 2001 A Collections Systems Odyssey: Integrating O&M and Wet Weather Solutions, WEF Specialty Conference Paper, July 2001

This conference paper details how a watershed approach to SSO management was applied as part of an SSO elimination program for the Vallejo Sanitation and Flood Control District (VSFCD) in Northern California. The watershed approach used a combination of monitoring and hydraulic modeling techniques to estimate the improvements to water quality for a variety of SSO elimination programs. Monitoring data included the use of radar and ground-level rain gages, flow monitoring data, and water quality samples. Modeling consisted of a detailed sanitary sewer collection model, an urban stormwater model, and a watershed model. By taking a watershed approach to SSO management, the impacts to both the public and the receiving waters were able to be minimized to a "cost-effective level." The watershed approach was applied to the VSFCD collection system to estimate pollutant loads from SSOs, a WWTP, urban stormwater, and the Napa River watershed. Monitoring and modeling were utilized to project loads from each of the aforementioned sources. The investigation of each of the wet weather pollutant sources within a watershed gives an insight into public health and environmental impacts by each of the sources. By understanding the pollutant contribution of SSOs in relation to other pollution sources, VSFCD were able to quantify when SSO impacts diminished significantly.

3. Shamsi, U., et al; "A Wet Weather Overflow Management Odyssey: From Videotapes to GIS," 2001 A Collections Systems Odyssey: Integrating O&M and Wet Weather Solutions, WEF Specialty Conference Paper, July 2001

This paper documents the managed reduction of wet weather overflows by conducting CCTV inspection of sewers using multimedia computer technology and GIS. It shows how GIS can be used for improved inspection and maintenance of sewer systems. The paper proposes a four-step method for implementing a GIS-based TV inspection program. The steps are described in detail with the help of real world examples. The steps are as follows:

- Prepare a work order for TV inspection of sewers using GIS. GIS based work order management requires Automated Mapping/Facilities Management (AM/FM) software extensions that can be run within the GIS software
- Migrate from video tapes to video files
- Link the digital movies to the GIS database
- Use the TV inspection logs to make a GIS map of service laterals. Service laterals can account for 60 percent of total wet weather I/I.

4. Crumb, S., et al; "AFTER THE RAIN: Blended Flow Process Alleviates Wet Weather Woes Cost-Effectively for Fort Worth, Texas," Water Environment & Technology, April 2000

This paper discusses how to reduce SSOs and CSOs during storm events against a background of increasing treatment capacity demands caused by population growth and wet weather inflows. A collection system master plan was developed to look at alternatives for resolving the existing flow and pipe configurations, and the impact of growth and collection system lines that have capacity issues during wet weather events. The options considered (and their estimated cost) were as follows:

- Option 1 – Capacity corrections ($554,100,000)
- Option 2 – Wet weather overflow facilities ($523,400,000)
- Option 3 – Wet weather storage ($396,200,000)
- Option 4 – Storage tanks with real time control (RTC) ($586,200,000)
- Option 5 – Satellite treatment plant ($620,000,000)
- Option 6 – Comprehensive sewer line replacement ($1,117,500,000).

Options 1 and 5 were selected for further detailed examination. The Citizens Advisory Committee recommended the implementation of either option (it is not stated in this paper which option was finally implemented.) Another key focus area for the city was to implement a long-term preventative maintenance (PM) program. This was also recommended in the master plan. After discussions with Field Operations staff, it was decided that pipes of 18-inch diameter or smaller would be cleaned at least once every eight years. This amounted to about 1,288,000 linear feet of pipes.

Based on experience, pipes of 20-inch to 33-inch diameter were scheduled for cleaning every 15 years. Pipes of 36-inch diameter and larger are cleaned by contract. Short-term routine maintenance due to clogging from debris, grease build-up, and root intrusion is carried out every one to six months. This accounts for about 944,500 linear feet of pipes per year.

5. Rugaard, L.C.; "CMOM++ - Improving Collection System Reliability to Achieve a Goal of No Overflows," 2001 A Collections Systems Odyssey: Integrating O&M and Wet Weather Solutions, WEF Specialty Conference Paper, July 2001

In 1996 Stege Sanitary District (California) adopted the CMOM program goal of "the ultimate elimination of any type of overflow from the sanitary sewer system." This paper shows how the management, engineering, maintenance and data management systems were improved to facilitate achievement of this target.

The system rehabilitation program (CMOM++) was developed as a means of eliminating overflows due to stoppages, blockages, and line failures. The program ranks line segments by probable damage, and then conducts a five-year program of video inspection line condition assessment. Each year 20 percent of the system is inspected. The most significantly damaged lines are scheduled for immediate repair/replacement. The District budgeted one percent of the system replacement value ($750,000) per annum for this work.

The District's service area was divided into six maintenance areas. The maintenance crews undertake cleaning in a different area each month. The crews are given color-coded maps of each area, sewer, and defect. A 50 percent increase in cleaning productivity has been attained by using this method.

The overflow response plan states the steps to be taken when an overflow occurs, as follows:

- Control the overflow by all means available
- Transfer information to a complete overflow report when back in the office
- Require an action request by the Maintenance Supervisor (e.g., change in cleaning equipment, change in cleaning frequency, a condition assessment, or immediate repair)
- Include date of implementation of the requested action.

A monthly report is produced detailing the requested actions from the overflow report. The record of all overflows, when and what actions were taken, are all part of the permanent record of the District.

This year (2001) completes the fifth year of condition assessment work. The average cost of the CMOM++ program for the first five years is $725,000. Not included in this is the $1.4 million for work related to elimination of capacity related overflows in local collector lines. It is expected that costs will drop to about 25 percent of the average annual expenditure of $725,000 for the first five years. The District feels that this is a reasonable assumption and will be sufficient to achieve the program target level of "no overflows." Between 1990 and 2001, overflows related to all causes have reduced from over 30 per year to 10 per year (72 percent reduction).

6. Hollenbeck, A.J., et al; "Comprehensive Public and Private Sector Rehabilitation Program Provides Documented 10-Year Storm Protection," 2001 A Collections Systems Odyssey: Integrating O&M and Wet Weather Solutions, WEF Specialty Conference Paper, July 2001

This paper details how the Rock River Water Reclamation District (Illinois) implemented a phased multi-year program to mitigate basement backups after intense storm events in the Harrison Alpine service area. This program resulted in the identification and rehabilitation of both public and private sources of infiltration in the study area. Post rehabilitation flow monitoring confirmed that 10-year storm protection from overflows and basement backups was achieved.

The project comprised the following (with costs, where available):

- Manhole inspection of 320 public sector manholes ($164,000)

- Dual blower testing of 71,000 linear feet of public sector sewers
- Dyed water flooding of potential sanitary sewer/storm sewer cross connections
- Television inspection (by District staff) of 71,000 linear feet of public sector sewers
- Flow monitoring of all three service area outlets
- Flow data/source data flow balancing
- Hydraulic modeling of sewer system performance.

Post rehabilitation flow monitoring was conducted in May 2000. This showed that the rehabilitation program reduced peak wet weather inflow in excess of 65 percent.

7. Roll, R.R., et al; "Correcting Wet Weather SSO Problems in Bite-Sized Pieces," Collection Systems Wet Weather Pollution Control, WEF 2000 specialty paper, May 2000

This document details the steps that the City of Niagara Falls, New York is taking in dealing with levels of infiltration and inflow in its collection system that are creating service problems for residents. The region was divided into three areas where detailed infiltration and inflow studies were conducted in three consecutive years. Components of each study include thorough sewer cleaning, video inspection of all sewers, dry weather and wet weather inspections, smoke testing, dye testing, sewer flow measurement, groundwater level measurement, rainfall measurement, and water quality monitoring. The city took a "partnering" approach in working with the engineering consultant and subcontractors in order to realize performance gains from rapid correction of defects with in-house resources. The use of in-house resources also reduced costs. More extensive corrective work is prioritized for future implementation by contractors, also phased over a multi-year period.

8. Kurz, G.E., et al; "Nashville Cuts Wet Weather SSOs Using Sewer Rehabilitation," Collection Systems Wet Weather Pollution Control, WEF 2000 specialty paper, May 2000

This paper presents results from flow monitoring studies, and overflow reporting over the past nine years in Nashville, Tennessee. To develop a database of objective measurements of sewer rehabilitation effectiveness, twenty seven project areas in the Nashville, Tennessee, OAP (Overflow Abatement Program) were analyzed which included 83,781m (274,871 ft) of sewer lining or replacement.

Some of the projects showed sufficient I/I reduction to allow a five-year payback from treatment costs avoidance. A cumulative annual I/I reduction of 10.36 x 10^6 m^3 (2,737 million gallons) has been documented for these projects. The trend of results indicate that an I/I removal rate of about 10,000 m^3 /year/100m of lining (8.2 million gallons/year/1000 ft of lining) may be expected from rehabilitating deteriorated sewers in the Nashville area.

9. Heaney, J.P., et al.; "Research Needs in Urban Wet Weather Flows," Water Environment Research, Volume 71, Number 2, March/April 1999

This document presents the results of a national assessment of research needs in urban wet weather flow management. The results were organized into ten categories: (1) sources and monitoring; (2) receiving water effects; (3) other effects; (4) management; (5) models and decision support systems; (6) watershed management; (7) regulatory policies; (8) source controls; (9) collection system controls; (10) storage/treatment systems.

10. Wade, M.G., "Sealing Springfield," Civil Engineering, May 2000

This details a twelve year program to reduce sanitary sewer infiltration and inflow in Springfield, Missouri. It will cost the city more than $19 million but it will help the city to avoid fines of more than $75 million for past SSOs. The program is in three phases: manhole rehabilitation, pipeline rehabilitation, and private sector I/I reduction. Manhole rehabilitation includes: top-end manhole repairs, coating of manhole walls, frame and cover replacements, plugging, and pressure grouting. Pipeline rehabilitation includes: joint repairs, lining and replacement of pipes, joint sealing, pressure cleaning, grease removal, and root removal.

The I/I abatement program will include the removal of about 9,500 sources of I/I from private properties at an average cost of $320 per connection. This is projected to remove more than 234,670 m^3/d (62 mgd). Post rehabilitation flow monitoring results show an infiltration reduction of 29 percent (against a program target of 15 percent). The measured reduction of peak inflow was about 60 percent, with a range from 0 to more than 90 percent. The program target for peak inflow reduction was 40 to 50 percent.

11. Hobbs, D.V., et al; "Equalizing Wet Weather Flows," Civil Engineering, January 1999

This document details the use of flow equalization basins (FEBs) as a means of increasing a system's capacity. FEBs do this by retaining excessive flows until the collection system is able to handle them. This paper suggests that FEBs may be a better solution to the control of wet weather overflows because they offer a better return on investment than alternatives which require new construction or treatment facilities. The city of Tulsa is given as an example. In 1990 there were 24 sites at which SSOs had to be eliminated. The city considered constructing relief sewers but abandoned this option due to costly upgrades required for a lift station, force main, and wastewater treatment plant. Another option was to construct two FEBs (one in each of two basins) eliminating the need for relief lines or upgrades to the lift station or plant. Both FEBs were open lagoon types, located near Creeks in secluded, sparsely populated areas in order to minimize odor nuisance to neighbors, and to provide access to the FEBs without having to go through residential areas. This plan (which Tulsa implemented) cost nearly 67 percent less than the alternatives.

12. United States Environmental Protection Agency (EPA), Office of Wastewater Management; "Featured Case Studies, Factsheets, and Other Information," June 2001 (EPA Website)

The EPA's Office of Wastewater Management is sponsoring a series of community-based demonstration projects. These will illustrate innovative solutions to capacity problems that cause overflows of sanitary sewers. To date, there are two featured case studies: Greenwood County, South Carolina, and Johnson County, Kansas.

Case Study I – Greenwood County, South Carolina CMOM Program

Greenwood Metropolitan District (Metro) produced a Capacity, Management, Operations, and Maintenance (CMOM) program. During 2000, Metro recorded 77 SSOs, of which 48 were considered reportable (more than 500 gallons, posing an imminent health risk to the public or likely to degrade environmental resources). Metro established long and short term goals for its CMOM program. The short-term goals (complete within three years of program initiation) are as follows:

- Performing system survey and GIS-based mapping activities needed to fully develop the CMOM program
- Collecting water quality and hydrology data to characterize the collection system's current environmental impact
- Performing a system capacity evaluation to identify hydraulic deficiencies
- Performing short-term, high-priority system rehabilitation projects to immediately improve system performance.

Long-term goals (addressed during the three-year start-up phase, but will continue on into the future) are as follows:

- Implementing a prioritized capital improvement program to resolve identified structural failures and ensure adequate capacity
- Reducing SSOs
- Improving customer service
- Instituting information and asset management systems to facilitate long-term planning and ongoing operations and maintenance.

The measures that Metro adopted to achieve SSO abatement included the following:

- Routine preventative operation and maintenance activities. Metro is in the process of completing a thorough system cleaning and rehabilitation program. As this work progresses, Metro is developing a GIS layer that will be linked to information management software to be used for developing and scheduling a planned preventative maintenance program for all pump stations, treatment plans, and the collection system.

- Identification and prioritization of structural deficiencies along with short-term and long-term rehabilitation plans to address them.

The CMOM program is expected to yield SSO reductions within four years.

Case Study II – Johnson County, Kansas, Private Inflow/Infiltration (I/I) Source Control Program

In Johnson County, Kansas, a successful private lateral disconnection program was shown to account for almost 40 percent of the total I/I reduction achieved, or 110 million gallons per day (mgd) during the 10-year storm event. This program, together with collection system rehabilitation, reduced I/I by as much as 280 mgd during the 10-year storm and has led to significant reductions in the number and severity of sanitary sewer overflows (SSOs).

In 1985 Johnson County Wastewater (JCW) undertook the repair or replacement of 17,000 manhole structures, and disconnection of more than 15,600 unpermitted sources of storm water inflow on private property. This was the largest private I/I disconnection program in the United States. This program has resulted in SSOs being reduced overall and eliminated up to the 2.5-inch 24-hour storm. JCW's I/I reduction program cost a total of $60 million. Of that total, the private connection program was the least expensive component, at just under $10.3 million. Another $30 million went to collection system improvements, and the remaining $19.7 million was used to cover program-specific engineering and administrative expenses.

Post-reduction program flow monitoring conducted between 1995 and 1997 revealed that wet weather flows in the target communities had been reduced between 42 percent and 71 percent. In every case, exceeding the expectations based on the initial surveys. Overall infiltration and inflow during the 10-year, one hour storm were reduced by more than half - from a total of 494 mgd to 214 mgd. Storm water inflow, the dominant component, was reduced by 280 mgd, from 465 to 195 mgd. Private connections were estimated to account for almost 40 percent, or more than 110 mgd of the inflow reduction. Similarly, groundwater infiltration was reduced from 29 mgd to 19 mgd, largely through collection system improvements.

13. Nezat, M.A.; "Innovative Method for Cleaning Large Bore Sewer," WEF Specialty Conference Paper, July 2001

In 1998 Montgomery Watson (MW) had about 15,000 linear feet of large diameter pipe in Fulton County, Georgia to clean, CCTV, and evaluate. MW contacted AMTEC to perform a CCTV of the system but was unable to complete the inspection because of large debris and sediments in the pipe. Local contractors were also unable to clean the pipe due to extremely rough terrain, a ban on tree removal, and no roads were allowed to be put in. Access to a manhole was only every 2,000 to 3,000 feet.

Nezat Training and Consulting (NT&C) were contracted to use their patent-pending Jigawon cleaning method. This restricts the existing flow inside the sewer and creates turbulence within the pipe, causing material to be put into suspension and moved downstream. Debris is removed from a selected manhole downstream. A total of 147.78 tons of debris (sand) was removed from the 14,740 feet of sewer trunk line cleaned.

14. Nelson, R.E., et al; "Balancing Collection System Performance and System Maintenance," Proceedings of WEFTEC '99, 1999

This paper presents a rational approach for balancing collection system performance and system maintenance. The study is based on an analysis of maintenance, performance measures, and reinvestment data from 42 wastewater collection agencies across the

United States. The paper shows that there is a correlation between system performance, maintenance frequency, and reinvestment rates.

- Routine maintenance: 41 of the agencies reported having a cleaning maintenance program. Annual cleaning rates varied from about 0.29 miles per mile of sewer lines per year to about 0.32 miles per mile of sewer lines per year.
- Inspection maintenance: The overall average reported shows that manhole inspection activity has increased from 10 percent per year to 26 percent per year in the last 20 years. Smoke/dye testing has increased from 2 percent per year to 8 percent per year over the same period. CCTV inspection has had similar increases of 2 percent per year to 7 percent per year over the same period.
- Rehabilitation status: Less than 50 percent of required rehabilitation has been completed.
- System maintenance costs: Relief maintenance costs have risen from $1 per mile per year in the pre-1970s era to $1,291 per mile per year in the 1990s. Equalization costs have risen from $53 to $322 per mile per year for the same period. Rehabilitation/ replacement costs have also risen for this period from $1 to $2,836 per mile per year.

Reinvestment for the period 1980 to 1996 was $9,328 per mile per year. Based on data collected from the agencies, a desirable range for system performance is from 65 to 80 percent. Responses from the agencies indicated that pipe failures, SSOs, customer complaints, and pump station failures were considered the most critical system performance measures. The rate of occurrence of each of these performance items was normalized using a normal distribution curve. A performance rating of 60 percent is equal to the mean value of each performance measure. The data shows that a reinvestment level of between $5,200 per mile per year to $6,500 per mile per year would be required to achieve a performance level of 65 to 80 percent.

15. Prins, Dr. J.G., et al; "Sewer Benchmarking Study Provides Operation and Maintenance Guidelines," Proceedings of WEFTEC '99, 1999

This paper details a sewer system benchmark study in 1998 to establish typical operation and maintenance (O&M) costs to operate, maintain, and monitor collection systems. The intent is to provide data for the evaluation of the performance of collection systems with similar capacity or O&M conditions.

From the data reported for this study, it was clear that no single maintenance activity is predominant to all agencies. The O&M activities are categorized as repairs and maintenance, preventative maintenance (PM), inspections and monitoring, or all three of these activities equally. The following is a breakdown of the most frequently used O&M tasks within each category. The costs are for work done by the agencies' own work crews and are based on 1998 figures:

- Inspections and monitoring: all 24 agencies focus their attention on sewer TV (CCTV) inspections (average cost of $5,490/mile). 80 percent of the agencies undertake manhole inspections (average cost of $35/manhole).
- Preventative maintenance: 95 percent of the agencies undertake hydraulic jetting (average cost of $937/mile). Most of the agencies spent less than 40 percent of their preventative maintenance effort on other PM tasks such as rodding (average cost of $2,319/mile), chemical root control (average cost of $2,612/mile), and manhole repairs (average cost of $703/manhole).

- Repairs and maintenance: about 90 percent of the agencies have crews for attending to blocked mains. Less than 40 percent of the agencies are involved in main replacement (average cost of $2,943/case) or line and manhole rehabilitation (no cost available) programs. Clearing mains blockages had an average cost of $141/case.

The data contained in this paper are primarily for the performance rating of collection system agencies, as viewed against an average for that activity.

16. Jaques, R.S.; "Developing a Spill Prevention Program," Proceedings of WEFTEC '99, 1999

This paper explains how an improved spill prevention program was developed by the Monterey Regional Water Pollution Control Agency (MRWPCA) in northern Monterey County, California, and provides guidelines and a model that other agencies can use in improving spill prevention programs. MRWPCA's spill prevention program was developed using a six-step risk management process. The six steps are as follows:

Step 1 – Risks to be managed are identified. In this instance, "risk" is a threat to achieving the objectives. For MRWPCA, the objectives were to: maximize protection of the health and safety of the public and MRWPCA's workers, regulatory compliance, protection of the environment, public confidence in MRWPCA, and regional economic stability and growth; and minimize operating and maintenance costs.

Step 2 – Potential causes of spills from facilities are identified.

Step 3 – The likelihood and consequences of potential spill scenarios are evaluated.

Step 4 – Options for reducing the likelihood of occurrence for each spill scenario are developed.

Step 5 – Spill reduction options are evaluated using a "value model" to score the performance of each option relative to achieving the operating objectives.

Step 6 – The most cost-effective measures to reduce the risk of spills are prioritized for implementation.

Although this paper details the activities in each of these steps for spill prevention, it does not go into detail about the solutions adopted in Step 4 for the reduction of spills. The paper also does not provide guidance on the cost (or benefit) for different types of sanitary sewer remedial works. There is an example of how this procedure works. MRWPCA has found this process to be an effective tool in analyzing and improving its existing spill prevention program.

17. Gorthey, M.L., et al; " 'Putting The Puzzle Together' The City of Auburn Uses a Multiple Technology Approach to Sewer Overflow Abatement," Proceedings of WEFTEC '99, 1999

This paper presents details of how the City of Auburn, New York, achieved CSO abatement, and SSO and interceptor sewer overflow (ISO) elimination. A unified approach was adopted for cost and practicality reasons. A total of 35 sewer overflows to New York State waters existed (of which 19 were SSOs). The strategy used for the abatement of these overflows and its costs (June 1998 figures) comprised the following:

- Parallel relief interceptors
- Reuse of decommissioned WWTP facilities
- Select sewer replacement
- Centralized storage facilities, near the city's WWTP: $20,447,000
- High rate CSO treatment facilities: $25,727,000
- Interceptor wet-weather flow storage and release facility: $25,493,000.

Construction commenced in 1993 and was completed in 1999. The improvements have resulted in the elimination of 31 out of 35 previous overflows, with four CSOs (each receiving treatment) remaining.

18. Prellop, J.A.; "Implementation of Offline Storage in an Urban Location for Control of Sanitary Sewer Overflows (SSOs)," Proceedings of WEFTEC '99, 1999

The City of Slidell, Louisiana elected to undertake an offline storage facility as a cost effectiveness analysis had shown that considerable capital cost savings over multiple line repairs were possible. The results that have been observed during initial system testing have shown that rain events that historically caused SSOs are now being contained. The main components of the offline storage system were as follows:

- 2.6 million-gallon offline storage tank
- Two wet weather pumps.

The basis of design for the hydraulic component of this system was focused on preventing overflows. This was mainly achieved by ensuring that water was rapidly conveyed from the pump stations to the holding tank. The pump stations were also reconfigured to allow free discharge into the wet wells.

19. Lough, H., et al; "Managing Fats, Oil, and Grease from the Food Service Industry," Proceedings of WEFTEC '99, 1999

Fats, oil, and grease (FOG) accumulate in collection systems and eventually cause blockages that result in sewer backups. The Oregon Association of Clean Water Agencies (ORACWA) produced a Fats, Oil, and Grease Best Management Practices (BMP) manual for the food service industry. The BMP gives guidance on three separate areas for FOG. These are as follows:

- Prevent blockages in the sanitary sewer system
- Properly maintain grease traps and interceptors to prevent introduction into the sanitary sewer system
- Prevent fats, oil, and grease from entering creeks and streams through the storm drain system.

The guidance for preventing blockages in the sanitary sewer system includes the following:

- Train kitchen staff and other employees about how they can help ensure BMPs are implemented.

- Post “No Grease” signs above sinks and on the front of dishwashers.
- Use water temperatures less than 140° F in all sinks, especially the pre-rinse sink before the mechanical dishwasher. The mechanical dishwasher requires a minimum temperature of 160° F, but the Uniform Plumbing Code (UPC) prohibits discharging the dishwasher to grease traps.
- Use a three-sink dishwashing system, which includes sinks for washing, rinsing, and sanitizing in a 50-100 ppm bleach solution. Water temperatures are less than 140° F. (See above)
- Recycle waste cooking oil.
- “Dry wipe” pots, pans, and dishware prior to dishwashing.
- Dispose of food waste by recycling and/or solid waste removal.

While there is a list of “Dos,” there is also a list of “Don’ts.” These are as follows:
- Do not discharge fats, oil, and grease in concentrations that will cause an obstruction to the flow in a sewer, or pass through or interference at a wastewater treatment facility.
- Do not discharge grease, improperly shredded garbage, animal guts or tissues, paunch manure, bones, hide, hair, fleshings, or entrails.
- Do not discharge wastewater with temperatures in excess of 140° F to any grease traps. This includes water from mechanical dishwashers that have a minimum required temperature of 160° F.
- Do not discharge waste from a food waste disposal unit to any grease traps.
- Do not discharge caustics, acids, solvents, or other emulsifying agents.
- Do not discharge fats, wax, grease or oils containing substances that will become viscous between 32° F (0° C) and 150° F (65° C).
- Do not utilize biological agents for grease remediation without permission from the sanitary agency receiving the waste.
- Do not clean equipment outdoors in an area where water can flow to the gutter, storm drain, or street.

20. Keller, J.A., et al; “How Much is that SSO Equalization Facility Going to Cost?” Proceedings of WEFTEC ’00, 2000

SSO equalization facilities are being constructed in many communities as a solution for eliminating or reducing the frequency of sanitary sewer overflows. This paper gives guidance for developing the costs of SSO equalization facilities so that their effectiveness can be properly evaluated during the planning stage. Six examples of equalization facilities are given. They were constructed for the following agencies: Farmington, Michigan; Lawrence, Kansas; Montgomery County Sanitary Engineering Dept., Dayton, Ohio (2 locations); and Tulsa Water and Sewer Dept., Tulsa, Oklahoma (2 locations). The important findings of the cost analyses are as follows:
- General requirements represent 7 to 9 percent (and in one case nearly 13 percent) of the total construction cost
- Pumping costs are highly variable and are between 9 and 27 percent of the total cost
- Cost of the equalization basin alone is 20 to 45 percent of the total cost
- Odor control facilities add 10 to 16 percent to the total
- Site work component is 9 to 27 percent of the total
- Electrical/instrumentation costs range from 7 to 15 percent.

21. Kelly, E., et al; "Standardized Manhole Inspection, Design and Rehabilitation – Delivering Cheaper, Faster, and Better Results," Proceedings of WEFTEC '00, 2000

This paper details the steps taken by the Sewerage and Water Board of New Orleans (S&WB) to develop a standardized inspection process and selection of rehabilitation method for manholes. Manholes can be a significant source of I/I into a system. The standardization of manhole inspection and rehabilitation has greatly reduced design effort and the effort required by S&WB to verify the condition data for each manhole. To ensure consistency in the interpretation of manhole defects, a manhole defect coding manual was developed. Standard manhole inspection forms were also developed. Field inspectors were trained to ensure that the requirements of the coding manual were being met. Software was developed that selects the manholes in need of repair and determines cost-effective methods for their rehabilitation. Examples of manhole inspection forms are given. Two examples of manhole defect codes are given:

- Corbel Condition Deteriorated – multiple cracks; openings in wall are visible but pieces (or brickwork) are still in place.
- Wall Condition Deteriorated (Heavy) – cementitious "shag" coating missing in some areas; multiple cracks, openings in wall are visible but pieces (or brickwork) are still in place; all mortar between bricks exists.

The following rehabilitation methods are currently utilized:

- Full depth lining, partial depth lining
- Install inflow pan
- Elastomeric frame seal
- Adjust manhole to grade
- Reset casting
- Replace casting
- Replace manhole
- Grouting.

22. Hannan, P.M.; "Collection System Practices for the New Age", Proceedings of ASCE Pipeline Conference, Convergence 2000, Kansas City, Kansas 2000

This paper provides information on the design, construction, and maintenance of the collection system. There are data on preventative maintenance of sewers, and rehabilitation. This paper discusses the most effective ways to design, build, and care for collection systems in a manner that will provide consistent, reliable, cost-effective service.

Traditionally, sewer design has concentrated on construction cost. However, the actual cost to the customer can be many times higher than this. "Life cycle" costing evaluates the design, construction, and maintenance expenditures during the service life of the pipeline. Life cycle cost analyses, which include sewer rehabilitation, must also incorporate prediction models for sewer deterioration and quantify other elements of the costing process. Minimum slope sewers illustrate this point. A separate Washington Suburban Sanitary Commission (WSSC) program review found some of these same minimum slope sewers required scheduled preventative maintenance (PM) cleanings beginning less than 10 years after construction. The WSSC review found that minimum slope sewers required 19 percent of all PM activity while comprising only 10 percent of the 6”-10” diameter inventory.

Pipe material selection and construction methodology are critical elements to enable the pipe network to handle the various loads imposed by soil, groundwater, and vehicle traffic and to provide the durability and longevity necessary for 75-100 year service life. A major part of future sewer construction activities will involve trenchless and “less trench” technology. Although the technology is in its relative infancy, the potential is readily apparent and more enhancements are desired. Those refinements most pertinent to sewer collection systems involve elements of microtunneling, efficient drive and reception shafts, and better methods for installing multiple utility lines within the same corridor.

Achieving success through I/I reduction efforts is as much “art” as it is an engineered outcome. Many elements of the sewer survey (flow monitoring, modeling, cost-effective analysis) utilize engineering principles. However, achieving actual flow reductions rely primarily upon those finding the I/I sources, interpreting their significance and effectively rehabilitating the defect. One facet of rehabilitation that needs to be improved is the ability to create a like “new” final line condition in the renovated pipe. Liners are a “mirror” technology. Poor line and grade are reflected in the final condition and appearance.

23. Blakley, D.J., et al; “A Synergistic Approach to Combat I & I with a Concentration on Manhole Rehabilitation,” WEF Specialty Conference Paper, July 2001

McCandless Township Sanitary Authority (Allegheny County, Pennsylvania) has had success in reducing I/I by adopting a combined effort in its resolution. McCandless Township Sanitary Authority (MTSA) has performed in excess of 3,600 dye tests since 1998. On average, 12 to 15 percent of homes in an area fail. A typical driveway drain, once removed, can eliminate 1,500 to 2,000 gallons of water from the system in a one-inch rainfall.

Line joint grouting has been undertaken on 8- to 10-inch diameter lines where they are in well-developed areas and excavation would be a limiting factor. MTSA has found line grouting to be 90 percent effective using “spot” air tests over a seven year period. Manholes have been found to contribute 10 to 20 gallons per minute in terms of I/I. Remedial works (by private contractor) have ranged from $1,800 per manhole up to $3,500. MTSA feels that the cost for manhole rehabilitation is excessive. Also the time to complete the work (ranging from 16 to 24 hours) was prohibitive. MTSA became involved with Sauereisen of Pittsburgh, PA. A “60-minute solution” was developed for the rehabilitation of manholes. MTSA can now rehabilitate three manholes in an eight hour period for about $800 per manhole. The process involves high pressure water washing of the manhole. A rotary nozzle spray is then used to spray-seal the inside of the manhole, without the need for man entry. The sealant can either be a cementitious material (for light I/I) or an epoxy material which forms a protective barrier against hydrogen sulfide attack. A flow monitoring program is used to monitor the system after rehabilitation. MTSA has two personnel solely dedicated to the flow monitoring program. They work closely with MTSA’s engineers to develop reports on each site.

24. **Moisio, S.E., et al; "Changes in Design Standards for Wet Weather Solutions," 2001 A Collections Systems Odyssey: Integrating O&M and Wet Weather Solutions, WEF Specialty Conference Paper, July 2001**

The Metropolitan Sewer District of Greater Cincinnati (MSDGC) has identified ninety SSOs. These SSOs are the result of wet weather and I/I entering the sanitary sewer system. MSDGC has a maintenance program to ensure that SSOs do not result from obstructions or blockages. MSDGC used three programs to eliminate SSOs:

- Maintenance program: MSDGC started a program to CCTV the sewer downstream of every identified SSO. Root intrusion or debris was cleared immediately. Structurally failed pipe was replaced using MSDGC crews on an emergency basis, or put into the annual Capital Improvement Program (CIP). This process eliminated all dry weather discharges of SSOs.
- Rain Dependent Inflow and Infiltration program (RDI/I): Drainage areas tributary to the remaining SSOs were targeted in this program. Sources of direct inflow were identified using smoke and dye testing. Once identified, MSDGC reimbursed the homeowner (up to $3,000) for removal of the connection. 14,800 inflow sources were removed between 1992 and 2001.
- SSO Removal Project: The purpose of this project was to determine the most effective ways to eliminate SSOs. As the maintenance program progressed, it became evident that the remaining SSOs were caused by high I/I exceeding capacity in the sanitary sewer system. Routine monitoring of SSOs found that SSO activity increased dramatically with wet antecedent soil conditions, usually in the spring. Several sewer replacement projects which were approaching the construction phase, were found to be under-designed using the "upsize a few diameters" rule by MSDGC staff upon review. In order to quantify the under-design problem, an intensive flow monitoring project was undertaken.

The basic location requirements for flow monitors for accurate estimation of flow are above points of SSO discharge and on major tributary branches near the confluence with main trunk lines. Additional locations were included for flooding of basements and a groundwater study. The flow survey revealed infiltration rates of about 20,000 gallons per acre per day. This is considerably greater than the 1,000 gallons per acre per day assumed in the original sewer design and in the "upsize a few diameters" rule. A SWMM model was used to route the flows through the sewer system. It was found that pipes which are currently 18-inch diameter, and had been resized to 27-inch diameter (prior to flow survey and hydraulic modeling), were now sized to be 42- to 48-inch diameter. MSDGC now requires that all replacement sanitary sewer designs be based on actual flow monitoring data and computer modeling calculations.

25. **Hilderhoff, S.R., et al; "Sanitary Sewer Rehabilitation by Mini-Basin to Eliminate SSOs in The Paxton Creek Drainage Basin," 2001 A Collections Systems Odyssey: Integrating O&M and Wet Weather Solutions, WEF Specialty Conference Paper, July 2001**

The municipalities of Susquehanna Township and Lower Paxton Township in Harrisburg, Pennsylvania are served by the Paxton Creek Interceptor. This interceptor experiences SSOs during extreme wet weather conditions. These events generally occur twice per year and last for 12 to 72 hours. Both municipalities have adopted a policy of "total sewer rehabilitation by mini-basin" as part of their I/I reduction programs after finding their traditional ongoing SSES and rehabilitation efforts were not successful. This was due to 50 percent of I/I from private laterals and rehabilitation of LPTA's system located in the public right-of-way would yield only about a 20 percent reduction in I/I. Each mini-basin generally comprises 100 to 300 connections.

"Total sewer rehabilitation by mini-basin" means that all sewer system components including mainline, manholes, service laterals, and building sewers in a mini-basin are repaired so that they meet the same acceptance testing standards as new sewers. House inspections to identify and remove suspect inflow sources are also performed at every property in the mini-basin. System components are investigated and repaired during dry weather conditions. Wet weather conditions are used to assess I/I removal and verify repairs. The major issues that rehabilitation programs need to consider are as follows:

- Groundwater migration
- Infiltration and inflow in private sources
- Limited time available to locate and observe I/I sources during a wet weather event.

A pilot study was initiated to determine the potential benefits from the program. The area comprised 113 connections of four and six inch diameter service laterals, 28 four foot diameter precast manholes, and 6,500 linear feet of eight inch diameter mainline. In January 1998, three flow meters were installed. Two contracts to rehabilitate the system were issued. One contract was to repair manholes and mainline via no-dig technology. The other contract was for repairing known leaking laterals and resetting all manhole frames in the mini-basin. The rehabilitated manholes had to pass a vacuum test. Urethane grout and brushed on mortar were used for the rehabilitation of manholes. Post project appraisal in 2001 showed that this had not performed well. All mainline joints were air tested and several cured-in-place sectional liners about three feet in length were installed over defects. Air testing was at five psi for at least three minutes with no pressure drop allowed.

The cost of various rehabilitation items is as follows:

- Installation of observation tee: $900 - $1,200 each item
- Air test of service lateral: $385 - $500 each item
- Air test of building sewer: $100 - 150 each item
- Lining of service lateral: $18 - $22 per linear foot
- Replacement of service lateral: $1,200 - $2,300 each item
- Replacement of building sewer: $1,500 - $3,600 each item
- Excavate and replace mainline: $75 - $90 per linear foot
- Excavate and replace both leveling rings and frames/covers: $1,000 each item.

26. Jewell, C.; "A Systematic Methodology for the Identification and Remediation of Illegal Connections," 2001 A Collections Systems Odyssey: Integrating O&M and Wet Weather Solutions, WEF Specialty Conference Paper, July 2001

The Boston Water and Sewer Commission (BWSC) adopted an Illegal Sanitary Connection Remediation Program under which BWSC would correct an illegal connection to its storm drain system, as long as it was not the owner of the property who originally made the connection. The area selected for investigation (Stony Brook system) covered 6,000 acres and had a population of 71,700. Storm water from this area discharges to the Charles River. There are roughly 140 miles of storm drain, 145 miles of sanitary sewers, 4,250 storm drain manholes, 4,450 sewer manholes, and 225 common manholes. The majority of the system in the separated part of the system was built in the early 1900s.

BWSC wanted to develop a cost effective, systematic, and quick method for identifying and correcting illegal connections. BWSC engaged Earth Tech, Inc. (ETI) in July 1998 to assist them in the investigations. The investigations started upstream and proceeded downstream to the point where the pipes were being affected by overflows from combined sewers. Crews would then trace the system downstream to a juncture manhole (a manhole where flow from two or more storm drains enters). The inspections were conducted during dry weather so that wet weather flow does not cover up possible contamination. The field crews would begin their inspections after 48 hours of dry weather and would then visually inspect manholes for evidence of pollution. If the manhole is found to have dry weather flow and evidence of contamination, an upstream section of drain is isolated for dye testing of buildings. Otherwise, inspections continue in the upstream storm drain manholes on the drains entering the juncture manhole. If there is still no evidence of contamination, a sandbag is placed in the juncture manhole for 48 hours because illegal connections discharge wastewater intermittently. If the sandbag captured flow is clear, it is tested with a field test kit to find traces of surfactants and ammonia. Probes are also used to measure pH, temperature and specific conductivity. If the flow is not contaminated or no flow is captured, the investigation continues to the next downstream juncture manhole.

A multi-year contract is in place for a contractor to be available to fix illegal connections as soon as they are identified by the field crews. A sandbag test confirms that contamination has been eliminated.

Since March 31, 2001, a total of 1,419 manholes have been inspected. Of these, 483 have had evidence of pollution. 232 of these manholes have been found by surface inspection, 232 by field test kits, and 24 have been found by using sandbagging. Thus far, 171 illegal building connections have been identified. 88 have been corrected so far. BWSC estimates that these 88 corrected illegal connections have eliminated 35,314 gallons per day of sewage from the storm drain system (based on metered water usage for each building).

Prior to this project, it often took over one year to correct an illegal connection. As of March 31, 2001, BWSC is averaging 64 days to correct an illegal connection (measured from date of dye test confirmation to date of correction). About 31 percent of buildings in the area have required a dye test, and about three percent of the total number of buildings in the area have been found to have an illegal connection.

27. Crowley, J.P., et al; "Collection System Equalization Preserves Downstream Capacity," 2001 A Collections Systems Odyssey: Integrating O&M and Wet Weather Solutions, WEF Specialty Conference Paper, July 2001

Charlotte-Mecklenburg Utilities (CMU) has provided storage for peak flows in the upstream parts of its system in North Carolina. This means that downstream capacity is still available for existing downstream peak flows. This has avoided the necessity to undertake system-wide expansion schemes. It has also stabilized flows at the treatment plants and reduced the risk of sanitary sewer overflows.

Long Creek Basin (about 23,500 acres in area) and Catawba River Basin (about 2,800 acres in area) are the two basins involved. Flows from Catawba River Basin are pumped to Long Creek Basin, which are then pumped to Paw Creek Basin. Paw Creek Pumping Station discharges into the Coffee Creek Interceptor, which carries flows to the McAlpine WMF. Long Creek is planned to have a new pumping station, and future flow impact analyses showed that Paw Creek Pumping Station and nearly the entire Coffee Creek collection system would be overloaded when the new pumping station is placed into service. There were two options:

- Increase downstream collection system capacity
- Divert wastewater from Long Creek and Paw Creek Pumping stations to an alternative treatment or storage lagoon.

The SWMM Runoff module was used with 26 years of historic rainfall data to predict hourly I/I flows to calculate hourly storage volume data. The new Long Creek Pumping Station is to be increased from 10 mgd to 15 mgd capacity. The storage model was used to simulate Paw Creek Pump Station at 10 mgd and 15 mgd capacities. Results showed that increasing Paw Creek Pump Station to 15 mgd reduced storage requirements at Long Creek by 2.5 to 3.0 million gallons.

The analyses for this project showed that a 2025 volume of six million gallons will be required if Paw Creek Pump Station is upgraded, 10 million gallons if it is not upgraded. This will meet both short-term and long-term needs, and will contain all two-year storage events for the high-growth scenario through 2015.

28. El-Hosseiny, T., et al; "Sewershed Approach to Optimize Sewer System Operation," 2001 A Collections Systems Odyssey: Integrating O&M and Wet Weather Solutions, WEF Specialty Conference Paper, July 2001

The City of Columbus, Ohio, Division of Sewerage and Drainage (DOSD) is to construct a sanitary trunk sewer in the vicinity of the Jackson Pike WWTP to replace an existing segment of the Scioto Main Sanitary Trunk Sewer. The Scioto Main Trunk Sewer Replacement (SMTSR) will eliminate all overflow structures at the Renick Run area as part of the West Columbus Local Protection Project (WCLPP.)

The sewershed approach was used to satisfy the following objectives:

- Provide primary and secondary treatment for combined and separate tributary flow due to dry weather flow and wet weather flow up to the six month storm
- Provide primary and secondary treatment at Jackson Pike WWTP for separate flow up to the 25-year storm
- Provide primary treatment at Whittier Street Storm Tanks for combined flow due to the one year storm frequency and above
- Maximize bypass flow from Jackson Pike WWTP to Southerly WWTP through the flow control structure to avoid backup in the Scioto Main Replacement Sewer
- Maximize in-line storage in the 156-inch Interconnector Sanitary Trunk Sewer
- Maximize pumping rates at the Interconnector Pump Station to its limit

- Regulate tributary flow from Scioto Main Trunk Sewer using the Hydrovex regulator to 60 mgd
- Provide in-line storage upstream of the Hydrovex regulator to a maximum elevation of 720 feet to avoid overflow at Rhodes Park overflow.

The construction of SMTSR will eliminate the following permitted overflows:

- West Side Sewer Regulator to Renick Run
- Raders Well Regulator to Renick Run
- Scioto Main Trunk Sewer Regulator to Renick Run.

SWMM model results for wet weather flow predicted overflows at the Rhodes Park overflow structure during a 5-year storm and above. Tributary flow to each trunk sewer was optimized using flow control devices in the collection system. Also, the following constraints were added to the model:

- No overflow at Rhodes Park overflow structure up to 25-year storm
- Maximum pumping rate at Jackson Pike WWTP headworks not to exceed 175 mgd
- Water surface elevation (hydraulic grade line) at any sewer should not exceed basement elevation
- Maximum pump rate at the Interconnector Pump Station (IPS) not to be higher than 100 mgd
- The Hydrovex regulator located at Rhodes Park to allow a maximum of 60 mgd.

The hydraulic model results indicate the following:

- The Jackson Pike WWTP will receive an average DWF of 88 mgd with a maximum of 110 mgd and a minimum of 64 mgd. Currently, normal operation of the Jackson Pike headworks provides a pump capacity of 80 to 85 mgd with 6 to 7 feet of water in the wet well.
- The current capacity of the Jackson Pike headworks can transport tributary DWF without potential overflow from any location in the study area (based on the ratio of maximum flow to sewer full capacities).
- SMTSR capacity is adequate to transport tributary flow. The SMTSR is modeled as a 120-inch diameter sewer with a 0.04 percent slope and a capacity of 213 mgd. The estimated peak flow ranges between 62 and 107 mgd. Due to backup effects at Jackson Pike WWTP, SMTSR can be used for in-line storage and the water depth may reach the full diameter of the trunk sewer due to velocities being lower than the design velocity.

29. Yingling, B.; "Experience Gained from Watershed Studies in Cleveland, Ohio," 2001 A Collections Systems Odyssey: Integrating O&M and Wet Weather Solutions, WEF Specialty Conference Paper, July 2001

The Mill Creek Watershed Study took place from 1995 to 1998. The watershed is about 17,000 acres in size. The Doan Brook Watershed Study was started in early 1998. This watershed is about 8,000 acres in size. The Northeast Ohio Regional Sewer District's (NORSD) watershed studies evaluated channel erosion and flooding, water quality, sewer systems, and aquatic life and habitat. Because the watershed study recommendations go beyond the jurisdiction of NORSD particularly in areas of stormwater, floodplain, and biotic community management, NORSD emphasizes the need to involve stakeholders throughout the process.

Significant findings of the watershed studies are as follows:

- Urban streams are highly impacted by increased imperviousness and lack of habitat.
- Man-made lakes have severe algae blooms caused by high phosphorous levels in urban stormwater runoff. The presence of algae reduces the available dissolved oxygen (DO) within the lakes. The low DO levels make it difficult for other aquatic life forms to flourish.
- Both combined and separate sewers are significant source of bacteria, largely due to the pipes being laid in a common trench. This facilitates contamination by infiltration/exfiltration between sewers.

The paper also lists the benefits and problem areas associated with the watershed approach. The problem areas are as follows:

- It can be difficult to define a watershed, especially in urban areas, where streams have been culverted over the past 50 to 100 years.
- There is often little public interest in watersheds.
- A watershed plan requires the cooperation of many organizations and individuals such as neighbors, residents, community officials, and the EPA.
- Understanding and dealing with all the issues that affect a watershed is a complex task. The Doan Brook is a small watershed, but in order to deal with the issues arising from the study, it was split into seven sub-watersheds.
- Watershed studies are expensive. In order for the study to be effective and worthwhile, a large amount of data collection and computer modeling is necessary. The costs for the two NORSD studies averaged about $500 per acre.
- The study recommendations may be expensive.

The benefits of a watershed study are as follows:

- Understanding the entire watershed leads to more realistic expectations for remediation measures. NORSD can document that controlling CSOs and SSOs alone will not eliminate wet-weather bacteria violations.
- A watershed approach helps to ensure that money is not spent on ineffective facilities and strategies.
- A complete and thorough watershed plan allows decision-makers and the general public to fully understand the interaction of various aspects of a watershed.
- Understanding a watershed leads to more creative and effective solutions. Renovation of a neglected stormwater retention basin in Mill Creek and reinstatement as a wetland can be beneficial for stream flooding and aquatic organisms.

30. Walch, M.P., et al; "Combining New Technologies with Computer Modeling to Prevent Sanitary Sewer Overflows Resulting from Urban Rainfall Induced Peak Flow Conditions: The Miami-Dade Water and Sewer Department Experience," Preparing for the 21st Century (Proceedings of the 26th Annual Water Resources Planning and Management Conference held in Tempe, Arizona, June, 1999)

Miami-Dade Water and Sewer Department (MDWASD) negotiated a settlement with the United States Environmental Protection Agency (EPA) which required the following:

- Collection and Transmission System Model
- Long-Term Adequate Transmission Capacity/Pump Station Upgrade
- Long-Term Collection System Operation Plan.

MDWASD requested that Post, Buckley, Schuh & Jernigan, Inc. (PBSJ) complete a wastewater conveyance system analysis which would satisfy the requirements of the Consent Decree. The Miami-Dade system is complex. Due to flat terrain, Miami-Dade employs a combination of gravity collection systems with manifolded pump stations - creating a pressurized system in which one pump station impacts many others tied to the same pressure pipeline. This situation required the selection of a computer model which simulated both gravity and forcemain systems simultaneously. The model selected was SWMM. Modifications and customizations have been made to the software to accommodate the specific demands of a large complex system. The model consists of over 4 gigabytes of data. It has over 9,000 nodes and almost 330,000 individual data entries, requiring the input of 6 people over two years of development. The model takes about 12 hours to run for a 48 hour simulation on a Pentium II PC.

The "Virtual Dynamic Computer Model" was created using a combination of technologies, such as: Geographic Information Systems (GIS - ArcInfo); Global Positioning Systems (GPS); Supervisory Control and Data Acquisition (SCADA) data; Oracle and MS Access Databases, WSI's NEXRAD Weather for Windows and Virtual Rain Gauge (VRG). These technologies are also used to continually update the model database with current data. MDWASD is currently planning to integrate these technologies using Internet and Intranet applications to facilitate information sharing between consultants, County Departments, and other data sources and users.

The model has been used to eliminate over $20,000,000 in construction projects found to be either unnecessary or unneeded at this time. Additionally, the model has the ability to predict the likelihood, location, and quantity of sanitary sewer overflows resulting from peak storm or flooding conditions. The County now has a means to prevent sanitary sewer overflows into receiving streams, rivers, canals, Bays, and surrounding neighborhoods. The model has the ability to identify the manhole or manholes which would overflow as a result of unusual flows caused by line blockages, increased Infiltration/Inflow or excessive flows caused by severe storm/rainfall events, thus allowing corrective action to be taken before these events occur.

31. Nelson, R.E.; Agbodo, M.N.; Neumann, K.; Parsons, L.G.; and Aillet, J.R.; "Optimization of a Junction Box Results in Significant Cost Savings," WEF Collection Systems Rehabilitation and O&M Specialty Conference held in Salt Lake City, Utah, 1999

In the City of San Antonio, Texas, a junction box was splitting flows such that two of the three sewer lines leaving the junction box were underutilized. The third exit pipe from the junction box was overloaded and was experiencing several overflows. A weir within the junction box diverted flows to the three outlet pipes in differing proportions. HydroWorks was used to calculate the flow diversion to each outlet pipe.

The flow split was optimized through an iterative process of raising the weir level. It was found that if the weir crest level was raised by one foot, none of the three junction box outlet sewers would be overloaded. Therefore it was not necessary to construct a relief sewer for the overloaded sewer section. This eliminated the need for an $8 million Capital Improvement Project (CIP).

32. Forbes, J.H., et al; "46 percent Reduction in Wet Weather Inflow is Achievable," WEF Collection Systems Rehabilitation and O&M Specialty Conference held in Salt Lake City, Utah, 1999

In 1994, the City of Wichita Falls, Texas, undertook a Sanitary Sewer Evaluation Survey (SSES) on 2.6 million feet of sewer to identify wet weather inflow and system capacity problems causing SSOs. In 1996, the City's Sanitary Sewer Improvement project rehabilitated 13 out of 42 sub-basins. This included the following items:

- Pipe bursting: 28,579 linear feet (lf) of 6"-18" diameter sewers
- Cured-in-place lining: 20,635 lf of 8"-21" diameter sewers
- Manhole rehabilitation: 514 manholes, 3,200 vertical feet (vf) of lining, 37 frame re-alignments, and 13 cover and frame replacements.

This rehabilitation work cost $2.0 million. Post-project flow monitoring showed a decrease in average inflow of 48 percent and a decrease in average peak hour flow rate of 46 percent.

In 1998, the City rehabilitated 18 sub-basins, as follows:

- Pipe bursting: 34,052 lf of 6"-18" diameter sewers
- Cured-in-place lining: 7,925 lf of 8"-21" diameter sewers
- Manhole rehabilitation: 1,800 vf of lining.

The total cost of this work was $2.2 million, with a net inflow reduction of about 52 percent.

The City has realized that replacing all aging infrastructure is not a viable option. Also, I/I reduction programs alone do not normally address structural deficiencies that contribute to reduced hydraulic capacity in sewers. SSOs may be caused by excessive I/I, hydraulic restrictions, or both.

The City's Sanitary Sewer Improvement project was successful because of the following tasks which were undertaken:

- Comprehensive flow monitoring: good hydraulic information is the basis of all successful projects
- Field testing: documentation of field observations is critical to recommending appropriate repairs
- Dynamic hydraulic modeling: a calibrated computer model will simulate current conditions and evaluate sewer improvements before any capital expenditure is incurred
- Cost-effectiveness: structural defects were addressed with as high a priority as infiltration/inflow defects
- Recognizing that the job is just starting: periodic retesting is required to ensure the integrity of the sewer system once it has been rehabilitated.

33. Alvarez, S., et al; "Geographic Information Systems (GIS): An Effective Management Tool for the Assessment of the Oil and Grease Problems in the City of Los Angeles Wastewater Collection System," WEF Collection Systems Rehabilitation and O&M Specialty Conference held in Salt Lake City, Utah, 1999

The City of Los Angeles uses GIS to assess and understand the extent of oil and grease (O&G) problems in their wastewater collection system.

The goal of optimization of inspection and preventative maintenance is to minimize or eliminate mainline stoppages and sanitary sewer overflows (SSOs). O&G buildup in the sewer system reduces sewer capacity. Grease buildup is one of the major causes of sewer blockages and overflows in most collection systems and accounts for an average of 500 mainline stoppages and 35 SSOs per year in the City. This is half of all their annual stoppages and SSOs.

The Labor-Management Joint Action Team (JAT) collected and assessed relevant system performance and maintenance history data using GIS. Analysis of two years of data showed a total of 1,002 stoppages causing 77 spills. 72 percent of the spills were classified as being severe. The remaining 28 percent were classified as light or medium, caused by O&G, debris, and roots. GIS maps showed that restaurants and businesses that did not require an industrial waste permit were responsible for 75- to 95 percent of grease stoppages.

34. Wang, J.W., et al; "Hydraulic Modeling: An Essential Tool for the Elimination of Sanitary Sewer Overflows. A Case Study," WEF Collection Systems Rehabilitation and O&M Specialty Conference held in Salt Lake City, Utah, 1999

The City of Los Angeles is faced with the challenge of minimizing expenditure while maximizing existing system efficiency. This was achieved through the use of MOUSE, a hydraulic modeling program developed by the Danish Hydraulic Institute (DHI).

The City had a number of wet weather sanitary sewer overflows mainly in the Eagle Rock area. These SSOs were estimated at 26 million gallons. Intense and lengthy basin-wide storms combined with supersaturated ground and excessively high groundwater tables caused these SSOs. Hydraulic modeling of the area was undertaken in order to understand the source and extent of the problem and the improvements required. The cause of the overflows was the inability of the Eagle Rock Boulevard sewer to convey its tributary flow. This caused the flow to backup into the local sewers which, in turn, caused the overflows. The hydraulic modeling analysis showed that the problem was not caused by lack of capacity in the tributary sewers. A 36-inch relief sewer was proposed to alleviate the capacity problem in the Eagle Rock Boulevard sewer. A new 12-inch sewer was also proposed to distribute the upstream system flow. Post-construction monitoring results showed a close correlation with the predicted hydraulic model results. The hydraulic model has also been used to analyze system modifications to prevent costly mistakes.

35. Kalkman, T., et al; "Strategic Sewer Rehabilitation," WEF Collection Systems Rehabilitation and O&M Specialty Conference held in Salt Lake City, Utah, 1999

The West Valley Sanitation District of Santa Clara County (District) serves the cities of Campbell, Los Gatos, Monte Sereno, and Saratoga, California.

In 1995, the District implemented a sewer system study of 300 acres in the center of Los Gatos. This area comprises 38,000 linear feet of sewers. The average age of the sewers is 60-70 years. The District undertook the following steps as part of the sewer study:

- Field investigations and data collection
- Smoke testing
- Manhole inspections
- Installation of flow meters
- CCTV inspections
- CADD mapping of the sewer system.

Review of this data showed that the system is reaching the end of its useful life. The majority of pipes have cracks, sags, offsets, and root intrusion problems. The defects and their repair/rehabilitation were prioritized according to District criteria. The rehabilitation methods used were pipe lining, pipe bursting, and open-trench replacement. Two-thirds of the District's rehabilitation program has involved pipe bursting as it is half of the cost of open-trench replacement. Prioritization is achieved as follows:

- Priority 1: undersized pipes and structural pipe failures
- Priority 2: sewers with cracks and root intrusion, although structurally adequate
- Priority 3: sewers with problems which are not likely to adversely affect flow, such as light root intrusion.

The Los Gatos sewer rehabilitation project is estimated to cost $4.5 million. The District views trenchless construction as a major benefit. Pipe bursting has been costing $40 per linear foot for 8-inch diameter pipes. Open-cut construction costs $80 per linear foot for eight inch diameter pipes.

36. Carabantes, J.M., et al; "Wastewater Collection System Construction Related Spill Prevention and Emergency Response Requirements," WEF Collection Systems Rehabilitation and O&M Specialty Conference held in Salt Lake City, Utah, 1999

The sewer system of the City of Los Angeles comprises 6,500 miles of sewers ranging in size from 6- to 150-inch diameter. There are also 48 pump stations and the system serves more than 3.5 million people. The average age of the system is almost 50 years. The City has spent over $800 million over the past ten years and plans to spend another $1.4 billion over the next decade.

In 1997, two major sewage spills were caused by contractors working for the City. The spills were a total of 150,000 gallons. Consequently, the City incorporated a minimum level of spill prevention and emergency response measures into its construction specifications. This has increased the total construction cost of projects by an average of two percent. The contract puts the onus of responsibility for preventing sewage spills on the contractor. The contractor is responsible for any fines, penalties, claims, and liability arising from sewage spills. The construction specifications also require the contractor to maintain additional Pollution Liability insurance.

To date, these requirements have been very effective in preventing major and avoidable sewer spills due to construction work.

37. McGregor, J.D., et al; "Eliminating Rainfall Induced Infiltration/Inflow," WEF Collection Systems Rehabilitation and O&M Specialty Conference held in Salt Lake City, Utah, 1999

The Warren Township Sewerage Authority (WTSA) in Warren Township, New Jersey, had hydraulic overloading at its Stage I-II WWTP and pumping stations in the tributary sewer system. There were occasional SSOs at two pumping stations and periodic overloading was limiting further development.

A 'Find-it, Fix-it' Sewer Rehabilitation Program was started to eliminate rainfall induced infiltration/inflow (RII/I) sources. Investigations showed that the 111,000 linear feet of sewers and manholes had very few structural defects or leaking joints. Service connection defects and a few illegal connections contributed 38 percent of the identified sources. 30 of the basin's 500 homes were identified as RII/I sources. Investigations of 33,000 linear feet (29 percent) of the sewer system identified sources totaling about 827,000 GPD. WTSA implemented a rehabilitation program for connections with RII/I from 1,500 to 95,000 GPD. The work items were as follows:

- Clean 1,275 linear feet (lf) of 8- and 10-inch diameter sewers
- Air-test 79 joints/shears
- Grout 9 joints/shears
- Chemical grouting of 19 manholes
- Coating of 57 vertical feet (vf) of manhole walls
- 15 spot excavation pipe repairs
- Reset 7 manhole frames.

In one instance, very high hydrostatic pressure caused a chemical seal to fail.

38. Dorman, W.A., et al; "Force Main Sliplining Minimizes Downtime and Costs in the U.S. Virgin Islands," WEF Collection Systems Rehabilitation and O&M Specialty Conference held in Salt Lake City, Utah, 1999

The Addelita Cancyn (main) Wastewater Pumping Station is the largest on the island of St. Thomas, U.S. Virgin Islands. The pump station has an average daily flow of 2.2 MGD. Wastewater is taken from the Charlotte Amalie harbor to the crest of Chinaman Hill via a 24" diameter 3,560 feet long ductile iron force main. From Chinaman Hill, the force main discharges to a 30" diameter ductile iron gravity sewer to the Airport Lagoon Wastewater Treatment Plant (WWTP). Hydrogen sulfide corrosion had damaged a concrete junction chamber at the crest of Chinaman Hill. 100 feet of sewer upstream, and 60 feet of sewer downstream of the junction chamber were also collapsing.

It was noticed that overflows sometimes occurred at the top of Chinaman Hill, when the pump station was operating with more than one pump. The overflows were caused by corrosion of the sewer lines and hydraulic inefficiencies in the junction chamber. A solution was required which could be implemented within an 8-hour period. This was so that the pump station would not overflow.

HDPE sliplining and gravity pipe enabled a rapid, cost-effective solution.

39. Arhontes, N.; “BMPs for Minimizing SSOs and their Impacts,” WEF Collection Systems Rehabilitation and O&M Specialty Conference held in Salt Lake City, Utah, 1999

Orange County Sanitation District (OCSD) in California serves a population of 2.2 million in an area of 471 square miles. There is a 475 mile long regional interceptor sewer and two regional treatment plants with a combined capacity of 295 MGD. Dry weather flows are about 249 MGD. OCSD also has local 8-inch diameter sewers totaling about 150 miles in length. Almost all of OCSD’s SSOs occur in this local network.

OCSD’s experience is that SSOs are caused by grease, roots, and other types of debris. Almost all SSOs occur in 8-inch diameter and smaller pipes. Dry weather SSOs are normally less than 1,000 gallons and there are about 10 spills per year on average. The elements of a good SSO response plan are as follows:

- Name/address/phone/fax number of local and state regulators for notification purposes
- Checklist for issuing mandatory notifications
- Standardized form and calculation method for reporting SSO incidents
- Agency organization chart and duties of personnel
- Planned site activities from initial response, containment through to cleanup, plus resources required
- List of emergency contractors and suppliers with phone numbers
- Staff training
- Update the response plan and equipment requirements with lessons learned
- Method for providing accurate information to the media
- Mutual aid agreements with neighboring agencies.

The response plan can be summarized into ‘the 5 Cs’: contact, contain, control, clean up, and calculate. The tasks involved in a typical SSO response are as follows:

1. An SSO is reported, usually by the public.
2. The report is routed to a Dispatch Center. As much detail as possible is obtained, using a standardized report form. A crew is routed to the SSO location.
3. A member of the Collection Facilities O&M staff reports an estimate of the spill volume or flow rate to the Dispatch Center.
4. The overflow is contained using a neoprene sheet to cover the catch basin inlet. The sheets are 4-feet wide and cut to 6- to 8-feet lengths.
5. The stoppage causing the overflow is relieved using a combination cleaning truck, hydroflusher, or rodder. The Dispatch Center logs the time that the SSO stopped.
6. Spill liquids are vacuumed up and returned to the downstream sewer. The street is also washed down. No chemicals are used during cleaning.
7. The containment sheeting is removed and cleaned for reuse.
8. A field report is completed, including photographs and relevant times.
9. The spill volume is calculated.
10. The OCSD Compliance Officer prepares a final report and submits it to the Regional Water Quality Control Board and other relevant agencies.
11. If needed, staff are debriefed on lessons learned.

OCSD encourages a proactive relationship with Regional Regulators.

40. Sukenik, W.H., et al; "A Recipe for Preparing an Effective Sewer Overflow Response Plan," WEF Collection Systems Rehabilitation and O&M Specialty Conference held in Salt Lake City, Utah, 1999

The objectives of a sewer overflow response plan (SORP) are as follows:

- Protect public health and safety
- Protect the environment
- Protect public and private property
- Contribute to the avoidance of regulatory violations
- Minimize liability of the municipality.

The SORP should document the actions to be taken when an overflow report is received; dispatching of crews; containment; correction; cleanup; and reporting.

Overflow containment measures include blocking or bagging of storm drains, recovering overflow spills with a vacuum truck, or diverting the spill into a downstream manhole.

41. Kathula, V.S., et al; "Integrating Sewer Condition With Sewer Management," No Dig 1999 Conference, NASTT, Orlando, Florida, May 1999

Most sewer repair and rehabilitation projects have been performed in response to sewer collapse, overflow, corrosion, or other operational problems.

There is no widely accepted protocol for assessing and classifying sewer structural condition. This is a barrier to agencies being able to share sewer condition data and rehabilitation techniques. There is no nationally accepted sewer condition rating system or index scheme available. The proposed Sanitary Sewer Management System (SSMS) will provide the following:

- A sewer condition index that can be used to classify the structural condition of a sewer
- A sewer prediction model that does not require expertise in data analysis.

A state-of-practice survey of over 450 cities and sanitation districts produced the following results:

- Average age of sewers is 43 years
- Maximum average age of sewers is 90 years
- 58 percent of cities have sewer systems with an average age of 65 years or more.

The following are the steps required in the implementation of a successful SSMS:

- Establishment of a sewer network database. 85 percent of cities have a paper inventory, 27 percent have a computer inventory, and 44 percent are moving toward a Geographical Information System (GIS) based inventory
- Visual inspection of sewer segments and assigning condition ratings:
  - photographs showing typical structural sewer conditions
  - sewer pipes can be compared to these photos to obtain a condition rating

- 95 percent of the public sewerage network is non-man entry due to small diameters. CCTV is the most cost-effective method for viewing sewer pipe condition.

- Definition of 'critical' sewer segments that will provide optimum use of current resources.

SSMS includes a model to predict the future condition of sewers, called the Structural Condition Matrix (SCM). Various experts were asked to assess the percentage of sewers that would deteriorate from one condition to a worse condition over a period of five years.

Therefore, the SCM model is entirely subjective, being based on opinion alone. There are no data to substantiate any of the findings.

42. Tingberg, F., et al; "Sewage Force Main Rehabilitation Using Cured-in-Place Pipe Technology," No Dig 1999 Conference, NASTT, Orlando, Florida, May 1999

The City of Boca Raton, Florida rehabilitated two force mains. The 14,000 linear feet pipe run was failing in many areas due to sulfide attack at the pipe crown. A cured-in-place (CIPP) pipe method was selected for rehabilitating this force main.

The contract was awarded for this work at $985,000. The estimate for doing this work using traditional open cut methods was $2,000,000.

The 6,000 linear foot cast iron pipe run was corroding and causing the City to spend about $30,000 per month in random open cut emergency repairs. CIPP was used to rehabilitate this sewer line. The cost of the contract was $480,000.

The liner segments used ranged in length from 200 linear feet to 1,800 linear feet. Six projects totaling over 30,000 linear feet have been undertaken so far.

43. Barsoom, J., et al, "Cost-effective Analysis of Denver's Sewer Sealing Program," No Dig 1999 Conference, NASTT, Orlando, Florida, May 1999

Wastewater generated within the Denver metropolitan area is treated by Metro Wastewater Reclamation District (District) prior to discharge to the South Platte River. The City and County of Denver accounts for nearly half of the 150 MGD wastewater flow treated. Denver Citys Wastewater Management Division (WMD) is responsible for the operation and maintenance of over 1,500 miles of sanitary sewers.

Most of the I/I in Denver's system is considered to be from infiltration. Therefore the City has a sewer inspection and joint sealing program. Sealing involves the injection of chemical grout into the voids of a defective pipe joint or crack to seal the area and prevent infiltration from entering the sewer.

WMD has six CCTV units which inspect 1,320,000 feet of sewer annually. The grout used is an acrylic resin chemical grout made by Avanti International (AV-118) which is safer to use than the previous AV-100 grout. However, cost has increased by $2.00 to $5.00 per mixed gallon for the new grout.

To measure the reduction in I/I achieved by the sealing program, WMD chose four test reaches for pre-and post-sealing flow monitoring. Groundwater infiltration (GWI) is defined as the minimum flow in the sewer. Changes in peak flows are defined as being attributable to changes in rainfall-dependant infiltration (RDI).

The results of the flow monitoring program are as follows:

- Test reach 1
  - 100 percent of 1,750 feet of sewers were tested
  - 65 percent of 871 joints were sealed
  - There was a 5,000 GPD reduction in GWI and 32,000 GPD reduction in RDI.
- Test reach 2
  - 31 percent of 2,770 feet of sewers were tested
  - 75 percent of 424 joints were sealed
  - There was no decrease in GWI or RDI recorded. Post-sealing flows actually increased. This may have been because a three foot section of broken pipe was not repaired during sealing operations, and infiltration moving to a part of the system that had not been tested and sealed.
- Test reach 3
  - 71 percent of 1,200 feet of sewers were tested
  - 40 percent of 398 joints were sealed
  - There was an increase in GWI if 2,800 GPD, and a decrease of RDI of 1,200 GPD.
- Test reach 4
  - 36 percent if 1,490 feet of sewers were tested
  - 68 percent of 176 joints were sealed
  - There was a 900 GPD reduction in GWI, and a 2,300 GPD reduction in RDI.

CCTV casts averaged $1.07 per foot and joint sealing costs were $11.96 per joint.

Cost of conveying wastewater flows were $19,526,739. The cost of treating 21,531 million gallons was $7,631,837. This equates to a cost of $1,261 per million gallons to convey and treat I/I. The above costs are 1994 figures.

Present-worth analysis was used to compare costs assuming an eight percent interest rate and 14 percent inflation. This analysis shows savings in conveyance and treatment costs of $5,233 per million gallons if the sealing operations last for 10 years.

44. Gunn, D.; "Spot Repair Assessment Project: Research into the External Load Characteristics of Cured-in-Place-Pipe Spot Repairs," No Dig 1999 Conference, NASTT, Orlando, Florida, May 1999

The Regional Municipality of Hamilton-Wentworth has evaluated the structural capabilities of cured-in-place pipe (CIPP) spot repair systems by asking contractors to install a sample of their spot repair systems in a section of existing clay sewer. Each firm was paid a lump sum toward the cost of the installations. These costs totaled about $7,500. The final cost of the research will be less than $25,000.

Each firm provided the following:

- A minimum two meter long spot repair installed in an existing 300 mm diameter clay sewer pipe
- Documents relating to product installation processes, specifications, and work references
- Design calculations for the spot repair installation, and design thickness of liner to be used.

The spot repairs were tested according to ASTM D 2412-93 "Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading."

The external loading capabilities of CIPP spot repair were found to be well within the accepted values for PVC pipe.

45. Gelinas, M., et al; "Trenchless Repair of Large Diameter Sewers: A Case Study in Decision Making and Design," No Dig 1999 conference, NASTT, Orlando, Florida, May 1999

This paper covers the following areas:

- Inspection and evaluation of defects
- Selection of a repair system
- Design of a repair system.

Inspection technologies for large diameter sewers include closed circuit television (CCTV), sonar, and man-entry inspection. CCTV is normally the least expensive. However, the aspect ratio of captured images can make wide cracks appear insignificant.

Sonar units use acoustic waves to scan the circumference of a pipe while under surcharge conditions. Combination CCTV/sonar units are available for partial flow conditions.

The applicability of repair systems depends on factors which include the following:

- The degree and type of damage in the pipe
- The shape and construction of the pipe
- The environment within the pipe
- Soil and water table condition around the pipe
- The depth of the pipe.

Repair and replacement options include the following:

- Cut and cover replacement
- Glass reinforced plastic lining
- Spiral wound polyvinyl chloride (PVC) lining
- Cured-in-place pipe (CIPP)
- Gunite lining.

Where corrosive attack is evident the Water Research Center (WRC) Sewerage Rehabilitation Manual (SRM) suggests repair using GRP, CIPP, or PVC. SRM has been researched for over six years and is considered one of the standard references for sewer and culvert repair.

46. Aguiar, L., et al; "When Routine Sewer Line Maintenance is Not So Routine: The Little River Crossing Project," No Dig 1999 Conferences NASTT, Orlando, Florida, May 1999

An 18-inch diameter cast iron gravity sanitary sewer line passing under the Little River Canal on the north side of the City of Miami, Florida, required rehabilitation. The sewer was heavily tuberculated which had reduced its hydraulic capacity and resulted in SSOs during wet weather conditions.

Two options for rehabilitation were considered: pigging the line, or power rodding. Pigging was ruled out because of the expense and the possibility of breaching the existing sewer pipe wall. Conventional power rodding is more cost effective and less likely to breach the existing pipe wall.

To ensure that the pipe did not become tuberculated again, a cured-in-place pipe (CIPP) was installed. The original cast iron pipe will not need this type of costly maintenance in the future.

The work was completed twelve days ahead of schedule.

47. Chusid, E.; "City of Santa Monica Repair of Earthquake Damaged Sanitary Sewer Mains," No Dig 2000 Conference, NASTT Anaheim, California, April 2000.

The City of Santa Monica, California, suffered extensive damage to its sewer system during the Northridge Earthquake. The wastewater collection system comprises over 140 miles of clay or concrete sewers with an average age of 35 years.

The City used CCTV to determine the extent of the damage to the sewers. It was found that 85 percent of the sewer main system was damaged. 35 percent of the existing system needed upgrading to conform to current design standards.

The City specified conventional open-cut, pipe-bursting, and microtunneling construction methods in areas with capacity related problems. Lining repairs were specified in other areas. The lining methods used were as follows:

- Cured-in-place pipe (CIPP)
- Folded-and-reformed PVC
- Deformed-and-reformed HDPE
- Spirally wound pipe liner.

A total of 180,000 linear feet of sewer mains have been repaired and/or upgraded at a construction cost of $22.5 million.

Installation of lining material temporarily blocks lateral connections at the sewer main until the connection is restored. This delay in service varies from three to ten hours. However, the contractor is required to maintain continuous sewer service to "critical facilities" such as health care institutes, restaurants, dry cleaners, and photo developers.

48. Kalkman, T., et al; "City of San Jose Dry Weather Infiltration Reduction Program," WEF 1999 Collection Systems Rehabilitation and O&M Specialty Conference, Salt Lake City, Utah

The San Jose/Santa Clara Water Pollution Control Plant (SJ/SC WPCP) receives 128 mgd of dry weather wastewater flow but only 120 mgd discharge is permitted by the Regional Water Quality Control Board (RWQCB). SJ/SC WPCP has a design capacity of 167 mgd. However, the plant has recently had extraneous flow of 10 mgd (more than 10 percent of the average DWF.) Extraneous flow enters the collection system through defective pipe joints, cracks in pipelines and manholes, and illegal storm sewer cross-connections.

Rehabilitation of the defects comprised either grouting, lining, or replacement. The type of defect, expected useful post-rehabilitated life, and present worth cost was used to select the appropriate rehabilitation method. Grouting is a low-cost approach for minor defects and for obtaining a short-term reduction in groundwater infiltration (GWI). All manholes and private service laterals on a main sewer line may need to be grouted as well in order to get the desired flow reduction.

Manhole rehabilitation is done either by grout sealing minor defects or complete lining of the manhole for significant problems. Sewer lining can extend the life of the sewer by 50 years or more. Sewer lining is generally used in sewers of 8-inch diameter or greater. 4-inch and 6-inch laterals are grouted or replaced. Lining is more expensive than grouting.

Replacement is the most expensive of the rehabilitation methods, but the new pipelines have an expected life of 75 to 100 years. Replacement is used for pipelines that are in danger of collapse. Replacement is the most effective method for sealing out I/I.

The results of a pilot program are not yet available.

49. Slack, J., et al; "SSO Abatement of Oklahoma City," WEF 1999 Collection Systems Rehabilitation and O&M Specialty Conference, Salt Lake City, Utah

The Oklahoma City Water and Wastewater Department (OCW) has a program for sewer line rehabilitation and preventative maintenance to control SSOs. This includes the systematic replacement of one percent of the City's 2,400 miles of sewer line. Sewer line cleaning, grease control, and other maintenance activities have been increased. OCW is also responsible for the O&M of four WWTPs with a combined capacity of 101 mgd and an average (combined) dry weather flow of 75 mgd.

OCW uses a lot of large diameter PVC pipe for sewer replacement. PVC is used for sliplining as well. The PVC pipes and sliplined sections have been revisited to evaluate performance. Video and photographic evidence has shown structural integrity, water-tight joints, and minimal pipe deflection.

Each sewer system complaint is entered into a database which helps to identify problem areas. Replacement work is targeted to these areas, achieving a significant improvement in wastewater service. 95 percent of OCW's line maintenance is preventative, not reactive. In the five years prior to 1998, an average of 1.8 million feet of sewer was flushed and CCTV of 105,500 feet of sewer was completed annually. OCW's emergency maintenance protocols require pre-qualified contractors to bid for emergency sewer work items within 72 hours of a sewer collapse. There are also field crews available 24 hours a day, seven days a week for sewer maintenance. All OCW staff has customer service training and site visits are used for customer outreach.

Line and manhole locations are documented using a GIS-based system. This system can also track service and line repairs.

The annual program of line replacement and I/I control has reduced total flow to WWTPs at a time when population has grown. The program has also had the following benefits:

- Reduced frequency of emergency maintenance
- Reduced damage to public and private property
- Extended infrastructure life
- Decreased overflows and stoppages
- Improved customer service.

50. Villee, R.A.; "Simple Maintenance Reduces Sanitary Sewer Overflows," WEF 1999 Collection Systems Rehabilitation and O&M Specialty Conference, Salt Lake City, Utah

Plainfield Area Regional Sewerage Authority (PARSA) had a history of overflow problems in wet weather. After multiple SSOs in early 1997, PARSA realized that the core problem of I/I had not been resolved. Twenty permanent flow meters had provided the data that proved this. It was also clear that when local brooks spread into their floodplains, the treatment plant interceptor sewer had an inflow problem. The manholes on the interceptor line had not been maintained. They were being flooded by waters from local brooks and the water was then getting into the interceptor because the manholes were not watertight. In early 1997, there were over twenty SSOs. PARSA focused efforts the following four areas:

- Reinstating manholes to make them watertight (there were about 100 manholes in this category)
- Use of mortar to repair cracks and open joints on 25 manholes
- 50 manhole frames were reset with flexible sealant and mortar
- 95 manholes with covers that had eight vent holes in them were blocked with inflow inserts.

1998 was 30 percent wetter than 1997. However, these measures reduced SSOs from over twenty in 1997 to zero in 1998.

51. Yee, V.; "Benchmarking Study Leads to Performance Improvements Opportunities for Collection System Maintenance and Operations - County of Sacramento Water Quality Division," WEF 1999 Collection Systems Rehabilitation and O&M Specialty Conference, Salt Lake City, Utah

Sacramento County Sanitation District No. 1 (CSD1) Maintenance and Operation Section (M&O) wanted to identify the most effective industry practices and improve the way they do business. CSD1 conducted an M&O improvement program which comprised a benchmarking study and an improvement implementation program. The benchmarking study identified the best practices among seven agencies.

The best-in-class performers' success was due to the following process practices:

- Focused preventative maintenance
- Proactive maintenance
- Focused rehabilitation
- Targeting of high risk areas
- Customer outreach
- Cross-training of staff
- Tracking of performance measures
- Exploitation of technology
- Continuous improvement.

Main line stoppages (MLS) were kept to a minimum by proactive maintenance and focused preventative maintenance. The best agencies cleaned their system on a 5- to 10-year cycle. Maintenance activities are targeted to the more critical pipes. Having a larger percentage of six inch pipes may result in more MLS. Older pipes also had more MLS. Fewer cleaning crews per mile of sewer also increased MLS.

Agencies with more maintenance crews per mile of sewer, age of pipe, and number of staff did not appear to have an effect on number of SSOs. Best-in-class agencies had installed backwater overflow valves in areas with a high risk of flooding.

CSD1 will start a public outreach program in the hope that customers will be more understanding if there is a problem with the sewers. Short-term rehabilitation projects will include the following:

- Double 'y' separation
- Double 'y' cleanout installation
- Maintenance hole installation for rear easement access
- Chemical root control
- Grease impact study
- Backwater overflow devices.

52. Swallow, W.J.; "Lessons Learned in Sewer Rehabilitation with Deformed HDPE in San Diego," WEF 1999 Collection Systems Rehabilitation and O&M Specialty Conference, Salt Lake City, Utah

The City of San Diego has a program to replace its deteriorated sewer mains using deformed high density polyethylene (HDPE) pipe. The pipe is about half the size of the existing pipe. The HDPE pipe is fitted to the existing pipe using heat and pressure. Service lateral connections are restored using remote controlled cutter equipment.

The rehabilitation projects comprised 200 mm sewer mains in an environmentally sensitive area. The problems encountered included the following:

- During heating and pressurizing, the HDPE pipe expanded beyond the deteriorated host pipe, into the surrounding soil. Subsequent pressure tests failed. The original defect was redone using traditional point repair techniques.

- Some sections of pipe had disintegrated completely. Wastewater flowed, essentially, in an earth cavern. Workers had to hand dig 20 m sections and replace them with new pipe before the rest of the sewer line could be lined with HDPE.

The City of San Diego has found that open trench excavation and point repair or replacement is usually an economical solution for easily accessible, shallow, deteriorated pipelines in un-congested residential streets. With increasing population and environmental restrictions, pipeline rehabilitation is becoming more cost effective.

53. Larsen, J.P.; "An Inside Look at Common Sense Application of Trenchless Technologies in South Florida," WEF 1999 Collection Systems Rehabilitation and O&M Specialty Conference, Salt Lake City, Utah

In 1994, Miami-Dade Water and Sewer Department (MDWASD) started an I/I flow reduction program. Costs are estimated at $120 million over five years to reduce more that 60 mgd of I/I flow.

The following is a list of the manhole rehabilitation technologies adopted by MDWASD:

- Manhole frame and cover rehabilitation: Manhole covers containing vent or pick holes are replaced with watertight covers. Deteriorated frames and covers are replaced with watertight sets. This requires excavation and resetting the frame on a mortar base.
- Manhole sidewall and base rehabilitation: When a manhole is structurally deteriorated, replacement is often the least-cost solution. In structurally sound manholes, a lining or coating system is used. Prefabricated fiberglass, polyurethane, and cementitious manhole liners are used for lining or coating. Chemical grouting of pipe entrances and drop structures is used to supplement manhole lining repairs.

The following is a list of pipeline rehabilitation technologies adopted by MDWASD:

- Chemical grouting: This is used to seal leaking joints and circumferential cracks in sewers. Acrylamide gel, acrylic gel, acrylate gel, urethane gel, and polyurethane foam are used as grout material. The material is injected into pipe joints. Chemical grouting does not enhance the structural characteristics of a pipe. Therefore it should not be used for repairing longitudinal cracks or where the pipe is severely cracked, crushed, or broken.
- Point repairs/excavation and replacement: Point repairs are made by the traditional method of excavation and repair. This method is used for isolated major structural pipe defects such as broken, severely cracked, or corroded sewer pipes or where other repair methods are not cost effective.
- Robotic repairs: These are point repairs from inside the pipeline using a remote controlled machine. This is used to repair isolated cracks, defective joints, and protruding and recessed laterals. The repairs are made using an epoxy material. This method is used where the pipe is deep and/or conditions are wet and open cut methods are not cost effective.
- Sectional liners: These are cured-in-place pipe (CIPP) liners and are limited to lengths of 3 to 15 feet (1 to 4.5 meters). CIPP liners are used to reline pipe segments which are cracked and/or leaking and where depth or location of the pipe makes point repair expensive.

- Slip lining: A liner pipe of a smaller diameter that the existing pipe is pulled from or pushed into it. Service laterals are reconnected to the new liner. This method is used mostly in larger diameter pipes with severe structural problems.
- CIPP liners: A resin impregnated felt tube is inserted into a pipe and allowed to cure. A cutting device and CCTV are used to reopen service lateral connections, located prior to installation of the liner. The fabric cures to form a new rigid pipe with no seams or joints and may improve flow capacity of the pipe, as the internal surface is very smooth. Two liquid thermosetting resin types can be used (polyester and epoxy). This method is well suited to rehabilitation of pipes beneath structures, large trees, or streets and highways.
- Fold and Formed (FAF) pipe liners: A folded thermoplastic (PE or PVC) is pulled into place and then rounded to the internal diameter of the existing pipe. Lateral reinstatement is done internally. This method is not as versatile as CIPP liners in terms of the pipe diameter and length that can be repaired. FAF liners are suitable for diameters of 4- to16- inches and lengths of 300 to 600 feet.
- Pipe bursting: This method is used for the replacement of sewers. The existing pipe work is fragmented and forced into the surrounding soil by a 'burster' which also pulls the new pipe into the expanded void. The replacement pipe is usually polyethylene and is assembled on-site using end- to -end butt-fusion. The pipe burster can be pneumatic or hydraulic. Pipe bursting is suitable for pipes made of brittle material such as vitrified clay, un-reinforced concrete, asbestos cement, and cast iron.

54. Aguiar, L, et al.; "Sewage Pump Station Evaluation for Operation and Maintenance Upgrading," WEF 1999 Collection Systems Rehabilitation and O&M Specialty Conference, Salt Lake City, Utah

The Miami-Dade Water and Sewer Department (MDWASD) serves a population of over two million in a 400 square mile service area. MDWASD maintains over 2,000 miles of gravity sewers up to 72-inch diameter, 640 miles of force mains up to 102-inch diameter, and nearly 1,000 pump stations. There are three WWTPs with a total annual average daily flow of 352.5 mgd. Supervisory Control and Data Acquisition (SCADA) has been installed in about 82 percent of pump stations to monitor flow, pressure, wet well levels, pump runtimes, power consumption, and I/I data. Volucalc is also used to obtain data similar to SCADA, except that it does not cover historical periods of interest.

SCADA showed that in one of MDWASD's pump stations, the night flow went from 50 to 250 GPM. This sudden increase in infiltration was comparable to similar breaks in the gravity system of other pump stations. The break was found and repaired.

At another pump station, it was noticed that the domestic and night flow was twice the expected volume (400 GPM). Crews subsequently identified a cross-linked manhole.

SCADA analysis at a pump station (PS) showed pump rates varying from 50 to 100 GPM. The pumps were performing at their rating, but the force main was allowing less that half the flow than it should. After the force main was cleaned, the pump rate matched the theoretical operation of 125 GPM.

Pump Station 655 was operating longer than the permitted 10 hours. This was because of a force main connection/valve problem. This was corrected and PS655 returned to normal operation.

PS338 pumps were running unevenly. It was found that the clearance setting on one of the pumps runtime returned to normal once the problem had been corrected. Uneven runtimes have also been found to be caused by an obstruction in the suction line of pumps.

SCADA analysis showed that PS672 was starting 80 times per hour, where 20 times per hour was normal. This was found to be because an air vent had not been installed in the PS wet well.

MDWASD has found the SCADA system to be a quick, efficient, and accurate way of assessing many common problems associated with pump station performance and diagnosis.

55. Rankin, A.L.; "Inflow and Infiltration Remediation on Lake Superior," WEF 1999 Collection Systems Rehabilitation and O&M Specialty Conference, Salt Lake City, Utah

Duluth, Minnesota, has a serious I/I problem. Average daily dry flow is less than 30 mgd. Wet weather flows are over 120 mgd.

The City of Duluth is part of the Western Lake Superior Sanitary District (WLSSD). In 1996, WLSSD would not allow new sanitary sewer connections until the City had an acceptable I/I reduction plan. The City appointed a Citizen I/I Task Force.

The Task Force's recommendations were as follows:

- Enforce a 1997 ordnance making roof drain connections to sanitary sewer system illegal
- Accelerate sanitary sewer cleaning and CCTV
- Conduct a demonstration project to show effectiveness of I/I remedial solutions
- Conduct on-going public education concerning I/I
- Enforce all existing sanitary sewer system related City ordinances.

The Minnesota State Legislature approved up to $400,000 for I/I remediation on private property from sanitary sewer rate increases. CCTV was used to confirm sources of I/I.

An overhead presentation and informational video were produced for public education of the issues.

95 percent of all roof drain connections were removed. Also, the cleaning of sanitary sewers increased by 55 percent and the CCTV of sanitary sewers increased by 250 percent. 2040 properties have been inspected. A further 1590 properties require work. $3.3 million has been spent with a further $2.3 million committed.

56. Kelly, E., et al; "Planning and Effective Use of GIS Technology Turn Massive Amounts of CCTV Data Into Prioritized Rehabilitation Projects," WEF 1999

Collection Systems Rehabilitation and O&M Specialty Conference, Salt Lake City, Utah

The Sewerage and Water Board of New Orleans (S&WB) has developed a computerized data collection and decision making process for the conversion of thousands of feet of CCTV survey into prioritized rehabilitation projects. Much of the City of New Orleans lies below sea level, protected by natural and man-made levees. The city's average annual rainfall is 1,476 mm (58.12 inches). S&WB's wastewater system services an area of about 220 km^2 (86 sq. miles) and a population of 497,000. The gravity wastewater collection system over 2,080km (1,300 miles) in length, trunk sewer sizes between 200 mm (8 inches) to 2,100 mm (84 inches) in diameter. There is over 160 km (100 miles) of force mains ranging from 150 mm (6 inches) diameter to 1,800 mm (72 inches) diameter. There are 83 pump stations and the city has two WWTP's with a combined capacity of 500 ML/d (132 mgd).

The tool for understanding system structural condition was the Collection System Evaluation Study (CSES). Hydraulic behavior was analyzed using a dynamic hydraulic computer model. There were ten CSESs to be conducted, each by a different contractor, so S&WB developed a system for consistent CCTV data collection and interpretation. ArcView GIS was developed into a Rehabilitation Decision Support System (RDSS) to convert CSES data into prioritized rehabilitation projects. GIS also provides the maps, plans, and bid documents for rehabilitation construction packages.

The defect coding system was a modified version of WRcs Manual of Sewer Condition Classification, which is the industry standard in the United Kingdom. CCTV data are linked to GIS using a time-line video counter. The CCTV tape is converted to MPEG format and pressed onto CD-Rom. When a user clicks on a defect in GIS, an ArcView script tells the MPEG viewer the filename and video counter time of the selected detail. The MPEG viewer goes to the correct place in the MPEG video file.

This process combines the planning and design phases into one. S&WB estimates that RDSS has the potential to reduce planning and design costs by over 50 percent per basin. This saving equates to a total of $3 M system wide.

57. Conegliano, B.; "Indirect Wet Weather Overflows," WEF 1999 Collection Systems Rehabilitation and O&M Specialty Conference, Salt Lake City, Utah

This paper discusses spills due to grease accumulations in service laterals that develop when interceptors surcharge and the inflow in tributaries changes from gravity to pressure flow. Such overflows occur after the passage of storms, so are not actually wet weather events.

Two clusters of stop-up and overflows occurred in City of Austin Water/Wastewater Utility's (CAWWU) Williamson Creek watershed in Austin, Texas. An important factor contributing to service problems is the presence of sags in the line because they appear to promote full-pipe flow conditions.

A sewer which had severe sag and some offset joints was replaced in 1991. In March 1995, there were four reports of overflows over an 18 day period in this sewer line. A storm five days before the overflows were reported had dropped 0.36" of rain at the airport. High water marks on trees showed that water had been 10 feet above the top of the manhole on the interceptor which receives flow from the Bitter Creek tributary. The hydraulic gradient at the outfall was 15 feet higher than had been assumed during design, causing the outfall sewer to become surcharged. Grease deposits had built up, the lines had backed up, and some service lines had become clogged with grease deposits as well. Replacement of the sewer is one solution. However, elimination of sags can prevent grease separation occurring.

58. Arnold, S.; "Has Your Utility Considered In-house Trenchless Techniques?" WEF 1999 Collection Systems Rehabilitation and O&M Specialty Conference, Salt Lake City, Utah

Columbus Water Works (CWW) in Columbus, Georgia, investigated and considered options for rehabilitation of its collection system in the early 1990's.

The costs and benefits of five projects using different rehabilitation techniques showed that pipe bursting was preferable over traditional open-trench replacement and in-site lining.

Of the five projects, one involved pipe bursting, two were traditional open-cut, and two were cured-in-place pipe lining contracts. These projects totaled 1.17 miles (6,177 feet) of sanitary sewer. The total rehabilitation cost was $385,000 or $62 per linear foot. CWW had almost another 90,000 linear feet (17 miles) of sewer to rehabilitate out of CWWs total collection system of 4.5 million linear feet (852 linear miles) of sewer.

CWW spent $225,000 to purchase the following pipe bursting equipment:
- 8-inch pneumatic pipe bursting Grundocrack tool and three expansion heads
- 10-ton Grundowinch
- McElroy pipe fusing equipment
- Small hand tools.

The Sewer Rehabilitation (SR) team comprised a three man crew and a field supervisor. Two weeks of hands-on training were required in the use of the equipment. The SR team's first project was the rehabilitation of 1600 feet of 8-inch concrete sewer. The project cost $29,000 including labor, equipment, and materials. Open-cut replacement would have been about $170,000; pipe bursting by outside contractors would have cost about $80,000.

One of the last projects was 1,015 feet of 8-inch sewer to be pipe burst. The total cost was $23,040.29 ($22.70 per foot). Within the first 18 months, CWW had rehabilitated 10,652 feet of sewer. The cost saving has been about $500,000. This compares to the cost of the pipe bursting equipment of $225,000. The equipment actually paid for itself in four months.

59. Mantione, M., et al; "Benchmarking Maintenance Practices for Effective Capital Assets Management," WEFTEC'99 New Orleans, LA

The New York City Bureau of Waste Water Pollution Control (BWPC) benchmarked its maintenance practices at three wastewater treatment plants with practices of best-in-class benchmark partners. The benchmark partners were as follows:

1. United Airlines at Denver International Airport
2. Denver International Airport Operations
3. Denver Metro Wastewater Utility
4. Baltimore Gas and Electric
5. Pennsylvania American Water Service Company
6. King County Wastewater Pollution Control Division (Seattle metropolitan area wastewater utility)
7. Weyerhaeuser Pulp and Paper Mill in Eugene, Oregon
8. Snohomish County Public Utility District No. 1 in Everett, Washington.

Listed below are the key findings and conclusions of the benchmarking study:

Institutional Structure

- The partners had both centralized and decentralized maintenance operations. This feature did not appear to affect quality maintenance practices.
- Plant managers were responsible for and evaluated on the financial performance of their operations
- Partner managers and foremen were evaluated on numeric performance standards (usually outcome- or results-based standards)
- The majority of the benchmark organizations embrace a customer-oriented culture where maintenance personnel are aware of intermediate and final customers.

Maintenance Management Systems

- A majority of the benchmark partners emphasized preventative and predictive maintenance on critical process equipment
- The partners rely on maintenance management information systems (MMISs) for planning and executing preventative and corrective maintenance work
- None of the benchmark partners has a formulaic answer for determining the "proper level of maintenance." Levels of maintenance are determined using manufacturer recommendations, equipment history, experience, and predictive maintenance tools.

Employee Performance

- A majority of the partners' management staff are given financial incentives to perform well
- In most cases, union staff (five of the eight partners) are not given annual performance evaluations or financial incentives for maintenance performance. Another partner had implemented a gain-sharing program for labor and management in O&M positions. The gain-sharing program was developed through labor-management negotiations and is ongoing.
- Characteristically, the benchmark partners use "dedicated maintenance staff." In contrast, BWPC has staff that work both operations and maintenance and are frequently redeployed to operations functions to ensure a full complement of operators on each shift.
- Several of the benchmark partners have initiated programs to train operations staff to perform routine PM work. One partner was assigning both maintenance and operations functions to maintenance crews for one sector of operations. This was

being done on a demonstration basis and had not been extended to other operational areas.
- Recruiting and retaining qualified employees was not defined as a problem for the benchmark partners.

Financial and Capital Planning
- Only one of the eight benchmark partners endorses the "run-to-failure" asset management philosophy for any of its systems. The other partners attempt to manage their assets at the lowest life-cycle cost.
- Seven of the eight partners use their MMIS to support requests for major maintenance proposals or capital replacement
- MMISs were used extensively to plan maintenance management activities
- Maintenance management was an integral part of capital assets management planning at each of the partner facilities.

Procurement
- Compared to the requirements of the BWPC, the majority of the benchmark partners have less restrictive procurement systems. The delegated authority for purchases was generally set at much higher levels of dollar value in partner organizations than at BWPC.
- The Snohomish Public Utility District and King County Water Pollution Control Division have procurement requirements similar to those of BWPC. However, due to more successful predictive maintenance management (PDM) programs, they are able to identify needs and plan far enough in advance to offset the impact of slower, more process-bound procurement systems.

The areas needing improvement are: (1) maintenance planning and scheduling, (2) use of MMIS in capital assets management, (3) staffing, staff training, and recruiting/hiring standards, (4) lead-time for equipment and parts procurement, (5) predictive maintenance, and (6) incentives for staff improvements and customer orientation.

60. Gabb, D.M., et al; "Benchmarking Identifies Best Practices in Seven Large West Coast Sanitation Agencies. Find Out How," WEFTEC'99, New Orleans, LA

The East Bay Municipal Utility District (EBMUD) started benchmarking its operations and maintenance costs in 1993. In phase one, representatives from EBMUD, Orange County Sanitation Districts (OCSD), and Sacramento Regional County Sanitation District (SRCSD) created a generic template that would represent all wastewater treatment areas. Phase two of the benchmarking study (the Multi-Agency study), included a total of seven agencies. The following were added to those from phase one: Central Contra Costa Sanitary District, King County Dept. of Natural Resources, City of Portland Environmental Services, and the City of Los Angeles Department of Public Works.

The significant findings of the benchmarking study were as follows:

- O&M costs are strongly influenced by labor/staffing costs
- Power costs are the second largest cost factor of total O&M costs. Costs can best be managed via access to and/or production of cheaper energy, use of more efficient equipment, and designs that require less energy.

- Residuals processing and handling accounts for nearly 39 percent, on average, of all O&M costs. Residual processing and handling includes sludge thickening, digestion, dewatering, haul and application, incineration, and grit and screenings disposal.
- Secondary treatment accounts for about 16 percent of all O&M costs, on average, and has the highest energy use of any process
- Disinfection/dechlorination costs vary greatly due to NPDES permit requirements, safety concerns, and product cost
- The standardization of equipment and systems can lower operation and maintenance costs.

61. Kido, W., et al; "Predictive Tools Trim Operating Costs," WEFTEC'99, New Orleans, LA

Sacramento County CSD-1 maintains a system of over 3,900 kilometers (2,500 miles) comprised of more than 50,800 sewer pipe segments. Several maintenance issues prevent long-term life of the system. These are as follows:

- Root intrusion – Little or no summer rain and a large tree population promote extensive root intrusion problems. Roots eventually separate the pipe joints and cause the loss of integrity in the pipe.
- High I/I – High I/I is noted in high-groundwater areas, including Natomas and Pocket areas. Sources include leaky pipes and joints, illegal connections, manhole barrel leakage, manhole lid leakage, and open cleanouts. Natomas and Arden Pump Stations are subject to I/I problems. The Natomas station is already running near capacity.
- Grease – Grease is a major source of blockages
- Corrosion – Corrosion does not appear to be an extensive problem. Over 90 percent of the pipes in the system are vitrified clay pipe (VCP). The District adds chemicals throughout the interceptor system to control corrosion. Granitic concrete pipe in the system has experienced corrosion problems.
- Pipe collapse – Pipe collapse is a symptom of pipe cracking or corrosion problems
- Backyard easements – Many of the over 1,500 miles of 6-inch lines are located in backyard easements. Sewers in backyard easements are more susceptible to root intrusion.
- Lack of clean-outs – Every service connection does not have a clean out
- Poor Installation – Offset joints, separated laterals, and cracked pipe are noted in many segments of the District's system. Cobble areas in the east part of the District are particularly susceptible to cracking due to poor back-filling methods using native material.
- Double-wyes – The District's system contains over 8,200 double-wyes. When one house sits higher in elevation than the other and a block in the lateral occurs, sewage from the higher house flows into the lower house.

A predictive failure model was developed to provide an estimate of the remaining life of existing pipes and project the effective life of new pipes in the sewer system. The model uses detailed knowledge of about six percent of the pipelines to predict the condition of the entire system. The model uses multivariate regression equations that predict a condition score. Once the equation is established, it can be applied to pipe segments where conditions are unknown but attribute data are available. The recursive statistical model provides a basis to update the predictive equations based on the newly gathered data. The predictive model development can be divided into four major parts, (1) sample identification and assessment, (2) database development, (3) statistical analysis, and (4) verification and compilation of the results. Several sources of data were used for the predictive model:

- Pipe history and inventory data: This data set provides the physical attributes of the pipe, such as pipe material, length, slope, and depth of bury.
- Pipe age database. This data set provides the actual pipe installation dates derived from as-built drawings.
- Engineer database: This data set provides design-related tracking with respect to individuals responsible for design, review, and project acceptance. These data are used as a surrogate for design and construction practices over the life of the pipe.
- CAD and GIS information: This data set provides pipe location information. Shed and subshed boundaries can be identified with this information.
- Closed Circuit Television (CCTV) data within Computerized Maintenance Management System (CMMS): CCTV inspection logs were the primary source of data. These data provide pipe defect incidence such as cracks and root intrusion. Data considered in the predictive model were obtained from VHS tapes recorded since 1987.
- Work order data within Computerized Maintenance Management System (CMMS): Work orders were the primary source of the most compromised pipes within the collection system. If warranted, the CCTV operator may opt to stop televising and begin a work order to initiate point repair of seriously damaged pipe segments. For example, sections of pipes that have collapsed or which are in danger of collapse, taps which are broken, etc.

The predictive model provides a running list of "at risk" pipes to focus future field work. The CCTV data can then be evaluated for maintenance, spot repair and/or other rehabilitation needs. As the model is used and refined, the model will aid in developing an optimum balance in maintenance and rehabilitation of the pipes in the system. It will also help target future efforts where they are necessary so that operations and capital dollars are spent when and where they are necessary. It incorporates the historical knowledge of CSD-1 staff and will allow a better means to plan for capital and operations expenditure.

62. Wong, P., et al; "Monitoring and Modeling Optimized System Planning and Operation in San Diego," WEFTEC'99, New Orleans, LA

The City of San Diego's Metropolitan Sewer System serves a population of 1.8 million and has an annual average daily flow of 8.3 m^3/s (190 mgd). The service area includes the City of San Diego and 14 other wastewater agencies. A network of trunk sewers and interceptors ranging up to 2,775 mm (108 inches) in diameter convey the wastewater to the Point Loma Wastewater Treatment Plant (PLWTP) and ocean outfall. Collection system facilities within the City (representing about 70 percent of the total Metropolitan Sewer System) include over 4,000 kilometers (2,500 miles) of sewers ranging in size from 100 to 2,400 millimeters (4 to 96 inches), and 82 pumping stations. The average flow generated within the Metropolitan Sewer System is projected to eventually increase from 8.3 m^3/s (190 mgd) to 14.9 m^3/s (340 mgd). The City's modeling team has developed or adapted various tools to support it in managing information about its collection system. GIS databases include the following:

- Extensive land base information such as compressed digital ortho-photos, address-coded streets, political boundaries, parcel boundaries, and topographic contours
- Sewer system facilities data covering the City's entire 70,000-pipe collection system, including pipe diameters, invert and ground elevations, materials, etc. This is the database used for producing sewer maps and is also used in the City's sewer maintenance management system.
- Population, employment, and land use information (existing and projected) by geographic unit such as a city block
- Major industrial dischargers' estimated wastewater flows and other discharge characteristics, maintained by the City industrial permitting group
- Flow monitoring sites, as digitized and maintained by the City flow monitoring group and modeling team.

The City has been using the HydroWorks dynamic modeling software for the past three years. The model has been linked to ArcView GIS so that the results of each validation check can be displayed graphically as a sewer map with disconnected or questionable manholes and pipe segments highlighted.

The benefits that have been recognized are the value of developing a custom GIS application to integrate and process data that is developed and updated by other agencies, and applications of the model on both planning and operational studies that result in reduced capital and operating costs.

63. Sims, W.D.; "Large Diameter Pipe Bursting to Upgrade a Sanitary Trunk Sewer in an Environmentally Sensitive River Valley: The City of Nanaimo's Experience," No-Dig 2000 Conference, NASTT, Anaheim, California, April 9-12, 2000

The City of Nanaimo is on Vancouver Island, British Columbia. The City has a population of 75,000 people. The City's Millstone Trunk Sanitary Sewer was installed in 1976/77. The Millstone basin comprises an area of 1,620 Hectares (4,000 acres). The trunk sewer is 12.5 kilometers (8 miles) long and increases in size from 350 mm (14 inches) to 600 mm (24 inches). At that time, the design population tributary to the trunk was established at 14,500, with a design life of fifty years to 2020. The Millstone basin now serves an existing population of about 15,800, or 22 percent of the city's population. The flow in the upper four kilometers of the sewer was over the trunk sewer's capacity. The final recommendation was to construct a series of five pump stations and pump to a sewerage area with capacity to take the additional flow. The estimated annual operation and maintenance expenses, for these five pump stations would be $93,000, escalating to $276,000 per year after thirty years. The pump option would increase the annual maintenance budget for pump stations by about 100 percent.

The existing 350 mm pipe needed to be burst to a 650 mm High Density Polyethylene (HDPE). Manufacturers felt that 14" to 26" diameter increase was possible. However, the lengths of pull in this project were double the lengths they felt were feasible. A demonstration section to test the viability of pipe busting was undertaken. There were nineteen property owners along the trunk's route. The property owners were impressed with the minimal disruption, and speed and efficiency of the technology. Millstone Trunk consisted of a total of 3,930 meters (12,900 feet) of existing 350 mm (14 inches) inside diameter asbestos cement sanitary sewer, which was upsized to a 650 mm (26 inches) outside diameter DR17 High Density Polyethylene (HDPE). There was a total of

33 manholes (and 32 bursts) to complete. The grade was very flat, ranging from 0.2 to 0.6 per cent. Average depth to invert was 3.0 m (10 feet), but ranged as high as 7.0 m (23 feet) in areas. Burst pull distances between manholes averaged 120 m (400 feet), but there were ranges as high as 185 m (600 feet). The demonstration section was 573 meters (1,900-ft), consisting of four runs of pipe, ranging in length from 110 to 185 meters (360-ft to 600-ft). The bid price of the lowest tenderer was \$3.9 million (CDN). The remaining 165 m (540 feet) was burst successfully in about two and a half hours. 171 m was burst in about 4 hours.

The 573 meter (1,900 foot) demonstration section was completed within two weeks. Forces required for all four pulls did not exceed 150 tons (3,000 psi hydraulic pressure). Within four weeks they burst 725 meters (2,380 feet). Forces required were usually less than 75 percent of the machine's capacity (1,015 meters (3,330 feet) within four weeks).

The final contract price was \$4,310,000 (including GST). The tendered price works out to \$11.50/inch diameter/foot; the final contract price works out to 12.85/inch diameter/foot. This is consistent with costs in the United States.

64. Hamid, A., et al; "City of Atlanta Combined and Separate Sewer Overflow Control, Program Meets the Challenge of the 21st Century," WEFTEC 2001

The City of Atlanta waste water system consists of 2,200 miles of sewers, 300 of which are combined sewers, four Water Reclamation Centers (WRCs), 7 Combined Sewer (CSO) facilities, and 14 pump stations. The City sewer system is 50 to 70 years old with some portions over 100 years in age. The City of Atlanta passed a \$1 billion bond in 1999 to fund the City's capital improvement program for water and wastewater facilities.

The City is spending \$225 million in construction of relief sewers related to providing added capacity in the sewer system and reducing sanitary sewer overflows. The City divided the 2,200 miles of sewers into 296 sewer sub-basins based on the topography of the area. Each of the sub-basins was ranked to determine the urgency of repair or replacement based on the hydraulic modeling, available Sewer System Evaluation Survey (SSES) data, and operation experience. The sub-basins were combined to form six sewer groups. Work in the first sewer group, comprising 280 miles of the worst condition sewers, is underway and comprises the following:

- Flow monitoring
- Hydraulic modeling
- Cleaning and CCTV
- Smoke testing
- Flow isolation
- Point repairs.

Planning level cost estimates indicate over \$900 million will be needed to upgrade the City's sewer system. About \$2.5 to 3 billion will be needed to meet the Consent Decree requirements for the CSO and SSO programs in the next 14 years. The City has estimated the future sewer rates for Atlanta will increase three times the existing rate, from \$30 per month to about \$90 per month.

65. Glynn, J.A., et al; "Multiple Diameter Pipe Bursting: Is it the Right Sewer Rehabilitation Solution for Your Project?" No-Dig 2000 Conference, NASTT, Anaheim, California, April 9-12, 2000

The town of Hillsborough's collection system consists of about 82 miles of gravity sanitary sewers with pipes ranging in size from 6- to 18-inches in diameter. The sewered area is about 3,700 acres, serving a population of around 11,000 residents. The Town's existing trunk sewer consists of about 15,000 lf of vitrified clay pipe gravity system ranging in size from 8- to 18-inches in diameter. Some portions of the alignment contain a parallel pipe system. In 1991, the Town completed an Infiltration/Inflow (I/I) study of its sewer system. A sub-basin monitoring program in 1995 produced some guidelines for trunk sewer improvements sufficient to convey the estimated peak wet weather flows from a five year, four hour duration rainfall event. This flow was estimated to be about 8.9 million gallons per day (mgd).

The existing system is sized to handle about 5.5 mgd. With the aid of the model, it was determined that the existing system needed to be upsized by up to three pipe diameters and the abandonment of the dual pipeline system and its replacement with one larger pipe. This would cut down on the number of manholes. The only viable choices that the designer had to increase capacity of the line were to install a parallel line, replace the existing sewer with open cut trenching, or replace the existing line using multiple diameter pipe bursting.

Multiple diameter pipe bursting would limit the amount of excavation required and prevent the contractor from having to enter the zone of potential habitat for any local endangered species. On average, the contractor saw a pipe replacement rate of 2 feet per minute. The first 450 foot run was installed in just over two hours. About 300 feet into the first burst, the winch cable snapped because of a 15 degree bend in the pipe. Once the cable was repaired, the first burst proceeded very smoothly.

Multiple pipe busting can be an effective rehabilitation tool that can dramatically increase the capacity of an existing system without the disturbance and cost of traditional excavation and open trench pipe replacement.

66. Troutman, B.; "Developing an Optimized Asset Management Strategy for Buried Infrastructure," WEFTEC 2001

A high percentage of water and wastewater assets are approaching or are beyond their average service life. While O&M funding has more than doubled from 1980 to 1994, capital expenditures have remained largely unchanged. This suggests that capital funding levels for major rehabilitation and replacement projects at water and wastewater utilities have not increased as assets continue to age. As a result, local entities have had to substantially increase their spending levels.

The development of a formal asset management program has several distinct benefits which are as follows:

- It communicates the utilities up-front commitment to optimizing asset management
- It provides a framework for the development of optimal long-term asset management practices and policies

- It creates an opportunity to examine alternative technologies that may result in a lower long-term asset management cost.

The goal of establishing an asset management baseline is to develop the critical information required to support future asset management decision-making. The evaluation requires developing or refining an existing asset inventory, characterizing the condition of those assets, and collecting asset-specific data concerning the effectiveness of past maintenance and renewal/replacement policies, if available.

The goals are focused on supporting the objective of providing sufficient maintenance and renewal and replacement activities to manage system assets in the most cost-effective manner. “Bottom up” approaches are based on a detailed consideration of asset inventory, average service life, and actual condition assessment to project future capital requirements. In contrast, “top down” approaches, such as the Nessie Model, consider the effects of asset preservation efforts on the economic life of system assets. Projected capital requirements are based on the year the asset was placed in service, the replacement cost, and the observed economic life of assets. The plan should be flexible and dynamic, to fully support the asset management program as it develops. Specific to asset management considerations, CMOM will require the following information for the collection system as follows:

- An inventory of system assets
- Procedures for determining the condition of assets and the documentation of condition
- Procedures for identifying repair and upgrade needs and the documentation of planned work compared to completed work
- Summary of asset rehabilitation and replacement needs and a plan for financial commitment.

Trenchless rehabilitation technologies, particularly those recognized as reliable and cost-effective, will be increasingly utilized in support of optimizing asset management of buried infrastructure.

67. Bagley, C.R., et al; “Applying Desktop GIS Technology to Manage Wastewater Collection System Facilities,” WEFTEC 2001

The Central Weber Sewer Improvement District collects and treats wastewater from an approximate 69-square mile service area that includes eleven communities. The District currently operates and maintains over 46.5 miles of trunklines and six sewage pump stations. The population of the service area is about 130,000. The population is projected to increase to about 200,000 by the year 2020.

Desktop GIS technology was utilized to develop a comprehensive inventory containing the general system attributes of the District’s wastewater collection that can be used by District personnel. This database was also used to develop a digital hydraulic model of the District’s collection and conveyance facilities. Information including locations of lost or damaged manholes, date of last manhole inspection, date of last line cleaning, and other pertinent field observations and problems have been added. The average flow at the plant was 43.5 mgd, while the average measured flow was 44.7 mgd. The Cedra Avsand computer package was utilized to develop the wastewater collection GIS database, linked with the SWMM hydraulic modeling software developed by the Environmental Protection Agency. Inflow hydrographs were developed for the hydraulic model using the flow monitoring data and service sub-area information. The hydraulic model was used to determine the impacts that future growth would have on the existing wastewater collection system facilities within the District's existing service area and the impact of annexing five areas currently outside its service area.

68. Hassey, P.; "Collaborative Benchmarking," WEFTEC 2001

Following the completion of a multi-agency benchmarking study in 1998, the seven California agencies recognized the benefits of establishing a long tem collaborative relationship to study and identify areas to reduce costs and increase reliability and efficiency of each Agency's respective collection system. The group selected "Hydroflush Cleaning of Small Diameter Sewers" as the first best work practices project because it is the most common sewer cleaning methodology used by the group. The guideline addresses the following:

- Safety
- Work Planning
- Quality Assurance
- Equipment Features
- Performance Expectation
- Performance Measures
- Nozzle Selection
- Standard Measures
- Field Applications of Best Practices.

The best-in-class performers attributed their success primarily to the following process practices:

- Proactive maintenance
- Customer outreach
- Cross-training of staff
- Focused rehabilitation
- Continuous improvement
- Exploitation of technology
- Tracking of performance measures
- Focused preventative maintenance (PM)
- Targeting of high-risk areas.

The data compares the agencies by using miles of sewer per mainline stoppage (MLS). The top performers in this indicator based on process benchmarking stated that they use a proactive maintenance program to clean their system on a five to ten year cycle. Fifty percent of flooded incidents were caused by MLS. MLS is the primary reason for flooded incidents in all seven agencies.

Flooded cost per claim measured how the agencies approached risk management and how they minimized their cost per claim. Quicker response time for cleanups can minimize damages, and constant customer communication can prevent potential litigation against the agencies. The Sanitary Sewer Overflows (SSO) data presented compared agencies by the miles of sewer per SSO. Agencies with more maintenance crews per mile of sewer experienced lower SSOs per mile of sewer. The staff productivity rate data was used to compare agencies by the productivity rate of their maintenance and operations employees. The top performers in this measurement had a targeted preventative maintenance program only on the critical pipes and did not have an area-wide maintenance program. The data for amount of sewer cleaned per year compared agencies by the percent of system cleaned per year. The cleaning efforts must be targeted on the most critical pipes for the preventative maintenance to be effective. These best-in-class performers attributed their success primarily to their maintenance activities. Both the maintenance and construction staff was cross-trained to perform both activities, which has resulted in more efficient and effective practices.

69. Nelson, R.E., et al; "Optimization of Collection System Maintenance Frequencies and System Performance," WEFTEC 2001

The level of service to customers is negatively impacted by a reduction in the hydraulic capacity of a collection system due to root ingress, accumulation of obstructions discharged to the system (such as grease, rags, paper towels), and structural failures (such as line breaks and collapses). Collection system maintenance and rehabilitation is necessary for not only improving service to customers, but also for meeting regulatory requirements. A questionnaire was developed to collect the data necessary to perform the analyses. Forty-two agencies, representing five different geographical regions, responded to the questionnaire.

Each agency was requested to provide five years of data (from 1992 to 1996) to establish routine maintenance rates. Forty-one out of forty-two agencies reported having a cleaning maintenance program. The overall average cleaning rate was 0.30 miles per mile per year. The overall average root removal during this five year period was 0.04 miles per mile per year. The overall rate of mainline stoppages cleared was about 0.23 per mile per year, and the overall average for house service stoppages cleared was 0.29 stoppages per mile per year.

The elements of an inspection program include flow monitoring, manhole inspections, smoke/dye testing, CCTV inspection, and private sector inspections. Most regions reported more than 100 percent manhole inspections during the last five year period. The overall average reported shows that manhole inspection activity has increased from 10 percent per year to 26 percent per year in the past 20 years, and the smoke/dye test activity has increased from two percent per year to eight percent per year over the same period. The TV inspection has increased from two percent per year to seven percent per year over the past 20 years. Less than 50 percent of required rehabilitation has been completed. The overall average for completed rehabilitation work was 42 percent for manhole rehabilitation, 38 percent for main line or public service connection repairs, 38 percent for relief sewers, and 47 percent for relief/equalization.

System maintenance costs increased from $1 per mile per year in the pre-1970s era to $1,291 per mile per year in the 1990s. The equalization costs have increased from $53 per mile per year to $322 per mile per year. The rehabilitation/replacement costs have increased from $1 per mile per year to $2,836 per mile per year. The O&M budget has increased from $3 per mile year to $2,796 per mile per year in the 1990s. The average cumulative dollars spent on system maintenance has increased from $5 per mile per year in the pre-1970s era to $8,000 per mile per year in the 1990s.

Pipe failures, SSOs, customer complaints, and pump station failures were considered the most critical performance measures. The average reinvestment was $2,594 per mile per year, which corresponds to an average performance rating of 71 percent. Reinvestment for the period from 1980 to 1996 increased to $9,328 per mile per year in 1996 costs. A high correlation for both time periods was observed between the reinvestment amount and the following independent variables:

- Average age
- Pipe failure rate
- SSO rate
- Pump station failure rate
- Peak hour/average daily flow rate
- Customer complaint rate
- Pump stations per mile of system
- Regional code.

Due to agencies trying to "catch-up" with system needs and to comply with Environmental Protection Agency requirements, the $9,328 per mile per year may be higher than the average reinvestment rate needed to properly maintain a collection system.

Based on data collected from the agencies, it was assumed that a desirable range of system performance would be from about 65 to 80 percent. The data show that a moderate reinvestment level of $5,200 per mile per year to $6,500 per mile per year would be required to achieve this performance. Once the existing maintenance frequency, performance rating, and reinvestment rates are determined, optimization of maintenance can be evaluated.

70. Romans, K.; "Chemical Grouting Longevity Research and Case Studies," WEFTEC 2001

Collection system managers have many options when it comes to sewer rehabilitation. However, chemical grouting remains the most cost effective method to reduce and eliminate unwanted groundwater flow into sewage collection systems.

Interviews with Water Quality Coordinators at the state government level have resulted in a consensus of permanence as 25 to 30 years, and the US EPA guidance documents refer to permanent as a remedy with a 30-year life.

Chemical grouting has been utilized longer than any other rehabilitation technology and has continued to perform for more that 20 years. Chemical grout placed in the soil does not dehydrate, crack or disintegrate during wet/dry cycles or freeze/thaw cycles. Chemical grout is cost effective when analyzed based upon the Water Environment Federation and US EPA guidance used to estimate the amount of I/I that could be eliminated as compared to the cost of the expanded physical facilities.

71. Atalah, A., "Cost Comparison Between Open Cut Construction and Pipe Bursting for the Repair of Tripler Army Medical Center Sewer Line Project," WEFTEC 2001

The repair of Tripler Army Medical Sewer Line project consisted of installing 937 feet (285.60m) of 20 inch (0.51m) ductile iron pipe by open cut, three connections to existing sewer lines, and six manholes. The sewer line profile indicates that the depth of the new sewer line ranged from 7 feet (2.13m) to 28 feet (8.53m).

The US government was the owner of the project, represented by Tripler Army Medical Center and the US Corp of Engineers, Pacific Ocean, Honolulu District, Hawaii. The estimated construction cost for the project, based on the open cut construction method, was $321,433. The cost of excavation shoring and disposal of surplus material is about 45 percent of the total cost. The saw cut excavation and restoration cost amounted to 10 percent of the total cost. The scheduled total construction time for construction was about seven weeks. It was a challenge to prevent the trench from collapsing and to provide a safe working environment at the bottom of the trench due to the nearby live loads and the after hour traffic over the steel plates.

As a result of these conditions, the scheduled construction time for completion was tripled (about seven months). The actual total construction cost for this project increased between two and three times the estimated construction cost. The estimated cost for the bursting alternative was $227,402. It is about 71 percent of the estimated cost based on the open cut method and at least 38 percent of the actual cost of construction.

Pipe bursting is an economical solution for sewer line replacement projects compared to open cut construction. The cost savings can amount to more than 10 to 15 percent if conditions are favorable to pipe bursting.

72. Chan, W.; "Sectional Pipe Installation and Existing Pipe SAG Correction by Pipe Bursting Technique," WEFTEC 2001

Pipe bursting is rapidly becoming an accepted method for trenchless pipe replacement. It also permits the diameter of the new pipe to be increased up to 300 percent by the up-sizing capability of this technology. Pipe bursting is recognized as the only methodology in trenchless rehabilitation that can replace an existing pipe with a completely new pipe of equal or larger diameter, to maintain or allow an increase in flow capacity. Existing pipe materials capable of being replaced by pipe bursting are those manufactured with friable materials. These types of pipe include but are not limited to the following: Clay tile, Concrete and certain reinforced concrete,
Polyvinyl chloride (PVC),
Cast iron,
Ductile iron,
Thin wall steel pipe,
Asbestos cement,
Fiberglass, and
Other pipes made of friable materials.

New or replacement pipe materials that have been installed by the pipe bursting method include the following:
High density polyethylene (HDPE),
Vitrified clay pipe (microtunneling grade),
Reinforced plastic mortar microtunneling pipe,

Hobas,
Ductile iron,
Steel, and
Polyvinyl Chloride (PVC).

Heavy wall HDPE pipe with added stiffness may correct or limit the existing sag in a pipeline after replacement. However, ground movement, soil condition, and added weight of the heavy wall pipe may allow reoccurrence of sag in the future. HDPE pipe is extruded with fixed outside diameter dimensions, therefore the heavier the wall thickness, the smaller the inside diameter of the new pipe. For effective correction of sagging in an existing pipeline using the pipe bursting method, employing sectional pipe has been proven to be successful.

73. Holmberg, D., et al.; "How to Implement an Automated Service Lateral Program," WEFTEC 2001

The Water Works and Sanitary Sewer Board of the City of Montgomery (Board) are comprised of nine members who are nominated and elected by the City Council of Montgomery, Alabama. In 1994 the Board initiated an I/I source detection program of manhole inspection and smoke testing. These activities were undertaken primarily to locate defects that quickly entered the sewer and generated peak flow rates in the sewer.

Of the 1,239 service lateral problems, about 591 (48 percent) were upper lateral and 648 (52 percent) were lower lateral related. Almost one quarter of the service lateral problems (24 percent) were a matter of restoring or replacing the cleanout cap. After performing these activities on about 865,000 linear feet of mainline sewers, the work indicated that 1,239 of 1,338 (93 percent) defects observed were service lateral problems. A maximum cost ceiling to the property owner for all repairs to the lower lateral was established at $1,200. The Board assumed the remainder of any cost over that amount. As of the spring of 1999, the Board has done lateral work in 35 of 113 sub-basins within the three main service basins, of which 23 have been completed and 12 are in the process of being completed. Nearly 2.2 million linear feet of mainline sewer (does not include service lateral lengths) were smoke tested since the start of the program. During that time, 3,394 defects were found, of which 518 were found on mainline sewers or manholes. The remainder of the defects (2,813) was on service laterals. Of these, 1,628 involved the cleanout in some way. For instance, the cleanout cap was missing or the cleanout casing was broken. For the 23 sub-basins that were 100 percent completed, the Board successfully completed 2,197 (97 percent) of the lateral defect repairs using the lateral program process. The remaining 3 percent were primarily defects located on abandoned or unoccupied property. The following is the service lateral summary:

- Number of sub-basins where lateral work was performed: 23
- Sewered area: 11,076 acres
- Linear feet of sewer: 1,520,720
- Number of smoke defects located (all types): 2,649
- Number of lateral defects successfully repaired: 2,197.

- The Board performed post-rehabilitation flow monitoring for four of the 100 percent completed sub-basins where the repairs could be attributed primarily to service laterals. For each of the four sub-basins, a planned 20 percent reduction was estimated. The average I/I reduction was measured at 42 percent (ranged from 23% to 78% in the four sub-basins). A total of 350 lateral repairs were estimated to reduce the annual I/I volume of 36 million gallons, which equated to about 100,000 gallons per year of I/I reduction.

97 percent of lateral defects were repaired by the property owners. 65 percent of the property owners corrected their lateral problem in response to the first notice. However, about 247 property owners had to have their water disconnected before they completed the required lateral repair. Of those, 62 property owners did not respond to the disconnection, primarily because the property building was vacant or previously demolished.

74. Zieburtz, W.B.; "Sanitary Sewer Lateral Repair and Rehabilitation: The Other Side of Economics," WEFTEC 2001

In recent years, it has been recognized that private building sewer connections (laterals) contribute significant amounts of I/I. Rehabilitation efforts focused solely on public sewer mains will not achieve as much reduction in I/I as is desired during study and analysis phases. But in 1981, Conklin completed a study for the EPA, where he noted that many sewer rehabilitation programs eliminated about 20 to 30 percent of I/I despite predictions of 60 percent to 90 percent removal.

It was concluded that building connections and non-rehabilitated pipe joints were the primary sources of remaining I/I, with private sources contributing 50 percent of the remaining total. Only three percent of the agencies surveyed describe themselves as being responsible for maintaining private laterals, but 26 percent of the agencies have assumed this responsibility for themselves in some fashion. Additionally, 38 percent believe they have the jurisdiction to repair private laterals in some circumstances. Leaking private building sewer connections cost utilities money, but these laterals are expensive to rehabilitate. Normal and appropriate cost-benefit analyses can document the need for a program, and detailed cost comparisons between alternative technologies can identify the best techniques for each situation.

If a utility intends to invoice homeowners for the cost of repairs to private laterals, or require that homeowners make needed repairs at their own expense, an increased level of outreach will be beneficial.

The City of Tulsa, Oklahoma has been able to make adjustments to the City Code to define I/I from private laterals as a public nuisance. Given this designation, the City can act to relieve the nuisance, and recover the cost through a lien on the property.

75. Holstad, M.S., et al; "Grit Buildups in Large Sewers - Projections versus Real World," WEFTEC 2001

The City of Phoenix's wastewater collection system includes about 4,000 miles of sewers, ranging in size from 8- to 90-inch diameters, and over 72,000 manholes. The City of Phoenix and other local municipalities have formed the Sub-Regional Operating Group (SROG), a wastewater collection and treatment partnership to provide wastewater collection and treatment for the common good of the membership communities. Grit depositions have caused operational difficulties in the collection system. Grit depositions are known to be a prime contributor to collection odor problems.

The grit evaluation includes grit volume estimates, system impacts and grit control strategies. The primary inspection method is closed circuit television (CCTV). The project started August 1999 and is scheduled for completion October 2001. For the purposes of this study, a grit problem was defined as the condition in which the tractor could not pass through the sewer due to the depth of debris. This was recorded as a "survey abandon" on the CCTV report.

76. Lukas, A.; et al; "In Search of Valid I/I Removal Data: The Holy Grail of Sewer Rehab?" WEFTEC 2001

If an agency could reduce stormwater I/I intrusion, then pipe or plant expansions, or the need for a new treatment plant could be deferred, thus potentially saving local ratepayers several millions of dollars. As of September 1, 2000, 44 utilities had been contacted, 28 of which have completed preliminary screening questionnaires. It is evident that not many communities have gathered sufficient data. For reviewing the short-listed projects in more detail, the WERF Project Review Committee (PRC) developed a comprehensive list of data to be collected in the following areas:

- System conditions
- Project information
- Evaluation methodology
- Rainfall records
- Data compilation method used
- I/I quantification method used.

To date, efforts to obtain data from agencies have been only partially successful. Good data have been obtained from five of the agencies. The I/I removal achieved in each of the projects reviewed will be estimated using a common technique. An I/I simulation model will be calibrated to before and after project flow and rainfall data for each project. Review of the literature and agency questionnaires collected to date indicate the following general methodologies for prediction of I/I:

- Local experience: For example, the observation activities in Nashville indicate an expected I/I reduction of 12-million gallons/year/1000 ft of sewer relining
- Assignment of I/I rates to observed defects: This method assigns flow rates (either by direct observation or from an experiential database) to defects observed in CCTV or smoke testing activities. Predictions are made by calculating the remaining I/I assuming elimination of all or a portion of these defects.
- Assignment of a quantity of I/I removed by rehabilitation of a specific component of the sewerage system: In this method, the quantity of I/I assigned by engineering calculation for rehabilitation of a manhole is X gpm. Removal attributed to manhole rehabilitation is then the product of the assigned rate X and the number of manholes to be rehabilitated.
- Estimation of removal based on simulation model: In this method, a hydrologic simulation model is constructed including parameters intended to estimate infiltration and/or rehabilitation
- Assignment of an I/I rate after project implementation: In this method, a base rate of I/I is assumed after rehabilitation. The base rate is typically a result of local

experience. For example, one city assigned a remaining I/I rate of 5,000 gpad in a two-year storm after completion of "limited comprehensive rehabilitation."

For fair comparison, a single standard must be established for after-construction I/I of each project. This will be based on a rainfall-dependent I/I model and statistically analyzed peak flows. Many of the projects evaluated already had estimates made for the success of I/I reduction it caused. None of the information between projects was comparable, due to the many differences that can exist between projects. These differences can range from drainage area of the flow meter basin, amount of RDII present prior to rehabilitation, and the amount of system rehabilitation performed.

The City of Oak Creek conducted a pilot study for removal of foundation drain flows in a 51-acre residential basin. A six inch PVC drain line was laid on both sides of the street. This drain line was hooked to the existing storm drain system where convenient. Four-inch capped connections were installed at intervals of 90- to 200-feet. The homeowners were required to re-direct flow from their foundation drains. The City provided no funding assistance. The average cost incurred by the homeowners is reported to be about $300. The City cost to install the collection drain was about $218,000. Flow data was received for pre- and post-rehabilitation periods.
The 58-year rainfall record from the Mitchell gage was used to compute a 58-year RDII response from both pre- and post-rehabilitation models. Annual maximum hour flows from these records were analyzed using a Log-Pearson Type 3 analysis to develop a return period relationship. From these relationships, it is estimated that the project reduced the peak hour RDII with a 10-year return period by about 50 percent.

The City of Olympia conducted I/I removal pilot studies in two residential basins. Phase 1 consisted of replacement of the agency's mainline sewers along with a portion of building side sewers within the public right-of-way. In phase 2, the remainder of the private sewers were replaced from the property line to the house connection. Data received were analyzed in the same fashion described above for the Oak Creek project. I/I reduction for the 10-year event was only 17 percent for Phase 1. After replacement of private sewers in Phase 2, the reduction increased to a total of 67 percent. This result is consistent with other observations that rehabilitation of the public sewers only provides a relatively low I/I reduction. In the other basin, only private sewers were replaced on private property. Out of a total of 334 private connections, 64 were replaced. Replacement of 20 percent of the side sewers resulted in about a 50 percent reduction in 10-year RDII flows.

A documentation protocol for I/I reduction projects would be appropriate. Project background information includes a description of the sewer system and its surroundings. The types of information that should be included in the background information are as follows: type of system (separate or combined), system characteristics (length, inch-miles, number of manholes, number of connections, materials, previous rehab), and basin characteristics (topography, land use, total area, sewered area, soil types).

The information must be gathered for both the pre-construction period and the post-construction period. SSES data for analysis should include flow monitoring, sewer CCTV, smoke and dye testing, manhole and building inspections, and adequacy of storm drainage system.

The project details should consist of the "What was done and where" answers. Specific information to include is

the portion of flow was repaired (number of connections, length of sewer, number of manholes)

how much the project cost and the break down into project elements (inflow sources, sewer mains, manholes, private service laterals).

The post construction evaluation of the project is the final step of documenting the I/I project. The step consists of two key elements: 1) rainfall and flow monitoring, and 2) data evaluation. Determining pre- to post-construction I/I reduction depends upon a comparison of I/I characterizations during the two time periods. Several approaches have been used for performing the pre- to post-comparisons:

- Comparison of the R-factor relationship of I/I volume to rainfall between a rehabilitation and control (non-rehabilitation) basin
- R factor correlation method with envelope analysis
- Statistical comparison of continuous simulation models.

If more projects were reported according to this protocol, there would be ample data for municipalities to predict I/I removal prior to constructing projects.

77. Nelson, R., and Lyon, T.; "Sewer Design Practices - Are We Using the Right Criteria or Creating More SSOs," WEFTEC 2001

In this paper, actual data from I/I studies for 20 wastewater agencies in six states (Kansas, Kentucky, Minnesota, Missouri, Ohio, and Texas) are presented and compared, and guidelines for appropriate sewer design criteria are developed.

Average dry weather wastewater flow (ADWF) includes base sanitary flow plus dry weather infiltration/inflow (I/I). The most commonly used value for ADWF is 100 gallons per capita per day (gcd). The average value for the seven agencies is 131 gcd, with a range of 103 gcd to 153 gcd. In terms of flow per tributary acre, the average value for five agencies is 1,132 gpad, with a range of 897 gpad to 1,295 gpad.

Average infiltration is the difference between average annual daily flow and average dry weather flow. Average infiltration rates vary from nearly 35,000 gpd/idm for a tributary area with 240 idm of sewers, to about 200 gpd/idm for tributary area with 6,200 idm of sewers.

The average value of peak wastewater flow is 1,022 gcd, with a range of 451gcd to 2,343 gcd. In terms of flow per tributary acre, the average is 8,853 gpad, with a range of 4,920 gpad to 15,528 gpad. Key findings are a follows:

- Actual peaking factors for average flows less than 1.5 mgd typically exceed those predicted by the Babbitt Equation
- For two agencies, actual peaking factors exceeded those predicted by the Babbitt Equation for average flows up to 5 mgd and 7 mgd

- Actual peaking factors for average flows less than 3.5 mgd typically exceed those predicted by the 10 States Standards Equation
- For two agencies, actual peaking factors exceeded those predicted by the 10 States Standards Equation for average flows up to 9 mgd
- One agency had actual peaking factors that exceeded those estimated by either equation for average flows up to 7 mgd.

The data analyses serve several important purposes:
- Illustrate some of the evaluations that should be made of existing sewer monitoring data to arrive at design parameters for sizing relief sewers or for system expansion
- Show that use of older sewer design equations are likely to result in undersized sewers and potential sanitary sewer overflows
- Demonstrate both the similarities and the differences in the magnitude of major wastewater flow components from basin to basin and agency to agency. Comparing the various values provides measures for benchmarking sewer system performance.
- Underline the importance of having system-specific flow data
- Indicate that there is no consistent use of measurements for assessing I/I across a sampling of agencies over the past 15 years or so. There needs to be more uniformity of analyses to allow better information sharing and comparison of values.

There are clear indications that average per capita dry weather flow allowances need to be increased to better account for actual average infiltration quantities. Estimating peak flows by using a per tributary acre design curve that decreases as the tributary area increases appears to have the most merit.

78. Morgan, T.R., et al; "Managing Risks and Preserving Assets: Meeting the Challenge," WEFTEC 2001

The Water Works and Sanitary Sewer Board of the City of Montgomery (Board) is responsible for providing treatment and distribution of potable water and collection and treatment of sanitary sewage for about 225,000 people in the City of Montgomery, Alabama, including one water treatment plant, two groundwater pumping stations, two well fields, four wastewater plants, about 1,000 miles of water mains, and 1,000 miles of intercepting and collector sewers.

The Board plans to develop a management process for determining the useful lives of these assets and for preparing long-range plans for renewing, rehabilitating, and replacing these critical assets.

The objective of Phase 1 was to apply an approach to capital renewal planning, known as Infrastructure Capital Assets Management (ICAM), to the Towassa collection basin to evaluate the usefulness of this approach. The Towassa basin collection system includes about 52 miles of sewers and 10 pump stations, and has a replacement value of about $37 million.

Many wastewater utilities are not mandated to follow GASB Statement 34 because they are set up as enterprise accounting institutions. However, the EPA, bond rating institutions, oversight agencies, and the public will expect utilities to voluntarily comply and use the asset preservation approach to asset management. For the asset preservation, or "modified" approach, laid out in GASB 34, the following is required:

- Up-to-date inventory of infrastructure assets
- Standards for the condition level at which the assets will be preserved
- Replicable condition assessments reported on a measurement scale and performed at least every three years
- Estimates for each year of the annual funding amount needed to preserve the assets at the established condition level standard.

The ICAM process for capital renewal includes the following basic steps:

- Catalog assets in an asset register, which includes key attribute information such as replacement value
- Perform a condition assessment to determine deficiencies that need to be addressed in the near future
- Establish capital renewal schedules for anticipated future renewal, rehabilitation, and replacements
- Develop funding scenarios based on policy considerations that will provide varying levels of funding for correcting deficiencies and for performing future capital renewal
- Calculate Asset Condition Index (ACI) and Asset Risk Index (ARI) for individual assets, sub-systems and asset groups, and the entire system
- Calculate the financial implications of the funding scenarios, including effects on borrowing needs and rates.

Capital renewal schedules include the eventual replacement of assets. Projects are developed to correct any defects that are identified and entered into the ICAM Toolkit. A defect is defined as a condition in an asset that currently impairs, or is likely to impair in the near future (two to five years), the asset's ability to perform at its design intent. A five-level condition ranking classification, A through E, was used to describe the condition of the pipelines in the Towassa system as follows:

- Condition Ranking A: Nominal life expectancy 50 years. Condition description: New asset.
- Condition Ranking B: Nominal life expectancy 20 years. Condition description: In place for more than 20 years, but no known defects.
- Condition Ranking C: Nominal life expectancy five years. Condition description: Obvious problems, but not an immediate risk of catastrophe failure, and functional performance not hindered.
- Condition Ranking D: Nominal life expectancy one to two years. Condition description: Obvious problems, high risk of catastrophic failure, or effects on surroundings or public.
- Condition Ranking E: Nominal life expectancy more than one year. Condition description: Currently at catastrophic failure status or effects on surroundings or public.

The Board staff determined that there are no D or E condition pipes in the Towassa system. About 13 percent of the C ranked sewer pipes have problems and a life expectancy of only five years. There are 9.1 miles of condition A pipe, 35.6 miles of condition B pipe, and 6.9 miles of condition C pipe. Condition ranked C pipes are considered defective and projects were entered to replace or rehabilitate the pipes during the next five years.

Point repairs are made when defects are discovered, usually involving replacing one or two sections of pipe. An average of 1.0 defects per 1,000 feet of pipe was revealed. Board staff estimates that there was no backlog of manhole defects. Manholes were given an overall condition raking of B and are assumed to have a nominal 20-year remaining life. Force mains are considered to have an expected life of 50 years.

Capital renewal schedules were developed for rehabilitating, reinstating, and replacing the assets in Towassa. These schedules consist of renewal projects that are expected to be required during the next 40 years. The two elements that determine risk levels are the severity of a negative impact and the probability of its occurrence.

79. Girma, E., et al.; "Not Your Average Wallpaper Rehabilitation of the Wood Street Interceptor," WEFTEC 2001

East Bay Municipal Utility District (District) provides wastewater treatment for seven member communities with a total average daily flow of 80 mgd. The District owns and operates a wastewater interceptor system that consists of 30 miles of gravity pipelines, 7 miles of force mains, 14 pump stations, and four wet weather treatments and storage.

Most of the interceptor system was constructed in the early 1950s of unlined reinforced concrete. Several portions of the gravity pipelines have experienced severe corrosion, including the 105-inch-diameter Wood Street Interceptor. The Wood Street Interceptor is approximately 9,000 feet long and was constructed of cast-in-place reinforced concrete in a thumbnail shape. The interceptor is used to equalize wastewater flow into the District's treatment plant. Wastewater flow is backed up every day and pumped out at night. This results in high sulfide concentrations in the wastewater, sediment in the invert of the interceptor, and severe corrosion at the crown of the pipe which is not submerged by the daily back up of flow.

Extensive field investigations including man-entry manhole inspection, concrete corings, wastewater sampling, CCTV inspection, and walk-through inspections were conducted. Corrosion modeling was also performed to estimate the remaining useful life of the interceptor system. The results of the corrosion modeling indicated that the Wood Street Interceptor should be rehabilitated within the next 10 years.

A walk-through inspection was performed on the portion of the interceptor rehabilitated in 1993 with the Danby process. The walk-through revealed that the Danby liner was in excellent condition after five years of service. The pipeline rehabilitation methods considered were localized spot repairs and crown spraying, replacement, exterior encasement, cured-in-place pipe (CIPP), sliplining, and plastic lining.

Two types of sliplining were evaluated: round and horseshoe-shaped. The plastic liners considered were provided by Danby, Ameron (T-lock), Rondeau Bay Technologies, and Linabond. Sliplining would have an adverse impact on the interceptor hydraulics and were eliminated. Replacement and exterior encasement would be too disruptive to the local community, as would the bypass pumping required for CIPP. Spot repairs and crown spraying would not provide a long-lasting solution. Plastic lining was the best overall method and had an estimated construction cost of $11.6 million. Since the interceptor must stay in service, entry was limited to early morning hours when flows were low. This gave an in-pipe working window of no more than six hours.

With the Danby system, self-forming PVC sheets were installed and cementitious grout was placed behind the sheets in several lifts over several days. The lower terminations of the PVC liner where it anchored to the existing pipe were designed to support the weight of the grout and PVC. With the Linabond system, a high strength polymer is sprayed on to the surface of the pipe. The polymer expands in an exothermic reaction to form a section of rigid cellular plastic that adheres to the concrete pipe surface. A thin flexible PVC liner (impregnated with the polymer) is placed over the sprayed-on layer before it sets. Installation is significantly faster than with the Danby system.

80. Hix, D., et al.; "The City of San Luis Obispo's Voluntary Service Lateral Rehabilitation Program," WEFTEC 2001

The City of San Luis Obispo's wastewater collection system and Water Reclamation Facility (WRF) have been experiencing problems associated with excessive wet weather Infiltration and Inflow (I/I).

Past projects dealing with I/I have included construction of a $750,000 equalization basin at the WRF in 1983, installation of a $5 million relief sewer in 1990, and spending significant amounts of money upgrading WRF capacity to handle the storm flows.

During March of 1995, the WRF experienced flows of over 25 million gallons per day (MGD) and used $40,000 in chlorine during that month to disinfect the partially treated wastewater. During dry weather the average effluent flow is 4 to 4.5 MGD.

Two basins in the City's collection system were evaluated. The investigation showed that the largest contributor of rain dependant I/I in Basin B was privately owned service laterals. Staff developed a Voluntary Service Lateral Rehabilitation Program (VSLRP) for the City. The VSLRP is similar to other City programs such as the toilet retrofit rebate, fire sprinkler lateral, and seismic retrofit program, and has been extremely successful for the City. The program reimburses 50 percent, up to $1,000, of the work performed by a contractor to correct defects or replace their lateral. Below is a brief description of the VSLRP:

- Staff provide a report to the homeowner providing direction about the minimum amount of work that needs to be performed to the lateral to comply with the program
- If other deficiencies are discovered, City staff will visit the site and authorize further work to be performed
- Any work that does not meet specifications will not be accepted and must be brought up to City specifications before costs will be reimbursed
- Eligible costs are those necessary for the evaluation and repair of the lateral. The homeowner will only be reimbursed for the work performed by a contractor that was recommended by the City.

Currently the program has annual funding of $75,000. The City of San Luis Obispo's VSLRP program has replaced or repaired over 200 laterals since it inception in 1997. Because most repairs/replacements have been running well over $2,000, staff are considering recommending a funding increase to encourage more participation.

81. Roll, R.R., et al.; "Correction of a Six Million Gallon per Day Tunnel Infiltration Problem Under a Performance-Based Energy Services Agreement," WEFTEC 2001

The City of Niagara Falls, New York (City) operates a combined sewer collection system. It serves about two-thirds of the City, while separate storm and sanitary sewers serve the remainder. One component of the combined system is the Fall Street Tunnel (FST), a three-mile long tunnel crossing the City from east to west. It was constructed between 1894 and 1923, and ranges from a 6-ft. by 7-ft. section 30 feet below ground level (bgl) to an eight feet by 8 feet section 70 feet bgl near its discharge to the lower Niagara River. The outfall is at river level, about 200 feet below the top of the Niagara Gorge.

It was decided to construct a new treatment plant. The Gorge Pumping Station (GPS) is located about a mile down stream from the American Falls, halfway between the top of the gorge and the river. The plant capacity is 48 million-gallon per day (mgd). The facility has achieved its pollutant discharge limits with a 99.993 percent compliance rate.

In the early 1980's, the carbon system was offline. Dry weather tunnel flow (comprised of groundwater infiltration at many locations) at that time varied from about 11.5 mgd up to 15.5 mgd. A United States District court found the dry weather discharge from the tunnel to be an unpermitted, illegal point source. The goal was to terminate dry weather discharge from the FST, and was accomplished by the following actions:

- Open the orifice plates, re-establishing a flow pathway to the GPS
- Construct a small dam ahead of the FST Parshall Flume to divert flow from the tunnel discharge toward the GPS
- Rehabilitate the pumps, motors, drives, and other related equipment at the GPS to more reliably handle the increased flow
- Perform leakage reduction work in upstream tunnel sections.

Of the roughly 10 mgd of dry weather infiltration which the FST contributes to the GPS, six to seven mgd was leaking into a 200 foot stretch of tunnel from a power conduit crossing. A smaller amount of leakage, less than half the downstream leakage, was entering the upstream section. Alternatives to remove or reduce the flow were evaluated. The approach with the least cost and highest degree of confidence involved a grouting program.

- A series of grouting holes drilled along each side of the tunnel would allow the creation of a concrete cocoon around the tunnel. If the project were only 60 percent successful, the remaining flow would allow turning off one 500 horsepower gorge pump in dry weather. This would result in a simple payback of less than five years from the $1.5 million project.

The grout mixture water/cement ratio varied for 0.6 to 3.0. Over the course of the 3 month construction duration, about 150 tons of grout were pumped into 81 holes. The fall 2000 leakage rate of 5.8 mgd was reduced to a spring 2001 rate of 1.6 mgd, a difference of about 4.2 mgd. Average dry weather pumping from the GPS reduced commensurately, from about 16.5 mgd in October, 2000, to a little more than 12 mgd in January 2001.

82. Wong, P., et al.; "San Diego Experience: Application of New System for Sanitary Overflow Early Detection," WEFTEC 2001

The City of San Diego's Metropolitan Sewer System serves a population of 1.9 million and an average annual flow of 7.89 m^3/s (180 mgd). The service area includes the City of San Diego (the City) and 15 other agencies in a 1,165 square-kilometer (450 square-mile) area. A network of trunk sewers and interceptors ranging up to 2,890 mm (114 inches) in diameter convey the wastewater to the City's Point Loma Wastewater Treatment Plant and ocean outfall. The collection system facilities within the City itself (representing about 70 percent of the total Metropolitan System) include approximately 4,667 kilometers (2,900 miles) of sewer pipes, in which 547 kilometers (340 miles) are trunk sewers with size of 380 mm (15 inches) or larger in diameter. The collection comprises 81 pump stations and over 55,000 manholes. The City's Metropolitan Wastewater Department (MWWD) is responsible for the engineering, operation, and maintenance of the entire City's collection system.

Although the majority of spills recorded in the past were caused by root, grease, or other obstruction in small mains, the majority of the spill volume was associated with wet weather conditions.

In February 2000, an estimated 34 million gallons of raw sewage spilled from a 533-mm (21-inch) trunk sewer along the Alvarado Canyon. The spill resulted in beach closures, environmental impacts, and a $3.4 million fine against the City by the California Regional Water Quality Control Board. In 1995, a total of 429 spills were reported, of which 99 reached public waters. The total spill volume reaching public waters also decreased from 50,000 m^3 (13.2 million gallons) in 1995 to 1,080 m^3 (285,000 gallons) in 1999. The City had taken a number of remedial actions soon after the Alvarado spill.

The City installed a Flow Metering Alarm System (FMAS) by September 2000 to provide early warning for major sewage spills. Overflows from sewers in canyons or easements are much more likely to go unnoticed and unreported than overflows from sewers in streets. Of the City's 547 kilometers (340 miles) of trunk sewers, 225 kilometers (140 miles, 41%) are in canyons or easements.

The most effective way to detect a spill is by monitoring for a drop in flow in the trunk sewer downstream from the spill. Surcharging at the monitor may also be an indication of a potential overflow in the immediate downstream of the monitor. The objective of the FMAS is to detect monitored flow conditions, which are indicative of possible sewage spills or loss of flow conditions at 96 permanently installed alarming flow meters.

Each meter, programmed with ADS's Monitor Level Intelligence (MLI), continuously records flow depth and velocity, and detects anomalies such as high depths (indicative of a downstream blockage) and/or flows that are lower that normal for that time of day based on historical data (indicative of a upstream spill). When a potential anomaly is detected, the programmed alarm meter transmits an event alarm along with the flow data to the IntelliScan server for further validation. Based on the historical flow data and flow patterns for this meter, the IntelliScan software in the server will do further data analyses and quality control to verify the validity of the event alarm issued by the meter. Once the validity of the event alarm is confirmed, the IntelliScan will issue the spill warning to the operator on duty at the central control room through monitor screen flashing and phone paging. The operator should then conduct a final check on the suspected spill event using IntelliScan's functionality and other available collection system information. Informing the collection system crews for the field inspection should be the last means to verify the spill event. Emergency remedial actions will follow if required.

False alarms were often recorded. Some were due to erratic data patterns and/or stringent alarm limit settings, while others were due to code errors or data mis-interpretations.

83. Harlow, V.K.; "Asset Management: The Life-Cycle Approach," WEFTEC 2001

Utility managers are realizing that stronger asset management programs will help them achieve several important objectives:
- Improved regulatory compliance
- More meaningful financial reporting
- Improved reliability
- Long-term system integrity
- Eligibility for federal funding.

The US EPA estimates that improved asset management will likely result in savings of at least 20 percent of the costs of asset ownership. These are three important concepts in asset management:
- Each and every asset is managed on an asset-by-asset basis
- Each asset is managed against a plan, there is a plan for each asset
- Management of each asset follows a management cycle.

Asset management activities in terms of each step in the cycle are:
- Plan - A life-cycle plan is created for each asset. This plan includes all the activities associated with acquisition, maintenance, periodic refurbishments, disposal, and replacement of the asset
- Direct - Resources are allocated and asset-related activities are managed in accord with the life-cycle asset plan
- Measure - Costs of the activities directed in the previous step are measured, also in an asset-by-asset basis. The impacts of these activities are also measured, primarily through a condition assessment program.
- Control - Based on the results of our measurements, the asset plans are updated, which may involve re-allocating resources toward or away from each asset.

True asset management is a different way of doing business for most utilities:
- Fundamental change - Asset management is a fundamental change in the way a utility operates. It does not have a defined ending point; it is a continual cycle of improvement, a permanent change.
- Detailed measurement - Asset management depends on continuous measurement, feedback, and updating of asset plans
- Increased accountability - Asset management shines a clear light of accountability on people involved in procurement decisions, IT systems, and capital management, as areas of inefficiency are spotlighted
- Inter-function cooperation - Engineering, planning, finance, O&M, and information systems must work together closely.

84. Cavanagh, H.; "How JEA Saved Millions on a High Volume Pipe Bursting Contract," WEFTEC 2001

JEA is the major utility company providing water, sewer, and electrical services in the greater Jacksonville, Florida, area. JEA is committed to spend $200 million for sewer repair projects in the City of Jacksonville, Florida. Infiltration into the gravity sewers was creating a high number of sanitary sewer overflows (SSOs), approximately 1,500 per year. After comparing the performance and costs of repair techniques, pipe bursting was chosen as the preferred method. JEA then developed a bid package for bursting 150,000 feet of pipe per year for five years with one five-year renewable option. JEA fixed the price for items such as sidewalks, pavements, and curb and gutter replacement at an average cost based on previous bids. By applying the estimated costs from the Business Plan, JEA inserted target prices for critical items, such as pipe bursting and service connections. A maximum total price of $16 million was established. The production goal for the contract has since been increased to 90 miles for the first year and 120 miles for the next four years, for a total potential saving in five years of $84.3 million.

Two bids were received, both of which were below the maximum price. The bid totals for one year's worth of work were $14,844,600 and $15,385,100 both of which were below the maximum allowable price of $16,000,000. Their bid was approximately $109 per foot (all costs included) compared with an average cost of $137 per foot on previous projects, for a saving of 20.4 percent. For a 150,000 foot contract, this amounts to a saving of $4.2 million per year, not including savings in administrative costs.

The major advantages of pipe bursting over open-cut are as follows:

- Less expensive at $125/lf vs. $175 to $200/lf
- Faster to design and install, taking one-sixth or less of the total time
- Less neighborhood disruptions
- Fewer customer complaints
- Pipes can be upsized.

JEA developed their own Business Plan for a pipe bursting contract with 200,000 linear feet of pipe. The major components of the plan included salaries for three crews, per diem expenses and housing, materials, and overhead. The plan also included 20% for profit and 10% for contingency. The results indicated a cost per foot of $100.98.

By setting target and maximum prices in the high volume pipe bursting bid, JEA was able to control their costs and realize 20% savings.

85. Sullivan, M.O., et al.; "Implementation of the Private Sanitary Sewer Lateral Replacement Program (SSLRP) in Suburban Mobile, Alabama," WEFTEC 2001

The Mobile, Alabama, Mobile Area Water and Sewer System (MAWSS), evaluated many methods to reduce inflow and infiltration (I/I) into its sanitary sewer collection system.

Severely deteriorated sanitary sewer laterals make up about 65 percent of the collection system piping. These laterals may be responsible for up to 70 percent of the I/I measured in theses areas. Since approximately 60 percent of the sanitary sewer laterals lie on private property, the Private Sanitary Sewer Lateral Replacement Program (SSLRP) has been employed since January 2000, which requires property owners to replace defective sanitary sewer laterals on private property outside of easements or public right-of-ways. Under the SSLRP, the entire length of the private sanitary sewer lateral (PSSL) is replaced rather than in a piecemeal approach. This program also supplements the I/I reduction efforts of limited-area sewer rehabilitation projects and ongoing annual contracts for system-wide manhole rehabilitation, point repairs, and cured-in-place pipe installation.

Priority areas were identified as those areas that have an average increase in excess of 5,000 gallons/day/inch-mile during a one-inch rain event when calculated as follows, or when there is a 5,000 GPD flow increase per 1,000 linear feet of main due to any rain event.

The SLRPP is executed through separate publicly bid annual contracts. Structuring the SSLRP in this manner ensures that the unit prices for PSSL replacement work items are competitively bid, thus minimizing costs for property owners.

The amount transferred to the property owner is the sum of costs for each work item minus the cost for one (1) cleanout, one (1) site video consisting of a pre-construction and post-construction internal video. The cost of these items is assumed by MAWSS. To date, about 20,500 linear feet of laterals have been replaced. Assuming that an average of 50 linear feet of lateral has been replaced for each property and assuming that each remaining property will require PSSL replacement, a total of more that 30,500 linear feet of lateral pipe should ultimately be replaced in these areas.

86. Hassey, P., et al.; "Grease Impact Assessment Rehabilitation Pilot Project," WEFTEC 2001

The County Sanitation District No. 1 (CSD-1) of Sacramento County, California, is completing a two-year project on the impact of grease accumulation in selected areas of their collection system. CSD-1 provides wastewater collection to the developed and unincorporated areas of Sacramento County, the Cities of Citrus Heights and Elk Grove, and portions of the Cities of Sacramento and Folsom. This service covers about 270 square miles and includes approximately 2,180 food preparation businesses, mostly restaurants.

The goals of the project are to develop alternatives that mitigate grease impact, reduce operating costs, reduce blockages and overflows in the collection system, improve customer service, and work within the framework of the SSO and CMOM requirements.

A survey of 21 agencies nationwide with grease handling programs was conducted. Grease blockages account for 44 percent of the total annual mainline stoppages. Grease blockages from restaurants accounted for seven percent of the total annual mainline stoppages in the collection system. Grease stoppages attributed to restaurants accounted for 36 percent of the annual mainline stoppage flooded claims mitigation costs.

In the past four years, CSD-1 has experienced 88 mainline stoppages resulting in flooded claims costs of $4.3 million. Six specific mainline stoppages were directly attributed to restaurant generated grease that cost the district $1.4 million in flooded claims. The average claim where flooding is caused by mainline stoppages is $48,700, whereas the restaurant caused mainline stoppage flooded claim averaged $235,400 during the four-year period.

Measurable effectiveness of an active grease control program should be based on four key factors:

- Reduced number of system stoppages and overflows
- Reduced claims cost associated with cleanup costs due to grease stoppages from businesses
- Reduced need to clean certain sewers that are on frequent cleaning program
- Improved regulatory compliance by reducing the number of grease stoppages that could result in an overflow.

Costs to the food preparation facilities for installing grease interceptors for new construction averages $20,000 or more depending on the size. Under the sink units cost from $750 to several thousand dollars, depending on the size of the unit. Approximately 58 percent of the food preparation facilities in the project study areas have grease control devices of some type.

Observations of the sewers in the study areas resulted in the following conclusions:

- Low flows that have velocities less than 2 fps allow the accumulation of grease and other solids to deposit on the pipe wall, creating a capacity restriction
- Sewers in upstream reaches where wastewater flows allow should have steeper slopes to increase velocity of wastewater in the pipe
- Sewer slopes ranged from about 0.0020 to 0.0050 for the 8-inch diameter achieving a 2 feet second (fps) flow velocity when the pipe is flowing half full. For lower flows the velocity approaches 1-fps, which will allow grease accumulation on the pipe wall.
- Almost all of the sewers with minimum slopes also have minor sags that allow the wastewater velocity to slow down and the grease to accumulate quickly
- Many of the sewers have small offset joints and protruding laterals that create points where the grease can accumulate.

Key findings from the sewer agency survey are summarized below:

Most public agencies have some form of grease source control program. The method of implementation for the grease source control program varies from basic enforcement of the Uniform Plumbing Code to specialized programs with specific fats, oil, and grease (FOG) limits

- Costs associated with grease source control are considered as part of the operating budget for most agencies
- Some agencies use dedicated inspectors for grease source control, while others combine inspection as part of the industrial waste source control program. The most

successful grease source control programs have ongoing food producing facility inspection to achieve grease control compliance.

- Many agencies have successfully implemented a set of citations and fines to gain compliance with the grease source control ordinance or regulation
- Several agencies have implemented cost sharing or co-funding programs to encourage grease trap/interceptor installation
- Grease accumulations move through the collection system in an unpredictable manner, which results in the need for additional maintenance of the collection system.

87. Berk, J.; "Quantifying the Impact of I/I as a Result of Snow Melt on a Mountain Community's Collection System," Water Environment Federation, Collection Systems Rehabilitation and O&M Specialty Conference, Salt Lake City, Utah, 1999

Big Bear City, located in the San Bernardino Mountains about 30 miles northeast of the City of San Bernardino, California, is subject to about 60 inches of snow per year. The average daily dry weather flow is about 1.5 million gallons per day. However, in the spring when the snow begins to melt, the average daily flow can increase to 3.6 mgd and can be sustained for as long as four weeks.

The Big Bear City Snow Melt Dependent Infiltration/Inflow (SMDII) project consisted of breaking up the service area into sixteen (16) discrete sub-basins ranging in size from 20,000 to 30,000 linear feet of collection pipe. Seventeen flow monitors were installed at the outlet of each basin and monitored simultaneously for approximately two months. Two rain and temperature gauges were also installed. The equipment was installed during the week of April 10, 1998, and removed during the week of June 17, 1998.

At the beginning of the study period there was about thirty-six inches of snow on the ground. There were two new snow storm events that occurred during the study. Maximum daily temperature ranged from 40°F to 70°F over the duration of the study.

The traditional definitions of inflow and infiltration do not apply to snow where water is stored above the surface for days or months at a time and only seep into the collection system when an increase in temperature caused it to melt.

It was determined that the sixteen basins monitored had significant I/I due to snow melt that resulted in average daily flow peaking factors as high as 4 to 1. When a statistical analysis was performed it was found that maximum daily temperature correlated extremely well with I/I. Because the temperature increase was gradual, the collection system was subject to a sustained flow peak that lasted up to several days.

88. Watts, C.A.; "I/I Defect Deterioration Over Time" Water Environment Federation, Collection Systems Rehabilitation and O&M Specialty Conference, Salt Lake City, Utah, 1999

A Sanitary Sewer Evaluation Survey (SSES) in West Memphis, Arkansas, was undertaken during the fall of 1997 and winter of 1998, by Byrd/Forbes Associates, Inc. (BFA). The city of West Memphis, which rests on the western bank of the Mississippi River just across from Memphis, Tennessee, had retained McCullough Associates, Inc. to perform a similar study in the same area in 1976. This situation provided the opportunity to compare the defects located during both studies.

This paper was limited to a comparison of smoke defects in five basins. Two comparisons are possible: the overall number and type of defects in the five basins and a comparison of common defects located by both studies.

Basin 1 is comprised of approximately 140 manholes and 36,500 linear feet of mainline pipe. Pipe diameters range from 6 inches to 18 inches and pipe depths vary from 5 feet to 12 feet. Most of the mainline pipes are concrete with some PVC. Basin 4 consists of approximately 160 manholes and 38,000 linear feet of mainline pipe. Mainline diameters range from eight inches to 18 inches and depths vary from two feet to 15 feet. Most of the mainline pipes are concrete with some PVC. Basin 10 is approximately 10,000 linear feet of mainline and 60 manholes. Pipe sizes in this area range from eight to 10 inches and pipe depths are from three to 8 feet. The only pipe material present in this basin is concrete. Basin 15 contains about 155 manholes and 32,000 linear feet of mainline pipe. The most common pipe material is concrete and pipe diameters range from six to 12 inches. Pipe depths vary from two to 14 feet. Basin 17 is the largest of the five basins and consists of about 270 manholes and 53,000 linear feet of mainline pipe. Pipe sizes range in this basin from six to 15 inches in diameter with pipe depths between two and 20 feet. Truss is the most common pipe material with some clay and PVC also present.

The McCullough study located a total of 368 defects in the five basins. The smoke testing conducted by BFA found 299 defects throughout the five basins. McCullough located 32 manhole defects compared to BFA's 69 manhole defects. More mainline defects were found by McCullough than by BFA (111 compared to 42). For municipal service lines, the earlier smoke testing recorded 17 defects while the second round of testing found 4 defects. Private service defects were the most common defect found by both studies: 208 defects were observed by McCullough and 176 by BFA. Twenty-three specific defects located by McCullough were also located by BFA.

For basin 1, only one common defect was found. Basin 4 had the largest number of defects (18) located by both studies. Nine of these were located on private services, five on manholes, and four on mainlines. Three common mainline defects were found. There was only one common defect in basin 10: a service line with a hole. In basin 15, there were two defects located by both studies: one mainline defect and one private service defect. One common manhole defect was found in basin 17.

The number of defects located during the BFA study decreased from the McCullough study: this was most likely influenced by the fact that McCullough smoke testing was performed during the locally dry months (August and September) while the BFA study was conducted during a wetter period (November to March). This difference in total defects shows the importance of smoke testing during low groundwater conditions.

The only type of defect to increase in quantity was manhole defects. The number of manhole defects more than doubled between the two studies: 32 for the McCullough study and 69 for the BFA study. The severity of the common defects remained roughly the same. The number of mainline defects had the greatest decrease from the McCullough study to the BFA study. One hundred and twelve mainline defects were found by McCullough compared to only 42 by BFA. The severity levels for the common defects remained about the same. This decrease in quantity of defects may be the result of some of these mainline defects requiring emergency repairs between the studies.

23 common defects were found. These common defects seemed to change little in the 22 years between the McCullough and BFA studies. This demonstrates that older studies may be of some value today. If defects have not been repaired, these defects have most likely not changed significantly since when they were originally located.

89. Van Der Tak, L., et al.; "Collection System Modeling, Monitoring, and Optimization to Evaluate I/I Rehabilitation versus Storage of Wet Weather Flows," Water Environment Federation, Collection Systems Rehabilitation and O&M Specialty Conference, Salt Lake City, Utah, 1999

A Wet Weather Flow Reduction Strategy was prepared for the Alexandria, Virginia, Sanitation Authority (ASA) using a calibrated sewer system model. The ASA sewer service area covers 52.8 square miles. The sewer service area encompasses 37.0 square miles (70 percent) in the County of Fairfax, and 15.8 square miles (30 percent) in the City of Alexandria, Virginia. There are three main interceptor systems:
- The Potomac Interceptor
- The Commonwealth Interceptor
- The Holmes Run Interceptor.

The Four Mile Run pump station bypass and the Hooff's Run Junction Chamber overflow when the excess wet weather inflows exceed system capacity. The Four Mile Run pump station has three variable speed pumps with a combined peak capacity of approximately 17.2 mgd. The pump station is not operated at a rate greater than 8.5 mgd.

The Wet Weather Flow Reduction Strategy study addresses wet weather management options for the ASA's sewer area, in order to reduce bypasses at the Four Mile Run Pump station. This plan presents the most cost-effective approach to managing wet weather flows in excess of 108 mgd. This is the peak hydraulic throughput to the ASA Advanced Wastewater Treatment Facility (AWTF). An agreement between ASA, the County of Fairfax and the City of Alexandria says that the capacity of the ASA AWTF will be split 60 percent and 40 percent between the County and City, respectively.

For wet weather, the County's contribution of flow volumes during the monitoring period was about 52 percent. The Cameron Run area of the county was the largest contributor of wet weather flow volume (35 percent overall and 61 percent of flows to the Holmes Run Interceptor). Summaries of wet weather flow volume per drainage area show that on an area basis, the Commonwealth Interceptor portion of the system is wetter than other parts of the system, with ratios of greater than 0.21 MG/acre, compared to 0.18 MG/acre in the City portion of Holmes Run Interceptor. Ratios are 0.04 to 0.06 MG/acre in the County potion of the ASA sewer-shed.

The March 21, 1998 storm event was the largest event during the monitoring period. The measured rainfall depth of this storm event was 1.4 inches. The measured maximum rainfall intensity was 0.35 inches per hour. Peaking factors were 10.0 in the Four Mile Run pump station area and over 6.0 at sites along the interceptor. Measured peak flows nearly exceed the planned throughput capacity for the plant of 108 MGD. Total peak flow for this storm was 105 MGD.

The objective of the modeling effort was to update a model of the interceptor system to simulate flow and hydraulic head at various points in the interceptor system, particularly near the sanitary overflows, interceptor sewers, and pump stations. For the one year and five year design storms, the model predicts that there is excess wet weather flow entering the sanitary sewer system in the City of Alexandria and Fairfax County. The average peak flows reaching the plant are 112 MGD and 121 MGD from the one year and the five year design storms, respectively. Relative to the 108 MGD design throughput capacity, the allocation between the City of Alexandria and Fairfax County is 45% - 59% for the one year storm and 38% - 74% for the five year storm (total percentages exceed 100% because the total peak flows exceed 108 MGD).

An annual simulation was run based on a representative precipitation year (1993), at current hydraulic throughput capacity (90 MGD) and design capacity (108 MGD). The increased throughput capacity of the plant to 108 MGD decreased the simulated annual bypass frequency at the Hooff's Run Junction Chamber from 11 to 6 events and decreased the predicted annual bypass volume from 33.6 MG to 15.1 MG. To achieve annual reductions in bypass volumes of 50, 60, and 85 percent with a reduction in the number of bypass events from 11 to 4, and 2 per year, respectively, at Four Mile Run, will require capital investment of $216,000, $1.02 million, and $5.31 million respectively. Costs increase rapidly if tanks are added. The 85 percent level of capture includes a 750,000-gallon tank at the Four Mile Run Pump Station (in addition to the existing 650,000-gallon tank) in addition to I/I rehabilitation of $28,000 per year (amortized).

To achieve annual reductions in bypass volumes of 50, 60, and 85 percent with a reduction in the number of events from six to four, four, and two per year, respectively, at the Hooff's Run Junction Chamber bypass, will require expenditures of $3.86 million, $4.84 million, and $7.65, million, respectively. The 85 percent level of capture includes a 1.84 million-gallon tank adjacent to the Hooff's Run Junction Chamber, in addition to I/I rehabilitation of $133,000 per year (amortized).

90. Larsen, J.P., et al.; "An Inside Look at Common Sense Application of Trenchless Technologies in South Florida," Water Environment Federation, Collection Systems Rehabilitation and O&M Specialty Conference, Salt Lake City, Utah, 1999

Sanitary sewer rehabilitation projects in South Florida have steadily increased in scope and size during the past six years. The Broward County Southern Regional Wastewater Collection System serves the Cities of Hollywood, Dania, Hallandale, Miramar, Pembroke Pines, the Town of Pembroke Park, and a portion of unincorporated Broward County. It consists of 2,830,000 linear feet of collection sewers that covers approximately 106 mi^2. The collection system provides sewer services for a population of 288,000 inhabitants.
In 1994, Miami-Dade Water and Sewer Department (WASD) initiated an I/I flow reduction program. WASD has undertaken the program to achieve the economic benefits of deferring major plant expansions and to allow the sizing of the regional collection and transmission system. Program costs are estimated at $120,000,000 over the first five years of the program to reduce more than 60 mgd of I/I flow. The WASD collection system (13,110,000 linear feet) serves approximately 92 percent of the sewered population (1.33 million people) of Dade County.

The Broward County North Regional Wastewater Collection System encompasses approximately 88,000 acres of land located in the North section of Broward County which includes an estimated population of 455,000 of 34 percent of the total County population. Wastewater generated within each collection system is transported to the 80 mgd North Regional WWTP through a network of County operated pump stations and force mains. Broward County Wastewater Districts 1 and 2, consists of 162 pump stations and 1,384,000 linear feet of gravity sewers. Districts 1 and 2 provide sanitary sewer services for a population of approximately 113,700 residents.

A new approach involving instantaneous night flow measurements and pump run comparison between wet and dry seasons at each lift station was instituted. 100 percent of the manholes were inspected. The manholes were not descended. High density smoke testing was performed on 100 percent of the prioritized areas during the dry season. 100 percent of the prioritized system was cleaned and TV inspected. The next step after completing the SSES phase was to determine the best available rehabilitation technologies, including trenchless technologies, in order to repair the defects identified in the systems. The following are the rehabilitation options which were developed:

- Manhole Frame and Cover Rehabilitation: Where the manhole cover contains vent or pick holes, it should be replaced with a new, water tight, cast iron manhole cover with pick slots and containing no vent holes.
- Manhole Sidewall and Base Rehabilitation: A manhole liner can be applied to the interior of manholes. Prefabricated fiberglass, polyurethane, and cementitious manhole liners are used for manhole rehabilitation. Hard structural liners should be used for replacement of heavily deteriorated/structurally unsound manholes.
- Pipeline Rehabilitation Technologies: Pipeline repair alternatives include chemical grouting, point repairs/excavation and replacement, robotic repairs, sectional liners, sliplining, CIPP liners, and pipe bursting.
- Chemical Grouting: The grout material (acrylamide gel, acrylic gel, acrylate gel, urethane gel, and polyurethane foam) can be applied to pipeline joints by injecting it under pressure. An effective, but temporary repair method to stop leaks. Grout life diminishes with varying exposure to water.
- Point Repairs/Excavation and Replacement: Point repairs are utilized where there is an isolated major structural pipe defect, such as a broken, severely cracked, or corroded sewer pipe or a misaligned joint and where other repair alternatives are less cost effective. This option is the only way to repair medium to heavy root intrusion in pipes, broken drop pipe connections, collapsed pipes, and on pipes with jagged edges or offsets greater than one inch where robotic or sectional point repairs are not effective.
- Robotic Repairs: For service laterals, the robotic system grinds protruding laterals and patches the defect with an epoxy material to restore the service connection. Robotics should be used on protruding or mildly recessed laterals and on cracks with less than 0.5 GPM. It should not be selected for repairs to polyvinyl chloride, ductile iron or cast iron pipe as these materials are not conducive to the robotics routing process.
- Sectional Liners: These are cured-in-place pipe (CIPP) liners that are generally limited in lengths from 3 to 15 feet and are utilized to reline segments of pipe that are cracked and/or leaking. Sectional liners are limited to a maximum length of fifteen feet. Sectional liners should only be utilized as a repair option on pipelines in which there is less than one defect per 100 feet, or on a pipeline with

maximum of three defects per line (approximately 500 feet). They should not be utilized for pipe joints offset more that one inch (for eight inch pipe) as excessively out of round liners will lose their structural strength.

- Sliplining: Mostly used to rehabilitate larger diameter pipelines that have severe structural problems.
- Cured-in-Place Pipe (CIPP) Liners: Two resin types (polyester and epoxy) are widely used in this method of pipe rehabilitation. Vinylester resins are used where superior corrosion resistance is required at high temperatures and epoxy resins are used where adhesion to the existing pipeline is desired.
- Fold and Formed (FAF) Pipe Liners: Typically suitable for pipe diameters of 4 to 16 inches with lengths of installation from 300 to 600 feet. FAF liners should not be selected when any circumstance causes the pipeline to become out of round by more that five percent as this causes folds in the liner and eventual loss of structural strength. FAF liners cannot be utilized when the pipeline has varying diameters due to the stiffeners of the materials (polyurethane or polyvinyl chloride). FAF liners are more cost effective for eight and ten inch diameter pipes. CIPP liners can be utilized when sand is infiltrating into the pipeline and if the pipeline contains breaks or jagged edges that might otherwise have cut a FAF liner.

Pipe Bursting: Suitable for replacing pipe made of brittle material such as verified clay, unreinforced concrete, asbestos cement, and cast iron. This is most cost effective if the entire pipeline is defective and must be replaced and restoration is excessive or open cutting is not possible. Pipe bursting is also a viable option if the hydraulic capacity of the pipeline must be increased as pipe bursting can be utilized to upsize the existing pipeline's diameter.

91. Marshall, W.F., "Pipeline Evaluation and Repair Steel Pipelines," ASCE Pipeline Conference, Convergence 2000, Kansas City, 2000

To determine if or how a system requires rehabilitation, information about the condition of the pipeline is required. Three areas of pipeline that need to be considered are:

- Structural Integrity of the Steel Pipe: If the pipeline is not structurally sound, then repairing the coating or increasing the cathodic protection will not be a cost effective, long term solution. Test procedures for determining the structural integrity of the pipeline include: In-Line Inspection (Smart Pig), Bellhole Examinations, Hydro-testing.
- External Coating Condition: Reducing metal to electrolyte contact reduces the amount of cathodic protection needed while increasing the resistance to corrosion. A coating should be bonded to the pipe and free of holes. The coating should also allow cathodic protection current to flow to the pipe if disbondment does occur.
- Cathodic Protection System Condition: The most common method of determining the cathodic protection system adequacy is performing a Close-Interval Survey, which measures the pipe-to-soil potential and provides results that will detail the effectiveness of the cathodic protection.

The Smart Pig is an in-line inspection tool that shows deformities, mill defects, and wall loss in the pipe. Bellhole examinations are the only way to visually examine the external condition of the pipe. The disadvantage of bellhole testing is that only one section of the pipe can be examined during the dig.

Hydro-testing determines the failure pressures of a pipeline section. Hydro-testing will reveal all points that will fail at a certain test pressure in the area under test. It will not detect any possible future failures. This test is useful in determining what pressure the pipe will withstand before failure. Software such as RSTRENG, developed by Kiefner and Associates for the American Gas Association, will help in determining the remaining strength of corroded pipe.

Surface groundbeds are usually the least expensive method of rehabilitation. This alternative may be effectively applied where there is sufficient structural integrity and generally uniform cathodic protection potentials.

- The manual recoating method is cost effective for short bellhole sections. For larger diameter pipes and longer areas, recoating with automated equipment is more economical. For bellholes greater than 75 feet long, the automated equipment may be more economical.

92. Howard, A.; "Rehabilitation of Deteriorated Sewers by the County Sanitation Districts of Los Angeles County"

The County Sanitation Districts of Los Angeles County (Districts) are a consortium of 25 districts that serve 5.3 million people in Los Angeles. The District's service area covers approximately 1,990 km^2 (770 square miles), 78 cities, and unincorporated areas within the County. The Districts have approximately 2,090 km (1,300 miles) of main trunk sewers ranging from 152 to 3658 mm (6 to 144 inches) diameter which convey approximately 23 m^3/s (525 mgd) of sewage to 11 wastewater treatment plants Approximately 1,060 km (660 miles) of the District's sewers are made from unlined concrete pipes. Approximately 90 percent of the deteriorated sewers identified to date are unlined concrete pipes that have experienced significant hydrogen sulfide corrosion. To date, about 218km (135 miles) of deteriorated sewers have been identified.
The Districts have awarded more than 50 contracts to rehabilitate approximately 82 km (51 miles) of deteriorated sewers ranging from 203 to 2591 mm (8 to 102 inches) at a cost of more than $105 million. The Districts have awarded 50 additional contracts to replace 88 km (55 miles) of deteriorated sewer ranging from 305 to 3658 mm (12 to 144 inches) at a cost of more than $190 million. The construction cost for the replacement projects exceeds rehabilitation projects by $85 million, but the weighted average of diameter for the replacement projects was about 1,524 mm (60 inches) compared to only 1,143 (45 inches) for the rehabilitation projects.

Although the Districts have used a number of rehabilitation methods, the primary rehabilitation methods used include the following:

- Sliplining with Centrifugally Cast Fiberglass Reinforced Polymer Mortar (CCFRPM), High Density Polyethylene (HDPE) and Polyvinyl Chloride (PVC) Segmented Liner Pipes
- Cured-In-Place Pipe (CIPP) Liner
- Folded/Re-formed PVC and Deformed/Re-formed HDPE Pipe Liners
- PVC Pipe Lining System

- Machine Spiral Wound PVC Pipe Liner.

The District's sewers which are greater than 1,219 mm (48 inches) in diameter are most often rehabilitated by sliplining with segmented plastic liner pipe. One advantage of sliplining is that installation can be completed with flow in the sewer.
The PVC pipe lining system has been used to rehabilitate portions of some large diameter sewers when it is possible to divert and/or bypass flow. Sewers between 686 mm and 1,067 mm (27 to 42 inches) in diameter are usually rehabilitated by cured-in-place pipe (CIPP) liner or sliplining. The advantage to using CIPP liner in sewers this size is that it has minimal impact on capacity.

The sewers that are 610 mm (24 inches) in diameter or smaller are most often rehabilitated by one of the various pipe liner systems. CIPP liner is available in all sizes 610 mm (24 inches) or smaller. Folded/re-formed PVC and deformed/re-formed HDPE pipe liners are available in sizes from 100 mm (4 inches) up to 381 or 457 mm (15 to 18 inches) depending on manufacturer. Machine spiral wound PVC can be installed in as a radically expanding system for this size range. This system can be installed with some flow in the sewer. Sliplining non-circular sewers can be feasible; however, large reductions in flow area and capacity usually result. Non-circular sewers have been rehabilitated with the PVC pipe lining system.

Since 1986, the Districts have awarded a total of 32 contracts for sliplining approximately 65 km (40 miles) of deteriorated sewers ranging from 762 to 2,591 (30 to 102 inches) with a total construction cost of $93 million. CCFRPM liner pipe has been used on 26 contracts for rehabilitation of about 52 km (32 miles) of sewers at a construction cost of $80 million. HDPE liner pipe has been used on four contracts to rehabilitate 9 km (5.5 miles) of sewer at a construction cost of $8 million. PVC liner pipe has been used on two contracts to rehabilitate 5 km (3 miles) of sewer at a construction cost of $6 million.

Since 1990, the Districts have awarded thirteen contracts to line approximately 13 km (8 miles) of deteriorated sewers ranging from 203 to 1980 mm (8 to 78 inches) for a total construction cost of $9.7 million. CIPP liner has been used on portions of other projects, primarily to rehabilitate deteriorated air lines on sliplining projects. Approximately 90 percent of the CIPP liner installed to date has been in sewers having diameters 1,067 mm (42 inches) or less. Vinyl ester resins have better resistance to high pH environments. However, isophthalic polyester resins are generally less expensive. Epoxy resins would be considered in situations where aggressive industrial effluents are discharged to the system. Service connections are re-established by remote-controlled cutting devices or man-entry. Maximum pipe size where remote-controlled cutting devices can be used is about 610 mm (24 inches).
In the limited number of large diameter installations, a large amount of wrinkles, folds and other imperfections were observed in the liner. The Districts have not installed CIPP liner in a sewer larger than 1,067 mm (42 inches) in diameter since 1997. Since 1991, the Districts have awarded four contracts or portions of contracts for lining approximately 2,225 m (7300 ft) of deteriorated sewers ranging from 203 to 305 mm (8 to 12 inches) using deformed/re-formed HDPE and folded/re-formed PVC pipe liners. Total construction cost for work awarded to date totals approximately $580,000. The availability of these products is limited to sewers 457 mm (18 inches) in diameter or less. Service connections are re-established using remote-controlled cutting devices in combination with CCTV equipment. Since 1990, the districts have used the PVC pipe lining system to line approximately 1,524 m (5000 ft) of 1,372 to 1,981 mm (54 to 78

inches) circular and semi-elliptical sewers at a construction cost of approximately $3 million.

Based on the District's experience, sliplining is the preferred method for rehabilitating sewers greater than 1,219 mm (48 inches) in diameter. Sliplining is also the preferred method for rehabilitating sewers between 762 and 1,143 mm (24 and 45 inches) in diameter, if the reduction in capacity can be tolerated. CIPP liner has also been successful in rehabilitating sewers 203 to 1,067 mm (8 to 42 inches) in diameter. For sewers less than 457 mm (18 inches) in diameter, deformed/re-formed HDPE and folded/re-formed PVC pipe liner has been installed successfully.

93. Ganeshan, R., et. al; "Citywork: Application of Collaborative Technologies for Infrastructure Management," Journal of Computing in Civil Engineering, January 2001

A collaborative maintenance management application called CITYWORK is being developed for the Public Works Department at the Fort Gordon Army Installation in Augusta, GA. "CITY" is derived from **C**ivil **I**nfostructure (from **info**rmation and infra**structure**) **T**echnolog**Y**.

The management of facilities and infrastructure has common characteristics and requirements - the parties involved legal requirements, coordination, collaboration, and integration in the maintenance management process. The prototype software suite produced is called CITYSCAPE and includes map viewing capabilities (CITY-MAP); information about the responsibilities, skill, and interests of personnel (CITY-KNOW); and Web-based information access (CITY-INFO).

The Public Works Department (PWD) at Fort Gordon is responsible for maintaining the facility's infrastructure, including buildings, roads, and utilities. Military installations are similar to small cities with populations of 15,000 or more. The maintenance management process within the PWD at Fort Gordon is typical of the process found in most large infrastructure management organizations.

Maintenance management in the PWD starts with the production controller receiving a work request from a customer on the installation. The production controller creates the request using a predefined format and makes preliminary decisions on how to route the form or consults with the business manager or desk estimator on ways to accomplish the task. The desk estimator then determines the preliminary construction cost estimates using a spreadsheet.

Fort Gordon contracted with a commercial firm to perform maintenance at fixed contract rates. The contract is for 3 years. The base contractor maintains a presence at Fort Gordon of about 500 people and undertakes approved work requests that involve small-sized maintenance at fixed contract rates. Larger ones are sent out to bid.

Parts of this work process are supported by a database and application called IFS (Integrated Facility System). IFS is a mainframe-based relational database. It more than 1,300 attributes in approximately 300 tables.

CITYWORK supports workflow processes by providing private, object-oriented, persistent workspaces for each participant, integrated with the Virtual Workspace System (VWS). CITYDESK is intended as a Web application to allow customers to log maintenance problems and query the status of their requests. CITYKNOW is also a Web-based application. The purpose of CITYKNOW is to document the skill and interests of users. CITY-INFO provides a query facility for the status of aspects of maintenance management. CITY-MAP and CITYWORK are the only applications that are not Web-based. CITY-MAP is a Visual Basic/MapObjects application, and it provides the users with the ability to access existing drawing and maps in digital format and spatial data.

The maintenance management work processes use familiar software tools like spreadsheets and scheduling programs. Microsoft Excel is used to display and manipulate cost estimates. The integration of these tools with CITYWORK is achieved by using special interfaces. CITYWORK interfaces interact with the IFS database through the VWS and a translator (IFS-M Client), which is responsible for converting between the CITYWORK object representation and relational IFS format. The VWS server will keep the information synchronized in both CITYWORK and IFS.

It is clear that supportive, collaborative work environments will be important in the future management and maintenance of sustainable infrastructure.

94. Chae, M.J., et al; "Neuro-Fuzzy Approaches for Sanitary Sewer Pipeline Condition Assessment," Journal of Computing in Civil Engineering, January 2001

It is important to have effective methods for assessing the condition of sewer lines in order to evaluate the level of deterioration, and for determining the mode and the frequency of rehabilitation that will be most cost-effective, while being less disruptive. Detection of interior defects is the first step in assessing the condition of sewer pipelines and developing rehabilitation strategies.

The present state-of-the-practice inspection technologies are dominated by CCTV technology. Some non-destructive, diagnostic methods have recently been developed for condition assessment of sewer pipelines. These include the following:

- Infrared thermography systems that use temperature differentials between surfaces/elements
- Sonic-distance measurement methods
- Ground penetrating radar techniques that utilize the emission of short pulses of electromagnetic energy.

The inspection process does not give a complete picture of the condition of sewers due to reliance on technology that depends on only one method of data collection. New systems such as the pipe inspection real-time assessment technique (PIRAT), KARO and the Sewer Scanner and Evaluation Technology (SSET) have been developed.

A German industry-research collaborative group developed the robot inspection system, KARO, to automatically detect the type, location, and size of defects in sewer lines. However, the technology is not yet proven.

The Australian water developed PIRAT, a multi-sensing technology. PIRAT uses a laser scanner in low-flow sewers or a sonar scanner in flooded sewers where the pipe surface is not visible. The in-pipe vehicle also carries a high-quality CCTV facility for navigation and video recording.

SSET provides as CCTV video record, a full-circumference scanned image of the pipe, a computer-generated color-coded printout of the defects, and a written description of each defect along the pipe defects. Feature recognition uses techniques ranging from statistical methods of the knowledge-based artificial intelligence (AI) system, to artificial neural networks (ANNs).

Combining two methods/technologies is becoming common. Appropriate pre-processing is important to make images suitable for various purposes. The processing does not create new information from the original information. One of the most useful methods for extracting a feature of interest from an image is to perform binary transformation of a gray-level image through thresholding. The image is represented with only two different values - one or zero. If the image is binarized at a gray level of 150, all the pixels having a level greater than 150 will be assigned as 1; the others will be assigned 0. Therefore the binary image is a pure black-and-white image without any intermediate gray level. Using an edge enhancement algorithm, the image is modified into one that has amplified edges. These algorithms are used to find large contrasts in the original image.

ANNs are used for image recognition and assessment of condition. Neural networks consist of a number of neurons or simple processing units. Each input applied to the ANN is multiplied by a corresponding weight. The weighted inputs are summed to determine the activation level of the neuron. The weights represent the knowledge in the system. Information processing takes place through interaction among these units.

There are two learning methods used by neural networks; supervised learning and unsupervised learning. Since sets of target data and data related to sewer pipes (in the form of SSET images) are available, the supervised learning method is appropriate for sewer condition assessment.

Initially, input/output data sets and a neural network with random weights will be ready for training. When the first data set is input into the network, the network produces an output set that is far from the desired output. This task is done iteratively for all of the data sets until the network produces output sets. When the network can produce outputs that match the desired outputs, the network is trained. The trained network is able to simulate new outputs from new input data sets if the input/output patterns are similar to those used for training.

ANNs have learning and recall features. Information is stored in the form of weights in the neural network. All weights are distributed over the network so the stored information is as well. Therefore a single incorrect weight may not affect the output values of the neural network. This enables ANNs to be fault tolerant. As all image data have certain amounts of noise and undesired information, neural networks are good tools for image recognition.

Fuzzy inference rules enable the modeling of uncertainty associated with vagueness, imprecision, and lack of information. The fuzzy implication techniques automatically identify, classify, and rate pipe defects while minimizing errors from the neural network. This fuzzy estimator helps in describing the overall condition of the inspected pipe.

This methodology was applied and validated using SSET data from the City of San Jose, California. Twenty images were randomly chosen out 192 to train the network. The pipe material was clay. Target values suggested by only one expert were used to train the network. This leads to more consistent outputs for defect recognition, ensuring consistency in the condition assessment of pipes.

By comparing the network output with the expert's measurements, the accuracy of the neural network system can be validated. Thirteen randomly chosen images were used to test the accuracy of the system. The comparison process gave the following results:

- Overall correct answers: 83 percent
- Correct answers regarding joint condition and width: 84 percent
- Correct answers regarding number of pipe joints: 100 percent
- Percentage of correct answers regarding cracks: 72 percent.

This comparison shows a strong potential for using ANNs for condition assessment of sanitary sewer pipes. The following tools were used for the development of the system:

- Matrox Inspector for image segmentation
- Matlab for edge detection
- Microsoft Excel for data handling.

95. Ferguson, Bruce, et al.; "Restorative Development: The Nine Mile Run Model", Stormwater, 2001.

On approach to reducing SSO's is to reduce the quantity of stormwater entering the combined collection system. The Nine Mile Run model attempts to reduce inflow by making incremental upgrades to infrastructure while restoring urban areas. This restorative development model is a convergence of history, hydrology, recreation, and neighborhood revitalization". The model is guided by seven principles.

- Make components multifunctional – every project should produce multiple, mutually reinforcing benefits.
- Use every square inch – use every square inch for positive, multiple functions.
- Use freely available natural processes.
- Use disconnections and reconnections – separating stormwater drainage from sanitary sewer conveyance is a basic and essential task.
- Cooperate among disciplines – individuals must be open to the unanticipated insights of members of other disciplines and willing to work with them in design.
- Find out what is possible – diverse, flexible, economical techniques for treating and storing stormwater have been proven and are available.
- Engage the community – seek locally integrated forms of innovation.

96. Potts, Troy and Philip Farmer; "City of Greenville, Texas – Sewer System Improvement Program", City of Greenville, Texas, November 9, 2000.

In 1994 the City was notified by the EPA that they were in violation of the law prohibiting sewage from overflowing from the sewage system. Several meetings were held with the EPA about this matter. In 1995, a consulting firm completed a study of the City's sewer system. In August 1997, the City received an administrative order from the EPA which detailed an agreed upon schedule for the Sewer System Improvement Program (SSIP). The program is intended to repair the City's underground sewer piping.

Basin repair work was completed in the Spring of 2001. Mainline trunk repairs will begin in 2003.

96. removed

97. "Town of Cary – Grease & Oil Control Ordinance"; Town of Cary, North Carolina, December 10, 1998.

The Town of Cary City, North Carolina, adopted a FOG control ordinance on December 10, 1998. The ordinance requires all cooking establishments to install grease interceptors. FOG discharges from these interceptors are limited to 275 milligrams per liter. In addition, establishments are required to maintain a written record of grease trap maintenance. This record will be available for inspection by the town at all times.

98. "City of Durham – 2001 Annual Sewer Report"; Durham, North Carolina, 2001.

The City initiated a major grease reduction campaign this year. Remediation consisted of using a high-pressure jet wash to remove the grease from the interior of main trunk line pipes. Sand traps were installed at manholes below the area to contain the grease. The grease was then vacuumed out of the system and hauled from the site. This activity has resulted in a five percent decrease in the total number of blockages that the Public Works crews responded to in FY 2000-2001.

As of March 2001, a discharge limit for FOG of 250 mg/L went into effect. Food preparation and processing facilities are expected to meet this goal by the installation of grease traps or other grease removal systems.

99. Louisville/Jefferson County Metropolitan Sewer District – Sanitary Sewer Overflows"; Louisville, Kentucky, 2001.

MSD is committed to reducing or eliminating recurring Sanitary Sewer Overflows. As part of this commitment, MSD established the I&I program. The result of the program has been the creation of a 15-year master plan that is organized by sewershed. The plan includes a deliberate process of (1) flow monitoring and investigation of priority areas identified by flow monitoring, (2) SSES, (3) rehabilitation of critical areas optimized by hydraulic modeling as required, and (4) post-rehabilitation flow monitoring to document success. The program has a total annual budget of $7.1 million.

100. "City of Wilmington – Annual Wastewater Report, Fiscal Year 2000-2001"; Wilmington, North Carolina, 2001.

An inflow and infiltration study completed in 1995 identified problem areas in the collection system. The City has responded by implementing a cleaning and inspection program, replacing and refurbishing old and leaking sewer lines, and by regulating grease discharge.

101. "OWASA – 2000/2001 Annual Report"; Orange Water and Sewer Company, Carrboro, North Carolina, 2001.

OWASA performs the following to prevent SSO's.

- Inspects and repairs, renovates or replaces sewers and pump stations as needed to eliminate leaks and increase system capacity.
- Inspect and clear sewers with cutting and flushing equipment. Educate customers about proper grease disposal.
- Clear sewer easements to keep roots away from sewers; limit planting along easements.

102. Reuter, Don; "NCDENR – North Carolina's 1999 Environmental Accomplishments", State of North Carolina, 1999.

Enforcement decisions for municipal, industrial and other wastewater collection systems include operation and maintenance components. Evaluations can include whether operators conduct routine inspections, perform regular line cleaning and right-of-way maintenance, keep records of problems and repairs, maintain back-up equipment for pump stations and implement a schedule to address ongoing problems. The policy is designed to prevent spills and overflows through early recognition of trouble spots and preventative maintenance.

103. "Wastewater System Report – City of Raleigh", Raleigh, North Carolina, 2000.

During fiscal year 1999-2000, the City of Raleigh experience 61 SSOs. Grease caused 21. Tree root intrusion caused 13 SSOs. Excessive rainfall caused 10 SSOs. To combat these, the City has completed a large chemical root control contract and changed the manhole standard, reducing the vent holes to 1 vent hole per manhole in roadway areas. In addition, the City has increase funding for after hours maintenance.

104. "City of Ann Arbor Water Utilities Department, Sanitary Sewer Overflow Prevention Study – Executive Summary", Ann Arbor, Michigan, 2001.

The study recommends the implementation of a city-wide footing drain disconnection (FDD) program to combat SSOs. The cost of the program ranges between $80 – 130 million. The approximate cost per home is $5,000 - $6,000 to disconnect the footing drain and provide a curbside collection system to bring the rain/groundwater from the sump to the storm water system.

105. "La Grange Park – Sewer Operations/Flooding Concerns", La Grange Park, Illinois.

The intent of the deep tunnel and its reservoir system is to give he excess flow of combined storm and sanitary sewage a place to go rather than overflowing into the local river and streams as used to be the case. The deep tunnel has been highly successful in reaching this objective.

106. "SSO Elimination Program – Progress to Date", Vallejo Sanitation and Flood Control District, August 2000.

The SSO Elimination Program has been underway since July, 1999. Smoke testing and CCTV inspections were performed – deficiencies were entered into a database and used to develop a statistical model. The statistical model extrapolated the full condition of the collection system from identified deficiencies in portions of the system. Other deficiencies have been identified through flow monitoring and hydraulic modeling.

107. "1997 Year End Report", Kennebunk Sewer District, State of Maine, 1997.

Beginning in 1989, the District started a manhole rehabilitation program. To date approximately 230 manholes have been sealed and grouted. In addition, in recent years KSD has replaced about 2.3 miles of its clay sewer lines. The Trustees feel that the next logical step is to recapture capacity through the removal of illegal connections, which allow clean water to enter through the collection system. As a result the Sump Pump Removal Program was created in 1997. In 1997 the bypass clarifier at the wastewater treatment plant was active on 3 days to divert high storm water flows to the Mousam River. This compares with 10 days in 1996, 2 days in 1995, 6 days in 1994 and 9 days in 1993.

108. Schabath, Gene; "Clinton Township Hires Firm to Find River Polluters", Detroit News, September 14, 2000.

Clinton Township has hired a company to conduct tests in sewer lines to ferret out illicit cross connections that cause sanitary sewer overflows. In addition, the company plans to find homes with downspouts illegally connected to the sanitary sewer system. Clinton Township has also unveiled a plan that calls for the installation of several new pumping stations to carry overflow to a Detroit interceptor.

109. "Sewage Collection and Wastewater Treatment Report", City of Burlington Utilities Department, Burlington, North Carolina, 2000.

The City of Burlington has an ongoing program to clean and monitor the collection system. High-pressure washing, chemical treatment for root growth, and closed circuit television monitoring are a few of the tools used to maintain the collection system.

110. "DEC, Westchester County Agree on Plan for Sewer Improvements", New York State Department of Environmental Conservation, August 17, 1998.

The county will repair deteriorating sewage collection systems in 30 municipalities and construct overflow treatment facilities in one district. In addition, the County will work to disconnect illegal sewer connections from the system.

111. "Disconnecting Downspouts from Sanitary Sewer System", Kennedy Township, Pittsburgh, Pennsylvania, 2001.

The week of November 21, 1999, homeowners in Kennedy Township received a letter from the Board of Commissioners directing them to disconnect their downspouts from the sanitary sewer system.

112. "Sanitary Sewer Program Background Information", City of Berkley, Berkley, California, 2001.

The City uses the following methods to determine the condition of the Sanitary Sewer System.

- physical inspection
- flow monitoring/flow isolation
- smoke testing
- dye water flooding
- closed-circuit television inspection

113. Acitelli, Tom; "Grease is the Word", Spectator Online, Raleigh, North Carolina, 2000.

The city of Raleigh, NC, attempts to educate the public about the damage caused by introducing grease into the sewer system. Pamphlets and fliers have been distributed to residents. In addition, the city meets with restaurant owners to talk about the proper ways of disposing of grease.

114. "Sanitary Sewer Overflows", Wastewater System Report, City of Raleigh, North Carolina, 1999.

Efforts to reduce rainfall entry into the wastewater system include changes in manhole standards (reducing the vent holes to 1 vent per hole per manhole in roadway areas) and the addition of staff for system maintenance.

115. "Metropolitan Sewer District of Greater Cincinnati Operations Summary", City of Cincinnati, Ohio, 2000.

The City has implemented several programs to combat overflows. Approximately 60,000 feet of sewers are TV'd each month. Data is entered into a system wide model. The system model performs statistical analysis to process inspection results. The system model is divided into 300 individually monitored sewersheds.

116. Rutledge, Michael; "Metropolitan Sewer District Wasted $4M on Norwood Sewers", Cincinnati Post, Cincinnati, Ohio, 1998.

Under a 1993 agreement between MSD and the EPA, for each downspout that was disconnected, 6 new homes could be built. MSD paid dozens of contractors $4.9M to divert rain water by disconnecting downspouts and driveway drains from Norwood's sanitary sewers in an effort to prevent sewer overflows. MSD officials now say about 95% of that money was wasted, because once the rainwater nears Cincinnati, it was quickly dumped right back into Cincinnati's sewer system.

117. "Standards and Requirements for Food Service Establishments", MSD Sewer Use Ordinance, City of Cincinnati, Ohio, 2002.

This section of SUO outlines installation and maintenance instructions for oil grease interceptors.

118. "Recommendations of the Fort Wayne Sewer Task Force", Fort Wayne News Sentinel, Fort Wayne, Indiana, 2002.

The Task Force, working with Jones and Henry Engineers, decided to use ten critieria for prioritizing 39 combined sewer subbasins.

1. basement flooding
2. sewer overflows outside of buildings
3. poor structural conditions of sewers
4. design storm capacity
5. chronic maintenance problems
6. benefit/cost ratio of the improvements
7. financial support
8. service area
9. consistent with CSO program
10. order to abate overflows

The weighing number to be assigned to each subbasin for the cost criteria will be determined by comparing the benefit-to-cost ratio of all subbasins. The benefit is the sum of the subbasin's weighted scores for the other nine criteria and the cost is the estimated cost per acre to make the improvements to the subbasin.

119. "Funded Projects", Rivers Wet Weather Demonstration Program, Pittsburg, PA, 2001.

The 3 Rivers Wet Weather Demonstration Program administers grants to Allegheny County communities for innovative, cost-effective, watershed-based methods of wet weather sewer overflow elimination and management. Funded projects use some of the following methods to control/eliminate overflows.

- flow monitoring
- lateral sealing
- pipebursting
- trenchless technology to rehabilitate laterals
- sewershed grouting
- manhole sealing
- lateral replacement

120. "Inlet Control", City of Chicago, Illinois, 2001.

Rain Blocker is the City of Chicago's engineering solution to basement flooding that commonly occurs during intense downpours. It is a system of restructured sewers and catch basins and a simple, inexpensive disconnecting of home and apartment building downspouts.

ASCE Solutions for Sanitary Sewer Overflows
EPA Cooperative Agreement CP-828955-01-0

Footing Drain Disconnection Program, Auburn Hills, MI

By
Philip M. Hannan

I - Introduction

The information presented in this report was obtained from research in the literature and personal communications with City officials involved in the identification of the footing drain problems and their resolution. Private property contributions are perceived to be significant components of some City's wet weather flows. The purpose of this review of Auburn Hills, MI is to gain an understanding of the City's private property program and the cost-effectiveness of removing this type of defect and the related flow from sanitary sewers.

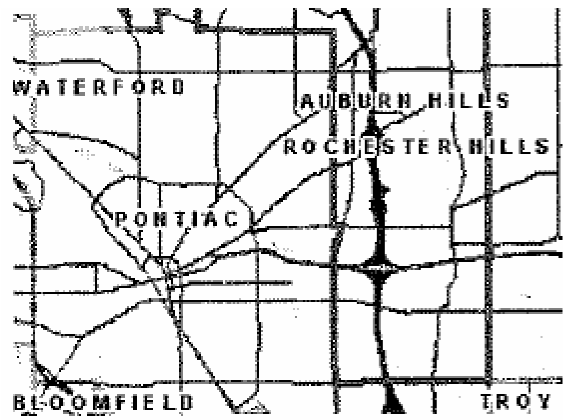
II. Background

Most wastewater agencies understand private property I/I is present in their collection systems to some degree or another. While the lack of legal authorities and the private property issues involved in the investigation and elimination of the extraneous flow inhibit widespread pursuit of this portion of the wet weather flows, some cities have moved aggressively to control specific sources of inflow from private building sewer connections (PBSCs). Downspout connections to the sanitary sewer are considered to be the "low hanging fruit" of the private I/I contributions due to their ease of identification (smoke testing), confirmation (dyed water flooding) and removal (re-direct the flow to surface or storm drains). Solutions to the PBSC problem are compounded by the inconsistent legal authorities that exist around the country for resolution to the problem. While some agencies already have a responsibility for the "public" portion of the PBSC from sewer main to the property line, the "private" portion from the property line to the building has generally been left to the customer.

Historical or regional building practices often influence the type of private property sources that may be found. In various Michigan communities and other regions of the Midwest a building practice had developed of connecting foundation or footing drains into the house lateral to the sanitary sewer. While initially considered acceptable in the context of a combined sewer applications, the practice appears to have drifted into separate sanitary sewer systems as well.

The foundation drain collects groundwater or percolating rainwater from around the foundation or basement walls below grade and discharges the flow to sanitary lateral or building sewer. The time of concentration is often very short within neighborhoods or subdivisions where this drainage feature can be found, leading severe surcharging, overflow or backup problems in the critical capacity sewer segments of the collection system.

Auburn Hills, MI, a suburb of Detroit and home of the "Palace" of the Detroit Pistons of the NBA, is just such a community where foundation drains are a common facet of the private property infrastructure. The City has established a "Footing Drain Disconnect Project" which is described below.



III. Footing Drain Disconnect Project

The City of Auburn Hill initiated this project to reduce the occurrence of basement flooding problems and to eliminate the effects of storm water inflow on the town's sanitary sewer system. The Bloomfield Orchards subdivision, which includes approximately 500 homes, was selected for implementation of this project. The project includes a "pilot phase" with houses with a history of basement backups selected for the pilot work. A list of owners who have voluntarily agreed to participate was also maintained by the City and was used in a chronological order to select additional houses for implementation of the program.

The Bloomfield Orchards subdivision experienced frequent basement flooding. In an effort to reduce the occurrence of basement flooding problems a foundation drain disconnect program was initiated. The house foundation drains within the Bloomfield Orchards subdivision collect excess ground water from around the basement wall or house foundation and discharges the collected water into the house sanitary lateral which connect to the sewer mains in the street. During heavy rain events the sanitary sewer mains become overwhelmed with the storm water discharged from house leads. As a consequence, some homes experience basement flooding.

With the completion of the foundation drain disconnect program, clear storm water is diverted to a separate storm drain which decreases the load that the sanitary sewer receives during a rain event. In turn, the sanitary sewer backups that cause basement flooding during rain events will be eliminated. This will help to bring sewer discharges back in line with the assigned town outlet capacity within the Evergreen-Farmington sanitary sewer system. The City of Auburn Hills along with other communities that are served by the Evergreen-Farmington sanitary sewer system is under a Federal Mandate to comply with town outlet capacity assignments.

For the program to be successful, it was determined that every home in the subdivision should have its footing drain disconnected from the sanitary lead and connected to a sump and pump for discharge to a storm drain. An important element of this project is that it is entirely funded by the City. The City estimated a unit cost o $2,000 to $4,000 for disconnecting the foot drains. The full program was expected to take five years to be completed and project costs could range up to $3million.

- Customer Outreach & Impact

Customer communication is a critical component of this project. Prior to construction, the contractor and the City representative meet with residents to discuss the necessary construction activities. The residents were fully informed and had a clear understanding of the conversion process and necessary materials to be used. A website was also established to post information pertaining to the project.

The typical installation requires a sump tank, sump pump, check valve and electrical connection. Although initially the electrical and mechanical equipment had been projected to be installed outside the home through an excavation, the sump units are now installed in the basement. This requires the floor slab to be cut and the equipment installed. The City has found the pumps (which are the owners responsibility to maintain) are easier to deal with if they are in the basement and they are less impacted by the freezing winter temperatures.

A 2 inch discharge line is run from the sump pump to a storm drain near the road edge. The discharge lines are both open cut and augured for installation purposes, the method determination made after a site visit. Some homes may require a conversion other than the norm and the process will be discussed with the resident prior to beginning of work. All restoration after the conversion is completed will be the responsibility of the contractor and will be completed to the resident's satisfaction before payment is made by the City. Final payment requires a sign-ff from both the City and the owner of the property.

The City hires the contractor to maintain quality control and to simplify the procurement process for the customer. Auburn Hills pays 100% of the cost for the necessary footing drain disconnect and sump pump conversion. The residents are given the option of incorporating other plumbing related work into the project, but this would be solely at their expense. Customers who performed the footing drain disconnect on their own, but in accordance with the program requirements, did have the opportunity to be reimbursed. The City had also considered a "seller to pay" Ordinance that stipulated that those residents who did not voluntarily allowed the City to disconnect the drains would have to disconnect the drains at their own expense when they sell their house.

- Status

The implementation of the project has progressed very well and is ahead of its original 5-year schedule. All 500 houses, except for nine, have been disconnected. Although a flow monitoring assessment of the wet weather flows has not been completed since the last of the disconnects were made, the flow during rain events in the system has been significantly reduced.

Before the disconnect program, it was not unusual for the City to get three to four times of the "contracted flow" (the purchased flow capacity by the City) during a 2-year storm event. Since substantial completion of the project, the flow has consistently been below the contracted capacity during all wet weather events.

ASCE Solutions for Sanitary Sewer Overflows
EPA Cooperative Agreement CP-828955-01-0

Clean Water Services, Portland Oregon
By
Ahmad Habibian

I - Introduction

The information presented in this report was obtained from phone conversations on Thursday, September 19, 2002, with Mr. Steve Lampert and Mr. Chris Bowles of Clean Water Services (CWS). Mr. Lampert is an engineering project manager and Mr. Bowles is manager of field operations. The objective was to get a close understanding of policies, procedures, and practices Clean Water Services has implemented to reduce the potential of Sanitary Sewer Overflows (SSOs) in its collection system.

II- Background

Clean Water Services is a public utility providing wastewater and storm water services for approximately 450,000 customers in the Tualatin River Watershed in Oregon. The name of the agency was changed from Unified Sewerage Agency (USA) to Clean Water Services on June 5, 2001. When formed initially in 1970, the objective of the Unified Sewerage Agency was to unify 26 wastewater treatment plants into one coordinated system. After more than 30 years of operations, the agency changed its name to Clean Water Services to better reflect its broader role in managing the water quality needs of the Tualatin River Watershed.

The CWS sewer system consists of approximately 766 miles of sewer. It operates 37 pumping stations and four treatment plants. It has a treatment capacity of 72 mgd. CWS has a staff of 268.

III - Sanitary Sewer Evaluation & Rehabilitation

CWS initiated a comprehensive series of Sanitary Sewer Evaluation Surveys (SSES) in the 1980s. The agency purchased 32 flow meters and conducted comprehensive flow monitoring programs to evaluate the level of infiltration/inflow (I/I). In addition to the flow meters, 13 rain gage stations were also established. The flow monitoring data was used to prioritize the basins for further investigations including smoke testing and CCTV inspections to evaluate the condition of sewer lines. The sewer lines in each basin were prioritized based on the severity of the defects identified during the investigation phase.

Based on past experience, WSD has developed a rule of thumb cost-effective level of I/I removal of $1.68 per gallon per day. I/I sources which cost more than this level to eliminate are not considered cost effective.

Following the investigation of each basin, a rehabilitation program was established to improve the condition of the sewer lines. The rehabilitation technologies utilized included Cured-in-place-pipe (CIPP), fold & form, cementitious lining of manholes, and grouting of joints, manholes, and lateral connections. Rehabilitated sewer lines are air tested, while manholes are vacuum tested.

Clean Water Services experience with CIPP has been very positive. However, it has encountered deficiencies in fold & form applications, mostly due to contractors lack of diligence. PVC lining installed by fold & form experiences tension, which if not released, causes the PVC liner to become brittle and crack when reinstating the lateral connections. Polyethylene liners remedy this shortcoming; however, they are subject to creep. Once the PE liner is pulled in place, it should be allowed to relax; otherwise, its movement may damage the lateral connections.

CWS has found that in order to achieve significant reduction in the level of I/I, service laterals should be fully rehabilitated or replaced at the same time the main line is rehabilitated. In one basin, when the lateral was rehabilitated to the property line only, the I/I reduction was less than 30%. As a result CWS has issued a "Lateral Resolution Order" in 1998, which calls for the CWS to rehabilitate the full lateral at its own expense. An "Entry Permit Form" is sent to the owners to get their permission to fully rehabilitate the lateral. Since the inception of this program in 1998, most home owners have agreed to grant the permit for rehabilitating their service laterals.

Most service laterals are replaced by open cut. Pipe bursting has been used for trenchless rehabilitation of laterals with great success and CWS is planning to utilize pipe bursting more frequently for lateral rehabilitation. Cured-in-Place lining has also been used for lateral rehabilitation; however, due to its high cost (approximately $4000 per application), it s only used when other alternatives are not feasible.

Acrylamide grout (liquid form) is used by in-house staff to seal pipe joints, manhole defects, pipe to manhole connections, and lateral connections. Every joint treated by chemical grout is air tested.

IV- Operation & Maintenance

In conjunction with its rehabilitation program, CWS has also a proactive maintenance program. Through years of experience, CWS has found that a two year cleaning frequency of its sewer lines, 15-inches and smaller, is optimal. Cleaning is performed by hydraulic jetting. Problem lines are scheduled for more frequent cleaning (weekly, monthly or quarterly). CWS has also an on-going CCTV program and inspects all of its 15-inch and smaller sewer lines every seven years. It does not have a proactive maintenance program for sewers larger than 15-inches in diameter; however, it is considering to institute such a program. All sewer lines which are found to have negative or inadequate slope, have settled or have sags are reported to the Engineering Department and are scheduled for replacement.

The CWS also uses chemical foams for control of roots and has found this practice to be successful. Each application has lasted at least four years.

V- Training

CW provides regular training for its operation and maintenance staff. Some of the safety training courses are web-based, provided through a vendor.

VI - New Materials

CWS has installed polyethylene manholes, in combination with PE pipe. The manhole cover is bolted in place. PE manholes have been in service for five years and have performed very well. The cost is relatively high, approximately $12,000 per manhole. It therefore is only used in critical areas (such as wetlands) where access is very difficult for maintenance.

Recently, CWS used fiberglass for 9000 ft of a new sewer line and its manholes.

ASCE Solutions for Sanitary Sewer Overflows
EPA Cooperative Agreement CP-828955-01-0

City & County of Denver Case Study
By
Ahmad Habibian

I - Introduction

The information presented in this report was obtained from a phone conversation on Wednesday, September 4, 2002, with Mr. Reza Kazemian, Director of Operations, and Mr. Jeff Snyder, Superintendent, both with the City & County of Denver. The objective was to get a close understanding of policies, procedures, and practices the City & County of Denver has implemented in the past to reduce the potential of Sanitary Sewer Overflows (SSOs) in its collection system.

II- Background

The City and County of Denver, Wastewater Management Division (WMD) is responsible for the operation and maintenance (O&M) of nearly 1,700 miles of sanitary sewers and 700 miles of storm sewers within the City and County of Denver, Colorado. WMD's sewer system is predominantly made of clay and PVC pipes. WMD serves more than 500,000 customers. The average dry daily flow (ADDF) is approximately 100 mgd.

Wastewater treatment services and maintenance of the interceptor system are provided by the Metro Wastewater Reclamation District (District) of which the City and County of Denver account for approximately half of the total flow treated by the District. WMD is organized into four functional areas of responsibility: finance, administration and human resources, engineering, and operations. WMD plans, designs, constructs, operates, and maintains Denver's sanitary and storm sewer systems. The goal of WMD is to provide high quality cost-effective service to the residents of Denver by using a team approach and recognizing that customers and employees are paramount to their success.

III - Benchmarking Study

The City & County of Denver engaged the services of a consultant to perform a benchmarking study of its sanitary sewer system O&M program. The study found the following best management practices (BMPs) by WMD:

- Proactive, preventive maintenance programs
- Cross training of maintenance and construction staff
- Development and monitoring of performance goals
- Identification and proactive maintenance of problem areas
- Standardization of equipment

The benchmarking survey results indicate that WMD spends 90 percent of its O&M budget on preventive maintenance activities such as hydraulic cleaning and CCTV inspection. Other utilities surveyed and information reported in the literature review indicated that preventive maintenance typically ranges from 50 to 60 percent of the total O&M budget. WMD's sewer cleaning frequency is nearly double that of the next two highest benchmarking partners and more than four times the frequency rates cited in the literature review. A similar conclusion can be drawn from the CCTV inspection frequency data. WMD's focus on preventive maintenance has resulted in the lowest total number of main line stoppages per mile of sewer, one of the lowest numbers of basement flooding events per 100 miles of sewer and total daily complaints per 1,000 customers.

WMD accomplished these results at a very low program cost per mile of sewer. WMD has an annual O&M budget per mile of sewer of $635, which is less than 25 percent of the average of the values reported by the benchmarking participants and the literature review. In comparing the number of personnel per mile of sewer and population served to the number of mainline stoppages, WMD appeared to be achieving a greater level of performance. This reflects the commitment of a large portion of their O&M budget to preventive maintenance.

IV- Specific Practices

The following specific practices were discussed during the phone conversation:

1. Aggressive Cleaning - WMD's sewer system has adequate hydraulic capacity. As such, WMD has focused its efforts on the maintenance of the system. WMD's average sewer line cleaning frequency is about 1.5 years (67%). Lines with known problems are scheduled for more frequent cleaning, as low as three months. Hydraulic jetting is the primary cleaning tool used. WMD has 10 jetting units, 4 rodder units, and 2 combination

units. WMD is responsible for the maintenance of both the sewer and storm systems. Due to the semi-arid climate in Denver, root penetration into sewer lines is a serious problem. In addition to root cutting equipment, WMD recently utilized a chemical root control material. The effectiveness of this method has not been established.

2. Pump Station Maintenance - WMD has two major pump stations which are monitored by the SCADA system. The SCADA system alerts the maintenance personnel when an alarm goes off. The pump stations are also visited twice a week by the maintenance personnel.

3. CCTV Inspection - WMD inspects all its sewer lines by CCTV. The entire system is covered every seven years (14%). WMD has five CCTV units which perform approximately 1.6 million ft of sewer inspection annually.

4. Sealing Program - WMD has established an in-house sealing program to repair minor defects in the system. It has one sealing unit which utilizes acrylamide grouting. The minor defects found during CCTV inspection are programmed to be repaired by the sealing unit. The liquid form of the grout is used to minimize health concerns. The average cost is estimated at $12 to $15 per repair. Approximately 16,000 sealing operations are performed annually. A cost-effectiveness analysis of the sealing program indicated that the operations were cost-effective when the entire sewer reach or mini-basin was inspected, and sealed. WMD is generally pleased with the results of its sealing program. It estimated the useful life of each grouting application to be approximately 18 to 20 years.

5. Line Rehabilitation - WMD spends approximately $2 million on rehabilitating its sewer systems. Techniques used include Cured-in-place-pipe (CIPP), fold & form, and pipe bursting. Pipe bursting is normally used when additional hydraulic capacity is desired. WMD has a six-year plan which is developed from the prioritization of the sewer lines based on CCTV inspection results.

6. Manhole Rehabilitation - WMD has also a manhole rehabilitation program. The techniques used include cementitious and epoxy spraying of manholes to eliminate infiltration/inflow sources.

7. Discontinued Practices - WMD used to flush certain sewer lines by dumping 600 gallons of clean water into an upstream manhole. WMD has concluded that this technique is not cost effective and does not use it anymore.

8. New Practices - WMD is currently performing research into the effectiveness of cleaning tools. A pilot program has been established for this purpose._WMD has also recently installed a GIS and Maintenance Information Management System (MIMS). These tools are expected to streamline its maintenance operations and improve its efficiencies even further.

ASCE Solutions for Sanitary Sewer Overflows
EPA Cooperative Agreement CP-828955-01-0

Fayetteville, AR
By
Philip Hannan

I – Introduction

The information presented in this report was obtained from City documents including wastewater collection system reports, annual budgets and other wastewater related reports as well as telephone conversations with David Jurgens, Water and Wastewater Superintendent for Fayetteville, AR. The objective was to glean the relevant information related to the City's responsiveness to SSOs and the Wastewater System Improvement Project (WSIP) to identify the elements of the comprehensive program to reduce its SSO frequency.

II- Background

The city of Fayetteville, AR is a thriving community of nearly 60,000 situated on approximately 45 square miles in the northwest corner of Arkansas. Home to the main campus of the University of Arkansas System, the City also serves as the gateway to the Ozark Mountains and as the county seat and economic center for the Washington County area.

The Fayetteville system serves the City of Fayetteville and satellite communities of Greenland, Farmington and Elkins. Respective populations for the service area are presented in Table 1.

Table 1
2000 Service Area Population

Community	Population
Fayetteville	58,047
Greenland	907
Farmington	3,605
Elkins	1,251
Total	63,810

The City is responsible for the wastewater treatment of all the flow and the maintenance and rehabilitation of the City's portion of the collection system. Flow within the City is collected and transported to the treatment plant through approximately 465 miles of 6" through 36" diameter gravity sewers, 11,000 manholes, 32 pump stations and 40 miles of force mains. Annual average daily flow at the Noland Wastewater Treatment Plant is approximately 12 mgd.

The City has contracted with Operations Management International (OMI) to operate the treatment plant, NPDES permit reporting, industrial pretreatment program administration, sludge disposal, and the 32 wastewater pumping stations.

By the City's reckoning, the quest for appropriate solutions to Fayetteville's wastewater infrastructure problems has been ongoing for nearly 30 years. Wastewater issues have dominated City Hall for so long that even in 1984, an informal survey humorously reported a 9:1 preference for getting poked in the eye with a sharp stick rather than read another sewer story. Issues related to water quality of the streams receiving the treatment effluent, treatment technology, costs and other elements kept the topics in the public forum. A major upgrade to the City's treatment facility, completed in 1988, provided additional capacity and advanced treatment to address the water quality issues of the receiving White River.

As a result of significant SSOs in the collection system, Region 6 of the USEPA placed the City under and Administrative Order (AO) in 1989. The AO required the City to improve the wastewater collection system and eliminate wet weather SSOs. While not eliminating the wet weather SSOs entirely, substantial progress was made and Region 6 allowed the AO to expire in 1995. The City has continued to make progress in further reducing SSOs by upgrades to its collection system and recent investments to bring additional treatment capacity online. This case study will report on the comprehensive nature of the City's investments in the wastewater infrastructure and their ongoing achievements in reducing SSOs.

III. Wastewater Infrastructure

The City has actively been engaged in reducing SSOs for 15 years and has projected an additional 6 years to complete the currently prescribed projects. An ongoing, sustained effort is expected to be a component of the Sewer Maintenance Program for the foreseeable future. A major SSO reduction initiative was undertaken in response to EPA's Administrative Order issues in 1989. After the lifting of the AO in 1995, the City completed a facility plan resulting in the Fayetteville Wastewater System Improvement Project (WSIP) in 1997. The WSIP captures the funding and the resources necessary to enable the City to manage dry and wet weather impacts to the wastewater infrastructure.

The following sections describes the progression of the City's infrastructure investment to move from reactive to proactive efforts and reflects a continuous effort to reduce infiltration, inflow and SSOs system-wide through sewer system surveys, implementation of rigorous rehabilitation and improved preventive maintenance.

III.1. Administrative Order Responsiveness

The City's escalating problem with SSOs captured the attention of EPA's Region 6 in the 1980's, culminating in an Administrative Order in 1989. That year, Fayetteville reported over 500 SSOs or more than 125 SSOs per 100 miles of collection system. The overflow problem was a combination of both dry weather maintenance issues (stoppages, roots, grease) and wet weather flows causing capacity exceedance in the collection system.

Although Fayetteville had performed an SSES in the 1970's when grant money was available, the subsequent rehabilitation had minimal effect in reducing I/I flows. In response to the AO and with that earlier learning experience, the City executed a comprehensive sewer system evaluation survey plan which resulted in more effective sewer rehabilitation. The result was a reduction of over 75% of the annual SSOs to a 1994 level of 123 SSOs. The City estimated that approximately 1/3 of the remaining SSOs were I/I related and the balance maintenance stoppage related. The City's success in reducing SSOs led to the lifting of the AO in 1995.

III.2. Fayetteville Wastewater System Improvement Project (WSIP)

With the momentum generated by the SSO reduction successes, the City broadened the infrastructure review in 1995 to look at both treatment and collection system needs. Through a facility planning process, the WSIP was developed and advanced the initiatives begun under the Administrative Order. The WSIP established a scope, schedule and funding mechanism for the continued studies and upgrades. The Project provides for both collection and treatment improvements to the wastewater system to improve SSO conditions and other performance aspects of the wastewater infrastructure.

III.2.1. Treatment/Collection System Capacity Expansion

The City has been served by a single treatment facility, the Paul Nolan Treatment Plant in the White River watershed. The ridgeline that splits the City required that all the flow from the Westside (Illinois River watershed) be pumped over for treatment at Paul Nolan WWTP. This factor plays a major role in the recommendations contained in the Improvement Project as the City proactively looks to the future growth of the region. The recommendations were contained in a 1997 Facility Plan and included;

- Separate the collection into its two natural gravity components, the White River and the Illinois River watersheds. With construction of a new treatment facility on the Westside in the Illinois River watershed, flows are reduced at the existing facility and future growth components are thereby served on both sides of the City.
- Improve and expand the collection system to deliver flow to the new treatment plant and continue the rehabilitation of the existing sewer pipes to reduce I/I. While the separation of the sewer areas required several additional pumping stations, six others could be abandoned that were no longer needed.

The separation of the collection service area by watersheds split the flow between the existing and proposed facilities almost equally, 50/50. This approach, while requiring additional sewers for service in the new Westside area, will immediately increase conveyance capabilities of the collection system. Removing flows from overburdened eastside sewers improves their wet weather performance by reducing the flow and the related threat of sewer overflow. The new sewers on the Westside are designed to handle both existing and future flows. Eliminating the obsolete pump stations that are no longer needed reduces energy requirements and removes 6 opportunities for electrical or mechanical related SSOs at these facilities.

The collection system portion of this improvement plan is summarized in Table 2. Including engineering and rehabilitation contract costs for manholes and sewers, over $24 million will be invested in I/I directed efforts under the WSIP. Flow monitoring improvements and selected pump station upgrades are also included.

III.3. Wastewater Collection System Performance

While significant capital investment characterized by the WSIP is underway, the Sewer Mains Maintenance Program is the primary, annual effort to tackle SSO precursor conditions in the collection system. For the 2003 budget year, the City has increased the maintenance staff from 17 to 20 field personnel with administrative support from the Water & Sewer Department. This raises the full time employees (FTEs) performing maintenance to 4.3 per 100 miles of collection system (gravity sewers only). Cleaning is the primary task for the staff. Approximately 135 miles are cleaned annually, or over 30% each year, using hydraulic flushing, hand rodding in limited access areas and bucket (cable drag) machines. The equipment is matched to the conditions found in the sewers.

This program has the full capabilities to implement, manage and/or inspect virtually any activity that is required in the collection system. The City performs manhole inspections and repairs, CCTV condition assessment, and sewer pipe rehabilitation (structural and non-structural). Replacement of under-capacity sewers is also an element of this program. A complete summary of recent performance within this Program is presented in Table 3.

Table 2: Wastewater System Improvement Project (1997-2007)

	Watershed	Mini-Basins	Nature Of Work	Cost ($ Millions)	Completion
Collection System Rehabilitation	White River	7,14,15	Engineering	$ 0.77	1997
			MH Rehab	$ 0.88	1997
			Sewer Rehab	$ 1.61	1998
		University of Arkansas	Engineering	$ 0.08	1997
			MH Rehab	$ 0.21	1997
			Sewer Rehab	$ 0.29	1998
		Phase II	Engineering	$ 0.89	2004
			MH Rehab	$ 0.95	2004
			Sewer Rehab	$ 2.65	2006
	Illinois River	16	Engineering	$ 0.72	1998
			MH Rehab	$ 1.02	2000
			Sewer Rehab	$ 1.60	2001
		Mt. Sequoyah Upgrade	Engineering	$ 0.16	2001
			New Construction	$ 0.60	2002
		1-5, 18, 19	Engineering	$ 0.97	2001
			MH Rehab	$ 1.88	2002
			Sewer Rehab	$ 1.26	2003
		15	Engineering	$ 0.35	2007
			MH Rehab	$ 0.34	2007
			Sewer Rehab	$ 0.80	2008
	City-Wide	All Basins	Sewer Rehab	$ 2.94	2009
Other Improvements	Pump Station Upgrades	Harnestring Creek	Engineering	$ 0.01	1997
			Construction	$ 0.13	1998
		Private Operator		$ 1.74	2009
		SCADA (All Stations)		$ 0.50	2001
	Flow Monitor Upgrade			$ 0.23	2001
	Hydraulic Cleaner Purchase			$ 0.23	1999
	Ongoing SSES			$ 0.30	2007
			Total	**$ 24.12**	

Table 3
City of Fayetteville
Sewer Maintenance Program Performance Measures

Measure	Units	Year 1997	1998	1999	2000	2001	2002 (Estimated)	2003 (Budgeted)	**Average** (Annually)	**% of System** (Annually)
Human Resources										
Full Time Employees	Each	17.4	17.4	17.4	17.4	17.4	17.4	20.4		
	Per 100 Miles	4.1	4.0	4.0	4.0	3.7	3.7	4.3		
Inventory										
Sewer Mains	Miles	425	430	435	440	465	470	470		
Manholes	Each	7,300	7,400	7,450	10,700	11,000	11,100	11,200		
Accounts	Each	23,066	23,944	24,466	25,506	26,321	26,941	27,561		
Maintenance Activities & Repair										
CCTV Inspection	Feet	37,478	28,479	49,596	30,880	37,037	50,000	52,000	40,781	2%
Sewers Cleaned	Feet	703,700	322,332	762,648	754,058	663,533	910,000	900,000	716,610	29%
Sewer Lining	Feet	4,797	718	2,525	2,967	1,837	4,200	4,000	3,006	0.1%
Point Repairs	Each	75	67	139	159	93	80	100	102	
Manholes Repaired	Each	139	154	170	110	230	400	400	229	3%
Performance										
SSOs	Each	103	136	138	133	136	150	100	128	
	Per 100 Miles	24	32	32	30	29	32	21	29	

III.4. Rehabilitation Effectiveness

As a result of the Administrative Order issued in 1989, portions of the collection system were studied through sewer system evaluation surveys (SSES) and subsequently rehabilitated. In order to evaluate the effectiveness and longevity of the rehabilitation techniques employed both then and now, the City undertook an evaluation of the $1.5 million renovations performed in 1993 in the 62,000 lf, 100 year old historic district area. Sewer pipe replacement, excavation point repairs, cured-in-place-pipe (CIPP) lining and various forms of manhole repairs were all utilized. The same area was inspected again in 2001 to identify those defects which were new, assess the integrity of the rehabilitated portions of the sewer and to determine if there was further deterioration of defects previously identified but not corrected.

In general, the rehabilitation work performed was found in a sound condition. Total manhole rehabilitation, CIPP with external lateral replacement, pipe replacement, and selected point repairs were all performing successfully nearly 10 years later. Defect selection and continued deterioration of the unrehabilitated portions of the collection system were found to be issues in need of further study and development. Ongoing “pipe intelligence” is critical to the City’s sustaining the extraneous flow reduction gains achieved through sewer renovation.

III.5. Financial/Customer Impact

The initiatives taken to reduce SSOs and expand treatment capacity come at a price. In a recent benchmarking comparison undertaken in 2003, Fayetteville was at the top of their peer group for cost impact of their 5-Year CIP in both wastewater collection (approximately $180,000/ 1,000 people served) and wastewater treatment ($220,000/1,000 people served). Combined, the indebtedness totals approximately $400,000/ 1,000 people served. In the benchmarking peer group, the median 5-Year CIP was just over $50,000/ 1,000 people served.

The reasons for the significant costs are evident from the ongoing maintenance and rehabilitation effort in the collection system and the capital investment in a second wastewater treatment plant. In November 2001, a sales tax was approved to repay the $100 million principal and interest from a state revolving fund (SRF) loan. If traditional bond revenue financing had been used, the debt ratio would be even higher. While the investments are major, the needs of the infrastructure were significant as well.

The other side of the financial balance is wastewater revenues. Despite the major program costs, Fayetteville's wastewater debt service/revenue ratio is approximately 20% and is judged to be average in comparison to their peers. Other benchmarking peer groups were in the 35-40% range for the debt service ratio. The planned CIP will increase the debt ratio and the City's leverage in capital investments.

III.6. Public Information Program

In order to successfully implement such a major investment, a public information program was developed. In April 2000, a major outreach initiative was implemented to establish credibility and build trust and support for the infrastructure improvements. A series of neighborhood meetings, briefings, workshops and presentations to both citizens and business groups alike were ongoing throughout 2000. The idea was to foster an information exchange that not only got the City's message out, but to understand the citizen's concerns, confidence levels about the project and the preferred method of payment. This dialogue was critical to the success of the proposed sales tax levy to fund the WSIP.

The public information outreach effort continues even though the ¾ cent sales tax levy to repay the loans to fund the WSIP was approved by the voters in November 2001. Ongoing information in the form of newsletters, budget information and other communications with customers maintains the information flow about the project status and accomplishments.

One measure of the success of the information campaign was measured in a customer survey of all City services conducted in August 2001, just months before the sales tax vote. Water and sewer services as a group received a "quality of service" rating of 75% in the excellent/good level. Only 7% identified the service as poor. Coming from a background of the Administrative Order for SSOs in 1989 to the capital intensive WSIP initiated in 1997, the City successfully got their message to the customers about their custodial role in the wastewater infrastructure. While much work remains, the City is better positioned to achieve their SSO reduction goals.

IV. Concluding Remarks

The City's investment in the wastewater infrastructure is significant. On average, the 10 year investment of the WSIP corresponds to approximately $.98/linear foot per year of collection system. If the annual operation and maintenance cost of $1.1 million ($.45/lf/year) for the Sewer Mains Maintenance Program described in Section III.3 is included, the re-investment for the City in the collection system is approximately \$1.43/lf/year. Expressed in different units, the City's total annual re-investment in the collection system is \$7,550/mile.

A 1999 American Society of Civil Engineer's report, "Optimization of Collection System Maintenance Frequencies and Performance," found a relationship that level of investment has a direct impact on system performance. The average 16-year investment level for the surveyed agencies in that report was approximately \$9,300/mile/year. While the City's investment is in the order of magnitude as the average reported in that study, there is still room for SSO performance improvement.

The City's SSO rate has declined from over 500 at the time of the 1989 Administrative Order to an average of 128 for the past several years. The gains from 1989 are significant, however, the performance has temporarily reached a plateau. The City's current goal is to reduce SSOs to an average of 75 per year which corresponds to a rate of approximately 16 SSOs per 100 miles. While the WSIP will continue to address wet weather flows for the next several years, there may be a need to optimize the ongoing annual maintenance to further target stoppages and other causes of SSOs.

ASCE Solutions for Sanitary Sewer Overflows
EPA Cooperative Agreement CP-828955-01-0

Miami-Dade Water & Sewer Services Department Case Study

By
Ahmad Habibian

I - Introduction

The information presented in this report was obtained from a phone conversation on Thursday, August 29, 2002, with Mr. John Chorlog, of Miami-Date Water & Sewer Department (MDWASD). The objective was to get a close understanding of policies, procedures, and practices MDWASD has implemented in the past to reduce the potential of Sanitary Sewer Overflows (SSOs) in its collection system.

II- Background

The Miami-Dade Water and Sewer Department (MDWASD) serves a population of over two million in a 400 square mile service area. MDWASD maintains over 2,000 mile of gravity sewers up to 72-inch diameter, 640miles of force mains up to 102-inch diameter and nearly 1000 pump stations. There are three WWTPs with a total annual average daily flow of 352.5 mgd. Supervisory Control and Data Acquisition (SCADA) has been installed in about 82 percent of pump station to monitor flow, pressure, wet well levels, pump runtimes, power consumption and I/I data.

III - Pump Station Improvement Program

The Pump Station Improvement Program (PSIP) has utilized numerous tools to identify, analyze, and prevent operation and maintenance problems in the County's wastewater collection and transmission system. The program was setup to meet the challenge of monitoring nearly 1000 pump stations and upgrading half of them to ensure compliance with the requirements of enforcement actions. The First Partial Consent Decree (FPCD), issued by the USEPA in 1993, mandated that all of MDWASD's pump stations be designed and operated to exhibit a nominal average pump operating time (NAPOT) of less than or equal to 10 hours/day. The PSIP has installed a Supervisory Control and Data Acquisition (SCADA) system throughout the wastewater collection system, and used the SCADA data as well as, the data obtained from gravity sewer metering, pump station elapsed-time readings, potable water consumption metering, permanent in-line flow meters on the force mains for the wastewater transmission system, pump down test of the wetwell, and night flow data, to review the operation of the pump stations and detect, analyze and prevent operation and maintenance problems. Problems such as blockages or breaks in the gravity sewer system, blockages or closed valves in the discharge force main system from the pump stations, Infiltration/Exfiltration/Inflow in the collection system, pressure problems in the force main system, O & M problems within the stations, capacity problems, etc. are identified using the various tools now available to the Department. The following is list of problems detected through analysis of SCADA data:

- High Flows, Pump Station 711
- Gravity Main Break, Pump Station 874
- Tidal Influence, Pump Station 51
- Crosslinked Manhole, Pump Station 147
- Clogged Force Main, Pump Station 814
- Valve Problem, Pump Station 654 and 655
- Impeller Problem, Pump Station 338
- Clogged Suction Line, Pump Station 799
- No Vent in Wetwell, Pump Station 672
- Level Control Problem, Pump Station 404

IV- Specific Practices

The following specific practices were discussed during the phone conversation:

1. Pump Station Operations Manipulation - During a storm event pump units of the pump stations equipped with SCADA can be turned on or their speed can be changed to control the flow. Pump stations may also be turned off and the flow rerouted to another basin. Most pump stations are equipped with alarm switches. During a significant storm, the data transmitted through SCADA is carefully monitored and actions are taken to prevent overflows. The maintenance and operating crews, who are placed on standby during significant storms, are ready to be dispatched to potential problem areas. If necessary sewerage is hauled away by tankers to avoid an overflow.

2. Auto Paging System - All operation and maintenance staff carry a pager. An automated paging system is programmed to automatically send messages to appropriate staff during an emergency. Staff are trained to respond to emergency situations. Key personnel also have access to SCADA data at their home through laptop computers assigned to them. Once an alert is received from the pager system, they can logon to the SCADA system and find out more about the nature of the emergency situation.

3. Hydraulic Modeling - MDWASD maintains a dynamic hydraulic model in-house. The model is used for planning and design purposes, as well as for confirmation of

observation. The model has not been used as a tool for controlling and rerouting flows during storm events.

4. Sewer Line Rehabilitation - MDWASD utilizes cured-in-place-pipe (CIPP) for rehabilitation of sewer lines. The Department is not utilizing fold and form lining, being concerned that groundwater would flow through the annular space between the liner and the host pipe. A proprietary system (Linabond) was used for rehabilitation of interceptors. The results, however, have not been satisfactory. Pipe replacement and point repairs (using sectional liners) are also performed.

5. Manhole Rehabilitation - MDWASD utilizes cementitious, epoxy, and urethane coating systems for rehabilitation of manholes. Rain stopper dishes are also used to prevent the inflow into the sewer system. In addition, chimney rubber seals are used to seal the upper portions of the manholes.

6. Grouting - MDWASD utilizes grouting for repair of minor defects in its sewer lines and manholes. MDWASD maintains in-house resources for application of chemical grouting.

7. Service Laterals - Service laterals are pressure tested. If they do not pass the test, the property owner is notified to take action and repair the lateral. Currently, MDWASD is exploring alternatives for financing and executing lateral repairs.

8. Satellite Systems - MDWASD recently completed a study on how to charge the satellite systems when they exceed the allocated peak flow. The recommendations of this study are not yet implemented. It is expected that when these recommendations are implemented, the satellite systems will be more likely to consider upgrading their sewer systems to reduce peak flows.

9. Spare Parts Monitoring System - MDWASD has an automated spare part monitoring system which alerts the purchasing department when the number of any stock item falls below a specified number. This allows the purchasing department to order the spare parts well in advance of running out of stock.

10. Design Criteria - MDWASD uses a 2-year 24-hours storm event for planning and design purposes. Based on the requirements of the consent decree, pump stations are designed to be operated at a nominal average pump operating time (NAPOT) of less than

or equal to 10 hours/day. MDWASD feels this criteria has been relatively conservative and has caused it to spend more money ($260 million for pumping stations and $100 million for force mains) than necessary upgrading the pumping stations.

11. Impact on Flows - MDWASD has experienced a minor reduction in the Average Daily Dry Flow (ADDF) form 320 mgd to 310 mgd after rehabilitating a major portion of its pumping stations and sewer lines. The peak flow has significantly increased from 550 mgd to 800 mgd. It appears that the significant increase in the peak flow at the treatment plant is an indication that the improvements have been effective in conveying the inflow to the treatment plant.

12. Employee Recognition - MDWASD holds an annual award ceremony during the Christmas season, which includes a cook out as well as a competition event. High performance employees are recognized for their efforts through the award program.

ASCE Solutions for Sanitary Sewer Overflows
EPA Cooperative Agreement CP-828955-01-0

New Castle County, DE
Department of Special Services
By
Philip Hannan

I - Introduction

A field visit was made to New Castle County, DE on December 12, 2002 to discuss and observe the bio-treatment of sewers and pumping station wet wells for the reduction of grease. The procedures and performance of bacteria applications in New Castle County were reviewed with Ted DeBoda, Operations Service Manager, Lynn Gillespie, Sr. Maintenance Technician, and Jim Woods, Maintenance Equipment Operator 2. The purpose was to obtain insight into the use of bio-treatment for grease and sanitary sewer overflow (SSO) reduction.

II- Background

New Castle County, DE, the first county in the first state, provides wastewater collection and treatment services for nearly 100,000 customers in the suburban Wilmington, DE area. The wastewater collection system comprises 1,860 miles of 8”-84” diameter sewers, 36,000 manholes and 140 pump stations. The Department of Special Services has been proactively addressing SSOs on a number of fronts, incorporating many elements of the proposed Capacity, Management, Operations and Maintenance (CMOM) requirements into their collection system operations. One key area is the development and application of sewer capacity management tools.

New Castle County is experiencing rapid growth and they recognized the need to track sewer allocation to ensure the collection system had adequate capacity. For this purpose, the County developed a geographic information system (GIS) based sewer model with three components; sewers, model, and service. “Sewers” represents the inventory layers retrieved from index maps and construction as-builts. “Model” is a subset of the sewers coverage and is only the portion of inventory that is actually modeled. “Service” provides the demand side of the model, providing existing water consumption and allocation for future growth demands. This module also locates the demands at the proper nodes for routing within the model.

The sewer capacity model not only provides assessments for future developments, but is also a tool for evaluating existing interceptors and projecting necessary CIP improvements. Sewer flows are updated annually (including I/I calculations based on measured wastewater flows less water meter demand readings from the two low quarters), service area boundary periodically, and sewer inventory as the new pipe is added to the system. The model has enabled the county to manage growth, provide adequate sewer capacity in a timely fashion, and eliminate the prospect of future overflows from development.

III. The "Bug Truck"

New Castle County has long recognized the impact of a sound Fats, Oil, and Grease (FOG) policy. Grease interceptors for commercial establishments are required with exceptions granted only after thorough review. However, grease can still be a problem from residential and other sources that needs to be addressed. For nearly 20 years, the County has been practioners of bio-treatment, the application of bacteria to sewers and wet wells for the reduction of grease. The earliest program began with a modest 4 gallon mix and 4 manhole sites where a one gallon mix was discharged. The limited program achieved demonstrated results (pre and post-CCTV for performance evaluation), gaining support for increased dosing capacities of 40 gallons, then 90 gallons and 180 gallons. The program has culminated the current "bug truck" with a maximum capacity of 360 gallons.

- The Truck

The bug truck is an insulated, closed body, utility truck designed exclusively for bio-treatment application of sewers. The truck contains four 100 gallon tanks where the bacteria are fed and cultivated. Each of the tanks contains ports for the addition of water, the dry bacteria cultures, and the food (dry pelletized dog food) to sustain the growth. Connections are available at the garage for hot and cold running water (optimal temperature for the bacteria is between 60 and 70 degrees Fahrenheit) and compressed air for aerating the mix. A small space heater is operated during the winter months to sustain the bacteria in the colder temperature months. Discharge of the bacteria to the sewer or wet well is by gravity from a hose at the base of each of the tanks.

- The Mix

New Castle has used three manufacturers of dry bacteria cultures have been used over the years, the latest being BioStim. Approximately 5 gms (about one tablespoon) of dry bacteria are added to 90 gallons of water. A mix ratio of approximately 30 gallons of hot water to 60 gallons of cold water yields the optimal temperature of 60 degrees F. for bacteria growth. 500 ml of dry dog food (about a cup) is added as food medium for the bacteria. Low grade, higher fat content dog food is preferred by the bugs over premium brand name feeds. The mix is aerated from a compressor onsite at the garage. While in transit, the truck movement and baffling inside the tank are sufficient to keep the mix aerated. If the truck is stationary for an extended period of time, a compressed air tank can deliver the necessary aeration. The "potency" of the bacteria is nominally ascertained through the distinctive odor while the dissolved oxygen uptake is the preferred quantitative test.

The dry cultures have an effective shelf life of approximately 1 year. The mix and application rate yields a bacteria cost of approximately $2,000 annually. The dog food is supplied for around $100/annually.

- The Application

There are currently 29 collection system sites and 12 wet wells receiving the bacteria dosings. The current sites have been culled from maintenance records where recurring grease stoppages have been relieved. Once the location has been identified, the targeted manhole is selected, generally 400' upstream of the grease concentration.

The truck is staffed by the operator and an assistant. The current weekly routine is to mix on Monday, make daily applications to the treated sites in the mornings Tuesday through Friday, and mix the next day's batch of bacteria each afternoon. Approximately 5 gallons per manhole for pipes and 90 gallons per wet well is the nominal bio-treatment application. The empirical evidence suggests the 5 gallons applied to the pipe will treatment approximately one mile downstream of small diameter (8", 10", and 12" diameter) sewer. The bio-treatment is applied by pouring the bacteria solution into an upstream manhole on 3-4 times per week per manhole application and 2 times per week per wet well.

There are not formal quality assurance/quality control procedures. The relatively low cost per gallon of bio-treatment doesn't demand exacting requirements for mixing or dosing. The performance is primarily evaluated by CCTV. Where the bio-treatment is applied, the grease is "knifed" off the pipe wall along the flow line. Although grease still remains above the diurnal wetted perimeter of the pipe, the portion that is removed is often sufficient to preclude future backups. Since regular applications have been in progress, only a handful of sites have experienced any relapse stoppages.

The majority of the sites have a commercial flavor to the upstream collection system. Several are discharges from multi-family high rise apartments where FOG requirements are more difficult to implement. While frequent dosings are a requirement with many forms of bio-treatment, the current product is reputed to contain naturally occurring bacteria and should be able to establish colonies. If the evidence should bear this out, a reduced frequency of application can be achieved and the number of sites increased to meet more of the demand with the same resources.

IV. Concluding Remarks

Since the completion of this case study, the County has moved to third party contracting for the dosing of the bacteria. The vendor is utilizing proportional, dosed point of application at the locations directed by the County. Results of the outside contracting were not available at this time.

ASCE Solutions for Sanitary Sewer Overflows
EPA Cooperative Agreement CP-828955-01-0

City of Rockwood, Tennessee
By
Ahmad Habibian

I - Introduction

The information presented in this report was obtained from a phone conversation on Wednesday, August 29, 2002, with Mr. Mike Macindoe of BWSC, an engineering firm providing consulting services to the City of Rockwood. The objective was to get a close understanding of policies, procedures, and practices the City of Rockwood has implemented in the past to reduce the potential of Sanitary Sewer Overflows (SSOs) in its collection system.

II- Background

The City of Rockwood is located approximately fifty miles west of the City of Knoxville, approximately five miles south of the Rockwood/Harriman Interstate 40 exit. Rockwood lies at the base of the Cumberland Plateau. Rockwood experiences high ground water conditions. The Rockwood collection system consists of approximately 29.0 miles of gravity sewer lines, five wastewater pump stations, and approximately 10,000 linear feet of force main. The gravity sewer is primarily constructed of clay, concrete, and PVC. It is estimated approximately 60% of the lines are clay, 20% concrete, and 20% PVC. The system has long history of excessive I/I. The high groundwater levels infiltrate the sewer lines along the collection system's gravity path and flow to the wastewater treatment plant.

The wastewater flow entering the Rockwood Wastewater Treatment Plant is comprised mainly of domestic and commercial flow, with some industrial. Domestic flow contribution is approximately 34 percent of average daily flow; commercial flow contribution is approximately 21 percent of average daily flow; industrial contribution is approximately 10 percent of average daily flow; and dry weather infiltration is approximately 35 percent of average dry weather flow. Average dry weather flow is approximately 0.80 mgd.

During periods of moderate to heavy rainfall, extraneous flow entering the collection system increases influent flow. The plant experiences excursions of untreated waste during periods of high influent flow. Rainfall on several successive days has resulted in flows of approximately 4.9 mgd (combined influent and bypass flow).

III - Facilities Plan Update

The City of Rockwood retained the engineering firm of BWSC to perform an update of its Facilities Plan. The objective of the planning effort was to determine the requirements of the Rockwood Planning Area for upgrading wastewater treatment and collection facilities to serve both existing and future needs. The Plan demonstrated the need for proposed wastewater treatment and collection system's upgrade and, by a systematic evaluation of feasible alternatives, and recommended cost effective measures to achieve established effluent and water quality goals.

The implementation plan will result in the elimination of wastewater bypassing and treatment plant compliance with the NPDES permit. The implementation plan incorporated the magnitude of the existing I/I problem; the ongoing work the City is implementing to identify the I/I problem areas; investments the City has made to fix the I/I problem; and continuous collection system rehabilitation program. The financial approach and an implementation schedule were also included. On the basis of the findings of this Plan, the following was recommended:

1. Investigate, utilizing City's collection system personnel, the condition of the collection system by methods of flow monitoring, smoke testing, and closed circuit television to identify I/I problem areas. Once problems are found, repair the problem areas by City forces. Work should proceed to use a sub-basin approach to systematically eliminate the I/I.
2. Upgrade the wastewater treatment plant components, including the conversion of exiting polishing pond to a flow equalization basin.

IV- Wastewater Management, Operation & Maintenance (MOM) Program

The City of Rockwood recently developed a MOM Program. Although the City performs many of the tasks associated with proper MOM Programs, its documentation or formal written structure of some MOM Programs was lacking. The MOM program will address this issue. The management elements of the program include:

- System Organization
- Financial Management
- Legal Ordinances (sewer use & industrial pretreatment)
- System Mapping, and
- Engineering Design & Construction

The O&M elements of the plan include:

- Collection System Maintenance
- Lift stations Maintenance
- Collection system Investigation
- Collection System Rehabilitation
- Collection System repair & Replacement
- Treatment Plant O&M and Upgrade.

V. Equalization Basin

The City of Rockwood decided to convert an existing polishing pond to a flow equalization basin in order to eliminate the occurrence of bypass at the wastewater treatment plant during heavy storm events. The year 2020 wet weather peak flow was estimated at 3.7 mgd, assuming a 10% reduction in dry weather infiltration, and a 30% reduction in wet weather infiltration and inflow could be achieved through continuous system rehabilitation. The plant capacity is 1.65 mgd. The 2.05 mgd excess flow will be stored in the polishing pond which provides approximately 2.3 million gallons of storage. The volume of equalization basin is approximately 110% of the excess flow. The combination of collection system rehabilitation and equalization basin capacity will eliminate the bypass flows at the wastewater treatment plant. The equalization basin was completed in 2002. System rehabilitation is an ongoing effort of the City of Rockwood through its internal staff.

ASCE Solutions for Sanitary Sewer Overflows
EPA Cooperative Agreement CP-828955-01-0

County Sanitation District of Sacramento County, Sacramento, CA

By
Ahmad Habibian

I - Introduction

The information presented in this report was obtained from a phone conversation on Friday, September 27, 2002, with Mr. John Bohem, Senior Civil Engineer, County Sanitation District 1 of Sacramento County (CSD-1). The objective was to get a close understanding of policies, procedures, and practices that CSD-1 has implemented in the past to reduce the potential of Sanitary Sewer Overflows (SSOs) in its collection system.

II- Background

The County Sanitation District 1 (CSD-1) and Sacramento Regional County Sanitation District (SRCSD) are independent political subdivisions of the State of California. While the Districts are independently governed and financed, unlike most other sanitation agencies in California, they have no employees of their own. Instead, engineering, operations and maintenance, laboratory, and administrative and management services are informally contracted from the County of Sacramento's Water Quality Department. Funds are transferred from the sanitation districts to the County to pay for those services.

County Sanitation District 1 provides wastewater collection services in the urbanized unincorporated area of the County, in the City of Citrus Heights, and in a portion of the cities of Sacramento and Folsom, with an approximate population of one million. The District operates and maintains over 3,200 miles of pipeline and approximately 150 sewage lift stations. The County's collection system is growing at a rapid pace of 40 miles per year.

SRCSD provides wastewater conveyance, treatment, and disposal services for the urbanized portion of Sacramento County. A single181 mgd capacity (400 mgd under wet weather conditions) wastewater plant provides all treatment services for Sacramento. The District also operates and maintains more than 70 miles of interceptor pipeline, ranging to 120 inches diameter and several large wastewater pumping stations.

III - Benchmarking Study

The CSD-1 along with six other public wastewater utilities participated in a benchmarking study to improve their performance. The Group of seven utilities decided to share information to identify "Best Practices". For example, the group developed a manual on Hydroflush Cleaning of Small-Diameter Sewers. The manual consists of the following Sections:

- Introduction
- Safety
- Equipment Features
- Nozzle Selection & Performance
- Work Planning
- Order of Work at Job Site
- Standard Measures of Observed Results
- Performance Measures
- Quality Assurance
- Field Application of Best Practices

IV - Statistical Approach to Condition Assessment

CSD-1 had detailed condition and characteristic information on approximately 2,500 pipe segments of its collection system. It developed a statistical model to rate all 55,000 pipe segments in its collection system. The statistical model considered characteristic factors such as age, pipe material, soil condition, contractor, and design engineer. The condition factors were mainly CCTV observations which were rated numerically. In addition the statistical model included a sensitivity factor, accounting for proximity to creeks, size of populations served, and type of customers (for example: hospitals were given high priority). The statistical model ranked all the pipe segments. CSD-1 used the results of the statistical modeling to develop a comprehensive condition assessment program. Initially, the worst 10% of the system as identified by the statistical modeling was targeted for investigation. Rehabilitation programs have been designed to remedy the defects. Condition assessment of other parts of the system is ongoing. CSD-1 plans to inspect approximately 10% of its system every year.

V - Condition Assessment by SSET

CSD-1 has inspected approximately 50,000 ft of its collection system by Sewer Scanner Evaluation technology (SSET) and plans to inspect another 200,000 ft. The advantages of SSET are the speed of field operations (no interruption necessary to document defects), and the consistency in documenting defects (as this is done in the office by a trained technician). The drawback is the inability to inspect the condition of laterals. As such, SSET can be very effective for inspection of interceptors.

VI- Electrode Leak Locators

CSD-1 has utilized electric leak locators in its collection system and have found them to perform satisfactorily. During this process, the sewer line is filled with water, and an electric current is imposed. An electrode is moved through the pipe. As the pipe moves across areas where a pipe defect exists, the electric current picked by the electrode changes, signally the existence of a defect. The drawback is that this system cannot give the clock position of the defect. However, in relatively dry climates where infiltration only may occur during wet periods, electrode leak locators is an effective means of locating defects, while CCTV images may not be able to detect such defects.

VII - Rehabilitation

CSD-1 has developed a rehabilitation program which relies on the results of the ongoing condition assessment program. Currently, rehabilitation projects are identified over the next five years. A pre-qualified list of consultants for large projects ($200,000 and larger), and a similar list for small projects (less than $200,000) has been developed. CSD-1 selects the consultants from the top of these lists as projects come up. Each consultant who is awarded a project moves to the bottom list. The pre-qualification lists have expedited the process of consultant selection.

There is no list of pre-qualified contractors. However, as the local contractors gain experience in the area of sewer line rehabilitation, it is likely that such a list would be developed.

The major problem encountered in the CSD-1 collection system is grade problems due to sag (approximately 70%). Most of these defects have to be fixed by open cut. Infiltration/Inflow is not generally a problem, except in a few basins.

In developing the rehabilitation program, consideration was given to several basins where major I/I was a factor. In these basins, the rehabilitation projects were expanded to the entire basin so that all defects within that basin are fixed.

The rehabilitation methods used include Cured-in-place-pipe (CIPP), Fold and Form, Spirally-wound Pipe, and crown spraying of concrete interceptors. CIPP is also used for rehabilitating short pipe segments (approximately 10 ft). With Fold & Form PVC lining, it has been difficult to make new connections as standard size saddles do not match the outside diameter of the liner. The effectiveness of crown spraying (with magnesium hydroxide) has not yet been established by CSD-1. It has established a 3-year core sampling program to assess the frequency of crown spraying applications.

Acrylamide grout is used for joint and lateral to main connections when the outside environment is always wet, and not used if the outside environment experiences wet/dry conditions. Acrlyamide grout is also used for manhole rehabilitation. Several manholes have been rehabilitated by fiberglass lining.

Service laterals are often renewed by open cut replacement. Approximately 1000 laterals per year are programmed to be replaced over the next five year. The lateral is replaced from the sewer line to the clean-out at the property line. An ordinance is under development which would call for periodic inspection of the private laterals by CSD-1, who would report any defects to the homeowner. The ordinance requires that such defects be disclosed when the house is put up for sale. The ordinance may also include financial assistance provisions under certain conditions.

VIII - Cleaning Frequencies

CSD-1 regularly cleans the sewer lines which have had a problem in the past. This covers about 1/3 of the system. The remaining 2/3 are not cleaned.

IX - Design Changes

CSD-1 has changed its design requirements to disallow 6-inch sewer lines. Also the farthest two segments of new lines are installed at a slope steeper than the minimum slope.

ASCE Solutions for Sanitary Sewer Overflows
EPA Cooperative Agreement CP-828955-01-0

3 Rivers Wet Weather Demonstration Program (3RWWDDP), Pittsburgh, PA

By
Ahmad Habibian

I - Introduction

The information presented in this report was obtained from a phone conversation on Friday, August 30, 2002, with Mr. Ken Orie of gateway Engineers, Inc. Mr. Orie was previously with 3RWWDDP. The objective was to get a close understanding of initiatives 3RWWDDP has implemented to reduce the potential of Sanitary Sewer Overflows (SSOs) in the collection system of participating agencies.

II- Background

The 3RWWDP was established in 1998 to provide municipalities located in Allegheny County, Pennsylvania, the technical means, institutional structures and financial mechanisms needed to control existing sanitary sewer overloading and overflow problems. The 3RWWDP is a ten year, $120 million program, funded by Federal, State and local resources, and in-kind services from the partnership of the Allegheny County Sanitary Authority (ALCOSAN) and the Allegheny County Health Department.

Approximately 83 communities in the "three rivers" area of Pittsburgh are faced with eliminating sanitary sewer overflows to comply with the U.S. Environmental Protection Agency regulations. The collection system is partially combined and partially separate, with the combined portion discharging into the separate portion, effectively making the whole system to act like a combined system. Wastewater services are provided by ALCOSAN. The dry weather flows are in the range of 225 mgd to 275 mgd, while the wet weather flows are in the range of 275 mgd to 875 mgd.

The 3RWWDP was established to help find innovative solutions with the least economic impact to the communities. The Program objective is to demonstrate the best available management practices for solving the region's sanitary sewer overflow problems. It also provides a technical, legal and institutional framework for the distribution of demonstration project funding and technical assistance.

Requests for demonstration project proposals are solicited from the municipalities and municipal authorities that are served by ALCOSAN. Watershed-based solutions are strongly encouraged. Grants are awarded based upon technical and policy objectives of the program. Technical assistance will include the expertise of ALCOSAN and Allegheny County Health Department technical expertise, and Geographic Information System data and mapping, system modeling and project financing tools. The rigorous review process has slowed down the approval of grant awards.

A benefit of the 3RWWDP has been the enhancement and promotion of cooperation among the wastewater agencies in the region.

III - Demonstration Projects

The following is a brief description of several demonstration projects which are either completed, are in progress, or are being considered for implementation:

1. Utilization of Abandoned Mine Voids for Storage

A feasibility study is under consideration to investigate the use of abandoned coal mines within the Chartiers watershed of Upper St. Clair in Allegheny County, PA as storage for excessive wet weather flows during a storm event. It is anticipated that the stored wastewater will be pumped out gradually once the storm subsides.

2. Calibrated Radar Rainfall System

This project was implemented to provide a standardized, accurate and cost-effective precipitation monitoring system that would utilize next generation radar (NEXRAD) data in conjunction with the existing rain gauge network to deliver calibrated radar rainfall data to the communities in the region via the internet. The radar data was calibrated through 21 ground rain gage stations.

Local municipalities will use the radar-calibrated rainfall data to support their flow monitoring program. To demonstrate the accuracy of the calibrated radar rainfall data, the data was used as input data for a hydraulic model in the Saw Mill Run Basin. Both the ratio of peak flows and the ratio of time to improved greatly when radar-calibrated data was employed. This demonstration of the radar rainfall system proved that the virtual rain gauge files being generated were accurate and dependable.

The implementation of the Internet portion of the project was put on hold until the calibrated rainfall system could provide a steady data stream to facilitate and consequently test the website's design.

3. Rehabilitation Technologies

Rehabilitation technologies under consideration for evaluation include pipe bursting, pipe lining, grouting, and waxing.

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