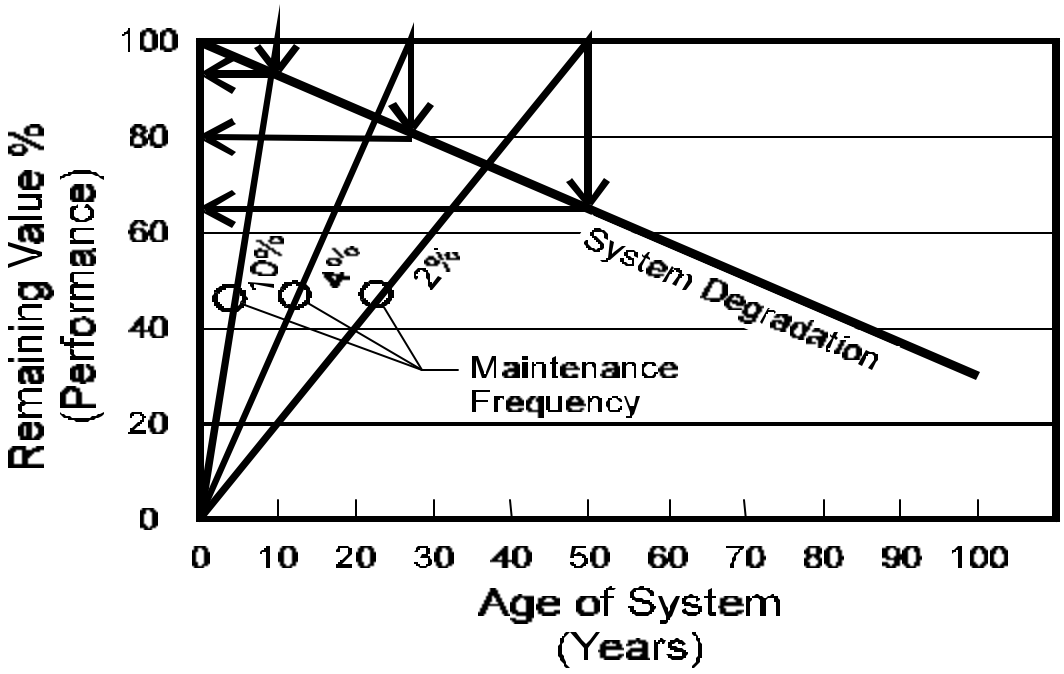
OPTIMIZATION OF COLLECTION SYSTEM MAINTENANCE FREQUENCIES AND SYSTEM PERFORMANCE



American Society of Civil Engineers
EPA Cooperative Agreement #CX 824902-01-0

February 1999

Optimization of Collection System Maintenance Frequencies and System Performance

Prepared

by

Black & Veatch LLP

for

American Society of Civil Engineers

Under

Cooperative Agreement

with

U.S. Environmental Protection Agency
Office of Wastewater Management
Washington, DC

EPA Cooperative Agreement #CX 824902-01-0
February 1999

NOTICE

The material in this document has been subject to U.S. Environmental Protection Agency technical and policy review and approved for publication. The views expressed by individual authors, however, are their own and do not necessarily reflect those of the U.S. Environmental Protection Agency

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Acknowledgments

The authors of this report wish to thank the United States Environmental Protection Agency (USEPA), Black & Veatch LLP, 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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Participating wastewater utilities and agencies provided needed information for this project are listed below. Only those agencies granting permission to do so are listed by name.

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Charlotte, NC

City of Albuquerque
Albuquerque, NM

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Columbus, OH

City of Council Bluffs, Department of Public Works
Council Bluffs, IA

City of Dallas, Water Department, Wastewater Collection Division
Dallas, TX

City of Durham
Durham, NC

City of Fresno
Fresno, CA

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Glendale, AZ

City of Tulsa
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Las Vegas, NV

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Columbia, MO

Columbus Water Works
Columbus, GA

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County of Sacramento, Public Works Agency, Water Quality Division, County Sanitation District No.1
Sacramento, CA

Little Rock, Wastewater Utility
Little Rock, AR

Madison Metropolitan Sewerage District
Madison, WI

City of Houston
Houston, TX

City of Indianapolis, Department of Capital Asset Management
Indianapolis, IN

City of Kansas City, Water Service Department
Kansas City, MO

City of Las Vegas
Las Vegas, NV

City of McMinnville
McMinnville, OR

City of Modesto
Modesto, CA

City of Phoenix
Phoenix, AZ

City of Rochester, Department of Public Works
Rochester, MN

City of Scottsdale
Water Operations
Scottsdale, AZ

City of Shreveport, Department of Water and Sewerage
Shreveport,, LA

City of Springfield
Department of Public Works
Springfield, MO

Louisville & Jefferson County Metropolitan Sewer District
Louisville, KY

Metropolitan Sewer District of Greater Cincinnati
Cincinnati, OH

Metropolitan Council Environmental Services, Regional Maintenance Facility
Eagan , OH

Metropolitan St. Louis Sewer District
St. Louis, MO

Miami-Dade Water and Sewer Department
Coral Gables, FL

Oklahoma City Water and Wastewater Utilities Department
Oklahoma City, OK

Pima County Wastewater Management Department
Tucson, AZ

Portland Water District
Portland, ME

Reedy Creek Energy Services, Inc.
Reedy Creek Improvement District
Lake Buena Vista, FL

Unified Sewerage Agency
Hillsboro, OR

Washington Suburban Sanitary Commission
Laurel, MD

Wastewater Management - City and County of Denver, CO

Executive Summary

The objective of this project was to develop an optimized approach for maintenance of separate collection systems. Maintenance has a broad definition as defined in this report, and includes any reinvestment in an existing collection system in the form of cleaning, monitoring, inspection, rehabilitation and relief. Hopefully, this project will benefit the general public, state and local decision makers, and other potentially affected groups by reducing the failure rate of collection systems. The reduction in the failure rate of collection systems will improve public health by preventing sewer backups, and will also benefit the environment by minimizing discharge of untreated sewage to surface waters. Specific objectives accomplished are as follows:

- the effectiveness of maintenance programs of agencies surveyed was evaluated by reviewing their maintenance activities and their frequency,
- a review of how maintenance and rehabilitation dollars spent are being spent,
- an overview of typical values for maintenance frequencies and system reinvestment expense amounts was performed to serve as benchmarks for local governments and agencies in evaluating their own programs, and
- guidelines and methods were developed to help agencies evaluate and Ameasure@ their own maintenance frequency and performance rating by developing a single number or Ayardstick@ which can be determined based on commonly collected data.

The wastewater collection system is a major capital investment, and agencies must ensure they are providing safe and efficient service to their customers. The level of service, or system performance, is difficult to quantify because of the many variables in collection systems. Nevertheless, system performance can be improved and maintained at an acceptable level with proper maintenance. This report provides guidance to answer the following questions: "How much maintenance is enough?", AIs the performance of my system adequate and is it improving or getting worse@ and "How do I determine the level of maintenance required?" Currently, there is no rational approach for determining the frequencies of various maintenance procedures except through experience and judgement.

Quality collection system maintenance consists of the optimum use of labor, equipment, and materials to keep the system in good repair, so that it can efficiently accomplish its intended purpose of collection and transportation of wastewater to the treatment plant. Serious health hazards and

extensive property damage can result from sanitary sewer backups and overflows. There should be some reasonable balance between the cost of maintenance and the benefits derived.

The scope of work for this project included the following major task groups:

- Task 1. Literature Search
- Task 2. Data Collection
- Task 3. Follow up and Data Compilation
- Task 4. Data Analysis
- Task 5. Report and Presentation

Very little data was identified in the literature search with respect to establishing maintenance frequencies or performance ratings. This report then is a preliminary effort to develop a rational approach to evaluating maintenance (reinvestment) and system performance. It is expected that future studies will enhance and result in modifications to the approach presented herein.

The data collection effort was somewhat protracted due to the amount of information agencies were requested to provide and the difficulty of collecting the data needed. Most agencies do not keep detailed records for all information requested and therefore the Abest guess@ was provided in some instances. It is believed that the lack of quality data by many of the agencies resulted in much of the scatter and broad range of data responses received. Nevertheless, it is also believed that the data received support the hypothesis that performance and reinvestment are related and that system performance and maintenance can be quantitatively evaluated to optimize the system reinvestment for selected levels of system performance.

Based on the agency responses received cleaning, root removal, and pump station service are the most important routine maintenance activities; although a total of 12 key maintenance activities are still necessary for a balanced routine maintenance program. Using a statistical method to develop a routine maintenance Ayard stick@, an average maintenance frequency, considering all routine maintenance activities of 6.6% was derived with a range of 2.4% to 12.6%. The relationship of maintenance and performance was explored and it was found that a strong relationship exists between the maintenance frequency and system historical performance. Independent variables related to maintenance frequency include customer complaints, manhole overflows, pipe failures, system sizes, number of pump stations, regional location, and pump station failures.

The agency responses received also identified pipe failures, SSOs, and customer complaints as the most important performance measures. Using the same statistical method used for establishing the maintenance yard stick, a performance yard stick was developed. Considering all performance measures, an average performance rating of 71.1% was derived with a range of 53.1% to 97.2%. In addition to this performance rating, the amount of reinvestment was reviewed and analyzed. It was found that the annual reinvestment has been increasing and for the period 1980 to 1996 has averaged $9,328/mi**$**yr or $1.77/ft**$**yr. The annual reinvestment for the life of the systems as reported was about $1.00/ft**$**yr. These reinvestment rates support the theory of reinvestment required presented in Chapter 1. The relationship between the performance rating and reinvestment was explored and it was found that a strong relationship exists between these two parameters.

Based on the methods developed for determining maintenance frequencies and performance ratings, a method or approach for optimizing collection system maintenance is presented with general guidance for the desirable envelope for performance and maintenance. Collection system maintenance can be optimized by creating a better balance of maintenance activities, increasing or decreasing budgets as appropriate, and evaluating performance of the system against the maintenance frequency being implemented. In time, by monitoring both maintenance and performance, agencies will be able to strike the right balance for their system and maintain acceptable performance and the least reinvestment cost.

Because of the importance of system maintenance (reinvestment) and system performance, it is recommended that ongoing research be performed to enhance and improve the work presented in the report. Specific recommendations are as follows:

1. Review and refine the maintenance, performance, and reinvestment measures used in this report. Develop detailed definitions of each.

2. Develop either an information collection guideline which would request agencies to collect data consistent with Step 1 or have a study with a core group of agencies to provide data that can be used to refine these analyses and to generate a AGuideline Report for Collection System Maintenance.@

3. Implement the information collection process and use the data to develop cost estimates, maintenance guidelines, and performance measures similar to those presented in this study.
4. Repeat the analysis on a regular basis every 2 to 5 years as the output will improve with the improved data collection.

1.0 Introduction and Background

Collection system maintenance and rehabilitation is being performed to meet regulatory requirements and to improve sewerage service to customers. Maintenance as defined in this report includes any reinvestment in an existing collection system in the form of cleaning, monitoring, inspection, rehabilitation, and relief. Rehabilitation is performed to correct the deficiencies identified from maintenance activities. With more emphasis being placed on maintenance, it is becoming increasingly important to determine Ahow much maintenance is enough?@ According to the Water Pollution Control Federation (WPCF) Manual of Practice No. 7, (1985), AThere should be some reasonable balance between cost of preventive maintenance and benefit derived.@ This need is demonstrated by a survey of 20 cities which showed a 1000-to-1 spread on main breaks and a 150-to-1 spread on stoppages per 1000 miles of sewer per year. Age and neglect were noted as the primary reasons for these differences. (WEF 1994)

This study was undertaken to evaluate collection system maintenance and rehabilitation needs based on information from a questionnaire completed by selected cities and agencies, hereinafter referred to collectively as agencies. Specifically, the objectives were to evaluate the effectiveness of maintenance programs by reviewing the inspection activities and their frequency; to review how reinvestment dollars were spent; and to provide an overview of typical values to serve as guidance for local governments and agencies in evaluating their own programs. It should be noted that this study pertains to Aseparate@ collection systems only and does not include data for combined sewer systems.

This project was performed by the American Society of Civil Engineers (ASCE) and Black & Veatch LLP under a cooperative agreement with the U.S. Environmental Protection Agency (USEPA).

1.1 Project Significance and Objectives

The objective of this project is to develop an approach for optimizing maintenance of wastewater collection systems. The project will help wastewater agencies plan for maintenance based on specific performance measures and will provide guidance on the total reinvestment required to meet selected levels of system performance. Improved performance of collection systems will benefit public health, and will also benefit the environment. This project presents a

decision making model which can be used by agencies in evaluating the cost of maintenance, as it relates to maintenance frequency and system performance.

1.2 Background

Collection system maintenance is performed to meet regulatory requirements and to improve sewerage service to customers. A collection system corrodes, erodes, collapses, clogs, and ultimately deteriorates. Collection system capacity can be reduced by root growth; by the accumulation of obstructions discharged to the system, such as grease, garbage, rags, paper towels, and by structural failures such as line breaks and collapses. Maintenance, in the broad sense used for this study, includes any reinvestment in an existing collection system in the form of cleaning, monitoring, inspection activities, rehabilitation, and relief. Relief can be in the form of relief sewers, additional pumping capacity or equalization facilities.

Wastewater collection systems are a major capital investment which agencies must properly maintain to ensure safe and efficient service to their customers. The level of service, or system performance, is difficult to quantify because of the many variables involved. Nevertheless, this study attempts to develop an approach to measure system performance so that it can be monitored and improved if necessary by proper maintenance procedures.

Many agencies have not provided the collection system maintenance necessary for an adequate level of customer service and to protect the sizable investment in their facilities. We have all heard the adage Aout of sight, out of mind@ as this relates to collection systems. Collection system maintenance functions are frequently treated as a necessary evil, to be given attention only as emergencies arise. Getting adequate maintenance budgets is dependent on justifying the level of maintenance required. Currently, there is no rational approach to estimating the frequency of the various maintenance procedures required, except through experience and judgment.

Quality collection system maintenance consists of the optimum use of labor, equipment, and materials to keep the system in good condition so that it can efficiently accomplish its intended purpose of collecting and transporting wastewater to the treatment plant. Serious health hazards and extensive property damage can result from sanitary sewer backups and overflows. There should be some reasonable balance between the cost of maintenance and the benefits derived.

1.3 Review of Literature

The authors of this project conducted an extensive literature search (see Appendix E, Literature Review) to obtain nationwide information on current trends in collection system maintenance planning. Very few publications were found that dealt with optimizing maintenance and no publications were found that specifically addressed system maintenance frequency determination or system performance rating evaluation. The literature contained very few papers on the subject of collection system operation and maintenance. Most papers focused on engineering design or sanitary sewer evaluation studies (SSES).

Details of the Literature review are contained in Appendix E.

1.4 Relationship of System Performance and Reinvestment

Collection system performance depends on regular and effective reinvestment. This study explores the relationships between system performance, maintenance frequency, and reinvestment. Without reinvestment and effective maintenance, collection systems will eventually fail.

1.5 Theory

The theoretical basis for establishing a relationship between system performance and maintenance (reinvestment) is the hypothesis that collection systems deteriorate over time, with consequent loss of system performance. To maintain system performance, ongoing reinvestment is required. For purposes of discussion, let us assume that the life of a sewer is 100 years, with 25 percent salvage value remaining at the end of the 100 years as shown on Figure 1-1. Furthermore, we will assume an average system value of $100 per foot, or $528,000 per mile. Given these assumptions, the rate of degradation would be $0.75 per year per foot of sewer system.

Next, let us assume that the life of a system can be extended past the 100 years through system reinvestment in the form of rehabilitation, capital improvements, and routine maintenance. A hypothetical cycle of degradation and maintenance is shown on Figure 1-2.

Figure 1-1 System Value and System Age
(No Rehabilitation)

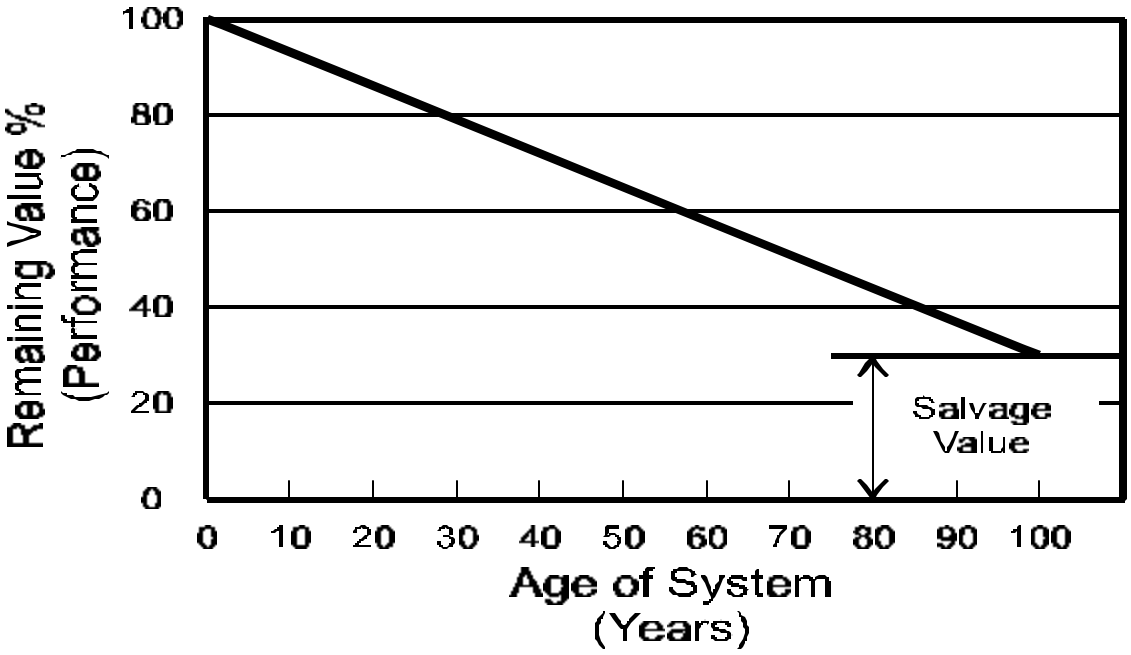
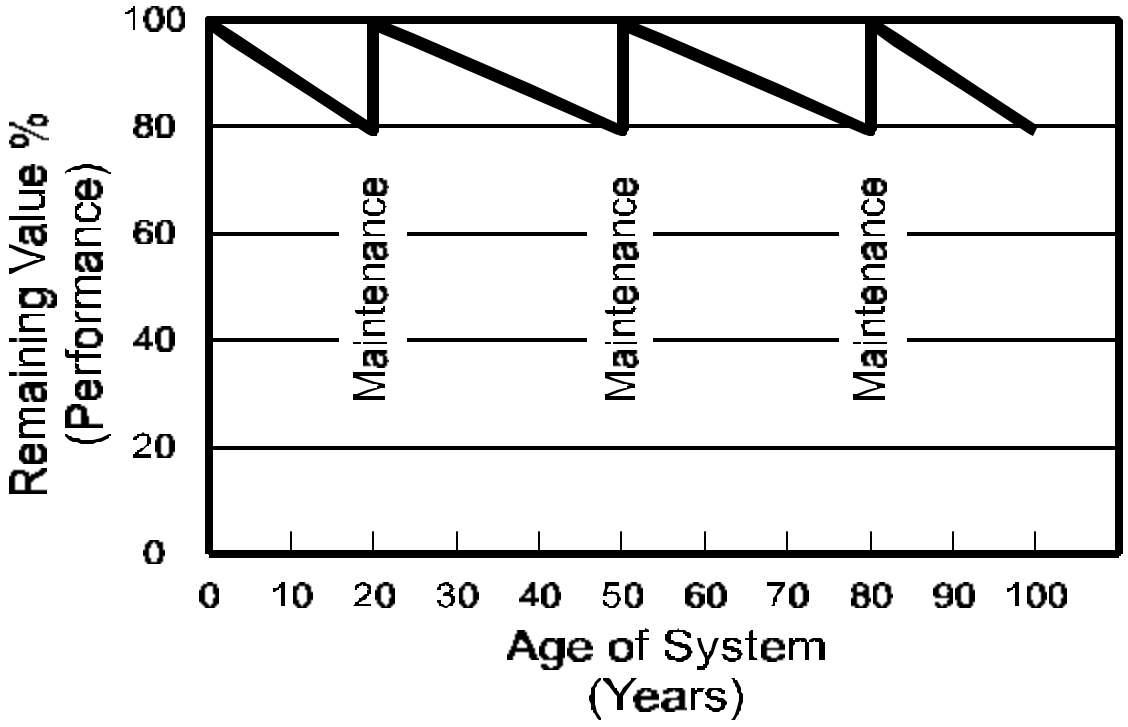
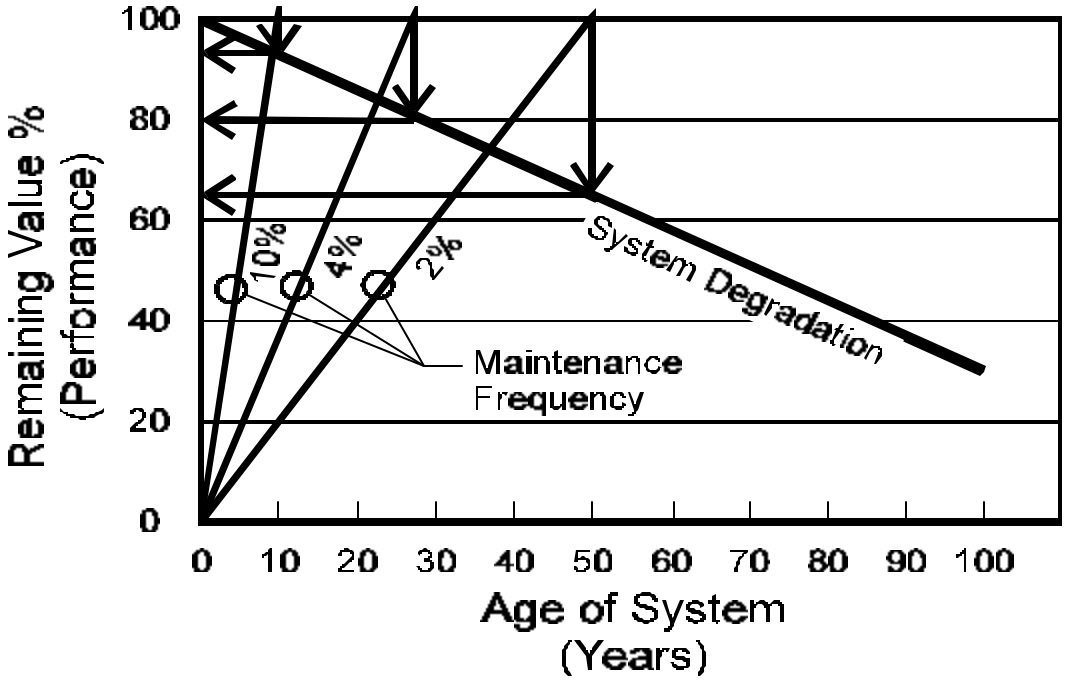


Figure 1-2 System Value and System Age
(With Rehabilitation)



If complete maintenance (reinvestment) is performed each year, the system will operate at 100 percent efficiency all the time. If maintenance (reinvestment) is never performed, then the system will degrade and perform at 25 percent of the efficiency of a new system after 100 years. If maintenance (reinvestment) is performed at a rate of 2 percent per year, the system performance will decrease to about 65 percent of a new system=s performance. If maintenance is performed at 4 percent per year, the minimum system performance would be about 80 percent; with maintenance at 10 percent per year, the minimum performance would be about 93 percent of new system performance. These scenarios are shown on Figure 1-3.

Figure 1-3 System Performance and Maintenance Frequency



This study researches relationships between system performance, maintenance rates, and reinvestment. The objective, in concept, was to develop an approach similar to that depicted on Figure 1-3, so that a desired maintenance frequency could be selected based on a minimum acceptable performance rating for the system.

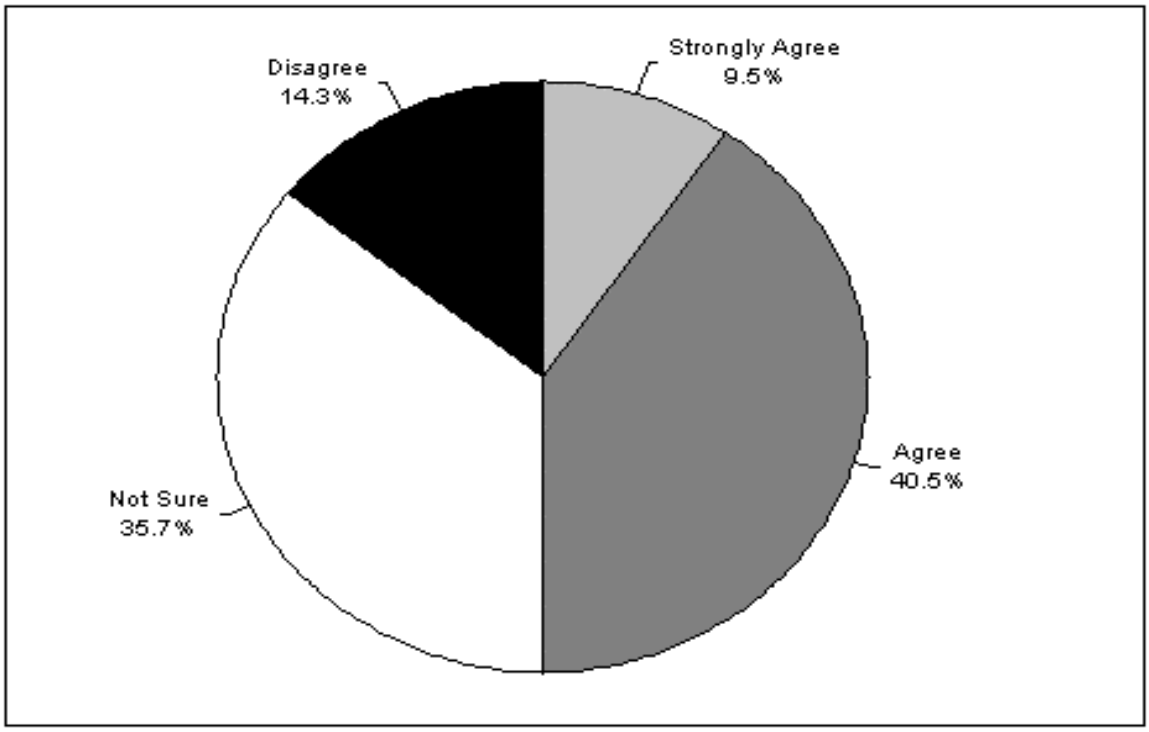
1.6 Perceived Effectiveness of Existing Maintenance Programs

Based on the survey responses obtained during this study, the effectiveness of existing maintenance programs was evaluated. Each agency surveyed was asked the question, AAre you satisfied with your system maintenance (total reinvestment) program?@ Each agency was requested to respond with one of the following answers:

1. Strongly Agree - system performance is as required, and budget is sufficient.
2. Agree - system performance is generally as required, and budget is adequate.
3. Not sure - system performance is not defined, and budget may be adequate.
4. Disagree - system performance generally not as required, budget is not adequate.
5. Strongly Disagree - system performance and budget unacceptable.

Of the 42 respondents 4 strongly agreed, 17 agreed, 15 were not sure, 6 disagreed, and 0 strongly disagreed, as shown on Figure 1-4. The need for improved maintenance and performance measures is evidenced by the high percentage of agencies that are not sure of how effective they are.

Figure 1-4 Perceived Satisfaction with Existing Maintenance Program



1.7 Statistical Analyses Performed

Statistical analyses were performed to evaluate data and data relationships. The analytical methods include functions of random variables such as mean, variance, and standard deviations as well as methods to evaluate relationships among independent variables in the form of linear regression and multiple linear regression analyses. The SPSS 6.0 statistical software package for Windows was employed for this purpose. The SPSS is a world leading statistical analysis software package.

1.8 Benefits

The benefits derived from this report include guidance for measuring system maintenance, system performance, and developing guidelines for reinvestment dollars. The methods developed will help agencies evaluate the effectiveness of their current maintenance programs and establish target performance goals. This study will also assist regulatory agencies in reviewing the effectiveness of collection system maintenance programs and the adequacy of collection system budgets which may result in environmental, economic, social, and public health improvements.

1.9 Report Organization

Chapter 1 describes the significance, objectives, background information on, and methods used to evaluate collection systems performance. Chapter 2 introduces the criteria and measures to be used in the evaluation of a collection system. Chapter 3 describes system characteristic data. Chapter 4 describes the system performance data. The measures associated with each criterion, the determination of maintenance frequency and performance rating are discussed in Chapters 5 and 6. Comprehensive performance evaluations are also discussed. Chapter 7 presents the use of these tools for optimizing collection system maintenance. Supplemental data , overview of relevant literature regarding collection system performance and maintenance, and the survey form are presented in the appendices.

1.10 Abbreviations and Definitions

Abbreviations

#ps/mi	number of pump stations per mile of sewer
$/mi$yr	cost per mile of sewer per year
$/ft$yr	cost per foot of sewer per year
%/system$yr	percent of sewer system per year
ADF	average annual daily flow
ASCE	American Society of Civil Engineers
avg	average (mean)
CCTV	closed circuit TV
fm/ps	miles of forcemain per pump station
fps	feet per second
gpcd	gallons per capita per day
hp	horsepower
hp/mi	horsepower per mile of sewer
I/I	inflow/infiltration
kWh	kilowatts per hour
ps/mi	pump stations per mile
max	maximum value
mgd	million gallons per day
min	minimum value
no/ps$yr	number per pump station per year
no/mi$yr	number per mile of sewer per year
O & M	operations and maintenance
PH/ADF	peak hourly flow to average daily flow ratio
PM/ADF	peak monthly flow to average daily flows ratio
sd	standard deviation
SSES	Sewer System Evaluation Survey
SSO	sanitary sewer overflow
USEPA	United States Environmental Protection Agency
WWTP	wastewater treatment plant
WEF	Water Environmental Federation

Codes for Use in Regression Equations

SIZE CODE

1 = small
2 = medium
3 = large

REGIONAL CODE

1 = central
2 = northeast
3 = northwest
4 = southeast
5 = southwest

Definitions

Backup: The backup of wastewater in a sewer, as a result of a stoppage, until the wastewater floods a basement or other lower portion of a residence or commercial facility.

Capital Improvement: A sewer line, manhole, pump station, forcemain, or other special structure added to collection system.

Complaints: A customer complaint related to the performance of the collection system, including issues such as overflows, odors, and loose manhole covers.

Equalization (Basin): A facility to store peak flows in excess of the hydraulic capacity of downstream facilities.

Linear Regression: A procedure of estimating a linear relationship between a dependent variable and one or more independent variables.

Maintenance: Any reinvestment in an existing collection system in the form of cleaning, monitoring, inspection, rehabilitation, and relief.

Normal Distribution: A continuous distribution of a random variable with its mean, median, and node equal.

Optimization of Maintenance: An effective balance of maintenance activities which results in an acceptable level of system performance.

Overflow: An incident where any measurable or observable quantity of wastewater exists in the sanitary sewer system.

Peak Hour/ADF Ratio: The ratio of peak hour flow at a selected design condition to the average annual daily flow. This calculation may require extrapolation of monitored storm events.

Peak Month/ADF Ratio: The ratio of the peak monthly flow at the WWTP to the average annual daily flow.

Performance of Collection System: The ability of the system to function as desired.

Performance Indicator: A measure of the level of service provided by a collection system agency, such as stoppages per 100 miles of sewer, number of complaints per 100,000 population, or time to respond to a service request.

Pipe Failures: A pipe which has lost its structural integrity as evidenced by total or partial collapse (loss of 50% of pipe area or 25% of pipe wall around any circumference).

Pump Station Failure: A condition that results in station overflows or an unacceptable surcharge of the system.

Rehabilitation: The upgrading and improving of existing facilities.

Reinvestment: The spending of money on the collection system.

Relief: Facilities to provide additional hydraulic capacity.

Sanitary Sewer Overflow (SSO): A discharge of wastewater from the collection system with the potential to enter surface water courses.

SSES: Sewer System Evaluation Survey. A key step in identifying specific sources of infiltration/inflow (I/I).

Stoppages: Any incident where a sanitary sewer is partially or completely blocked causing a backup, a service interruption, or an overflow.

2.0 Data Collection

2.1 Development of Questionnaire

To obtain the data needed for analyzing maintenance frequencies and performance measures, a questionnaire was developed for distribution to collection system agencies. The questionnaire was developed based on the following:

- Previous form used in a 1992 Sewer System Evaluation Survey (SSES) in Kansas (Nelson, p. 25).
- Review of literature.
- Input from the Technical Advisory Committee.

The steps taken to develop the questionnaire are described below.

Step 1

A Sewer System Evaluation Survey form developed by Nelson (25) was the basic guideline to develop the format of the questionnaire. Modifications to this form were based on data from the literature review and input from the Technical Advisory Committee. The questionnaire was structured to collect both system performance data and system maintenance data.

Step 2

The next step in developing the questionnaire was to identify the types of significant activities or events which could be used as possible performance indicators and maintenance frequency. System performance, for example, could be related to pipe failures, manhole overflows, treatment overflows, basement backups, customer complaints, and pump station failures. Maintenance frequency could be related to tasks such as cleaning, pump station servicing, and other maintenance activities.

Step 3

Once the activities or events were identified, it was necessary to define how each activity would be measured. To have meaning as an indicator of performance or maintenance, each activity or event was expressed as a ratio to allow comparisons between systems. Pipe failure, for example, was expressed as failures per mile per year. This ratio provides an indicator of performance that can be tracked over time and can be compared with other agencies' performance data.

Step 4

The next step in constructing the questionnaire was specifying the information that respondents would be asked to provide. The questionnaire also allowed respondents to indicate the quality of data being provided as "very good," "good," "fair," and "a guess."

Step 5

The next step involved arranging the questions for data needed in an easy-to-use matrix as shown in Table 2-1.

Step 6

The final step was a review of the questionnaire by the Technical Advisory Committee. Comments were received and incorporated and the questionnaire was finalized. A copy of the final questionnaire sent to each agency surveyed is included in Appendix A.

Table 2-1
Questionnaire Matrix

Category	Data Requested	Data Needed
Service Area Information	Miles of Public Sewer Number of Manholes Number of Connections Area Served (sq mi) Population Served Age of System (Age Distribution)	General collection system information.
Flow Information	Average Annual Daily Flow Maximum Daily Flow Peak Hourly Flow Maximum Month/Average Daily Flow Minimum Month/Average Daily Flow Percentage of System below the Groundwater Table	General flow information representing collection system.
System Characteristic Information	Percentage of System > 24-inches in Diameter Number of Pump Stations Total Installed Horsepower Total Energy Consumed Total Length of Forcemains, Miles Number of Equalization Basins Volume of Equalization Percentage of System Which is Industrial/Commercial Typical Velocity of Flow	General characteristic information related to the collection system.
Systems Performance Data	Pipe Failures Manhole Overflows Treatment Overflows Basement Backups Others Customers Complaints Pump Station Failures	Cumulative number of events in last 1 yr, 5 yrs, 10 yrs, and 20 yrs.
Routine Maintenance Frequencies	Cleaning, Miles of Sewer Root Removal/Treatment, Miles of	Total completed each year from 1992 to 1996.

Table 2-1 Questionnaire Matrix		
Category	Data Requested	Data Needed
	Sewer Main Line Stoppages Cleared, Number House Services Stoppages Cleared, Number Inspections and Services Pump Stations	
Inspection Method and Status	Flow Monitoring/Capacity Evaluation Manhole Smoke/Dye Test Television Inspection (Internal Inspection) Private Sector Building Inspection	Cumulative percent of system quality inspected in last 1yr, 5 yrs, 10 yrs, and 20 yrs.
System Maintenance Costs	Relief Equalization Rehabilitation/Replacement O&M Budget (Collection System Only) Equipment Replacement Other Costs	Total dollars spent in different time periods: 1990 - 1996 1980 - 1989 1970 - 1979 Pre - 1970
System Performance Importance (Weight)	Pipe Failures Sanitary Sewer Overflows (SSOs) Customer Complaints Pump Station Failures Peak Hourly/ADF Ratio Peak Month/ADF Ratio	Percentage of weight for each item, total weight should be 100%.
Maintenance Activity Importance (Weight)	Percentage of system Cleaned/yr Percentage of system Root/yr Pump Station Service Flow Monitoring/Capacity Evaluation Manhole Inspection Smoke/Dye Testing CCTV Inspections Private Sector Inspections Manhole Rehabilitation Main Line Rehabilitation Relief Sewer Construction Private Sector I/I Source Removal	Percentage of weight for each items, total weight should be 100%.
Effectiveness of Program	Strongly Agree Agree Not Sure Disagree Strongly Disagree	

2.2 Identification of Participants

During project startup, the Technical Advisory Committee members helped to define the collection system sizes and geographic boundaries for selection of agencies to be included in the survey. Three system size categories, shown in Table 2-2, were defined, based on the population. Agencies with populations less than 100,000 were classified as small, agencies with populations equal to or greater than 100,000 and less or equal to 500,000 were classified as medium, and

agencies with populations greater than 500,000 were classified as large. The geographic regions defined were Northeast, Southeast, Central, Northwest and Southwest. The boundaries of these regions are shown on Figure 2-1

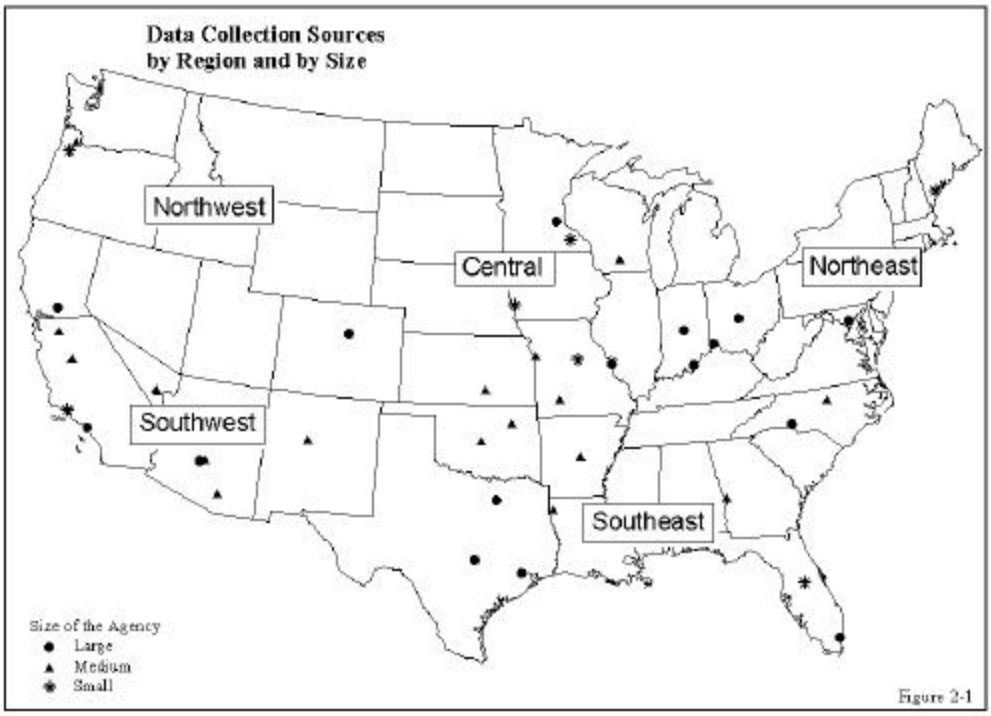
Table 2-2
System Size and Population Classification

System Size Category	Population
Large	> 500,000
Medium	100,000 - 500,000
Small	< 100,000

The initial listing of potential participating agencies was screened by contacts through the authors and Technical Advisory Committee. A list of more than 100 potential participants was developed. From this list, and in consultation with the Technical Advisory Committee, the authors selected 75 agencies to contact with a goal of ultimately receiving 50 completed questionnaires.

2.3 Data Collection

Initial telephone calls were made to get tentative commitments from the agencies. A 10-page questionnaire was mailed out to those agencies which agreed to participate. Follow-up calls were made every two weeks to every participating agency that had not returned a completed questionnaire to remind the participants to return the completed questionnaire.



Several difficulties were encountered during the data collection. Many agencies had limited time and staff to complete the questionnaire. Some agencies were apprehensive about providing performance data. Some of the agencies could not provide adequate data, as the requested data were unavailable. The reasons cited for this included data lost in natural disasters, such as flooding, limited storage spaces (e.g. keep only the last 10 years of data); or not having a good record tracking system to maintain any kind of record related to their collection system. In some cases, personnel initially involved in completing the questionnaire were reassigned and it was therefore necessary to reinitiate the process with new staff. Due to a variety of reasons, several cities and agencies canceled their commitment.

The questionnaire was mailed to more than 75 agencies across the continental United States. A total of 42 agencies fulfilled their commitment to complete the questionnaire. The summary of the number of respondents by size and region is shown in Table 2-3 and on Figure 2-1.

Table 2-3

Summary of Agencies by Size and Region

Region	Large Size System	Medium Size System	Small Size System	Number of Responses
Northeast	2	1	1	4
Southeast	1	2	0	3
Central	9	8	3	20
Northwest	2	1	1	4
Southwest	2	8	1	11
Total	16	20	6	42

The data supplied by the 42 agencies are listed in Appendix B. Each respondent was assigned a unique identification number.

3.0 Agency Data

3.1 Introduction

All collection systems included in the survey were designed as separate sanitary sewers. This chapter summarizes the data supplied by the 42 respondents. The majority of the respondents thought the quality of data in each section was either "very good," "good," or "fair."

3.2 Service Area Characteristics

3.2.1 Summary of Service Area Information

Each agency was requested to provide information on, among other things, the total sewer miles, total number of manholes, total number of connections, service area size, served population, and the age of the system. The system characteristic data for each agency is presented in Table 3-1.

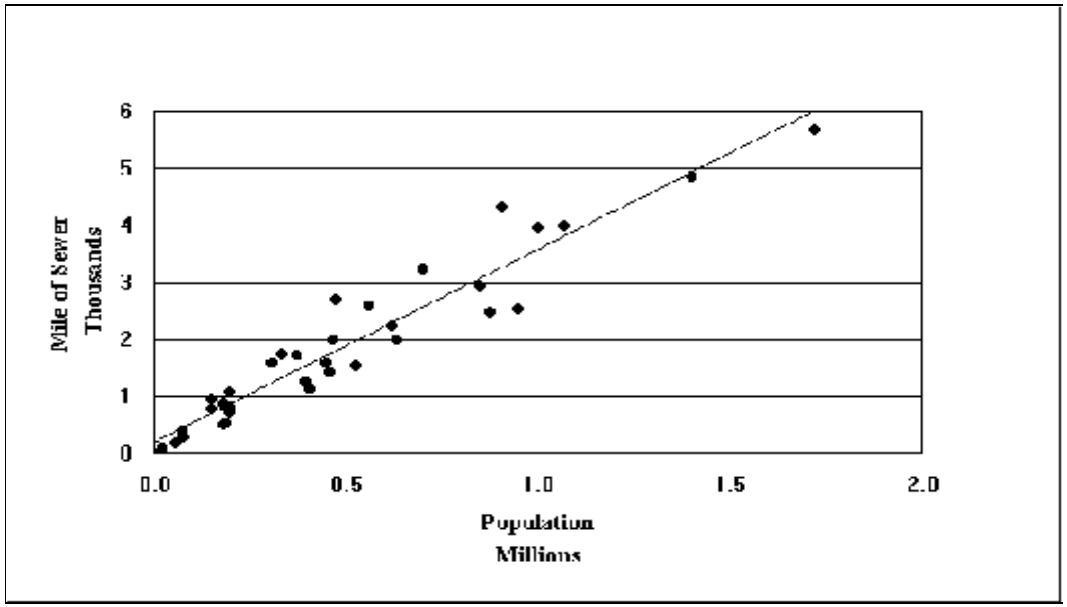
The agencies varied widely in terms of size and population served, number of manholes, and number of connections, with the smallest agency having a service area of 7 square miles and a population of 14,000, and the largest having a service area of 1,650 square miles and a population served of 4,770,000. The number of connections ranged from 390 to 1,143,980. The number of manholes ranged from 160 to 128,691. The miles of sewer ranged from 32 to 5,700. Some of the data reported indicates a mismatch between people served and miles of sewer. It is believed that some of these data are for regional systems where the smaller collection sewers serving the population are not included in the length of sewer reported. In addition, the same data for several agencies are suspect. As expected, sewer length is proportional to population. Eliminating these suspect agencies (agencies 4, 5, 7, 14, 21, and 32) results in an average sewer length density of 1 mile for every 245 people or 21.5 feet of sewer per person. Table 3-2 summarizes the population area, and sewer length by region, size, and average. Figure 3-1 shows a relationship between miles of sewer and population.

Table 3-1
Summary of System Characteristics

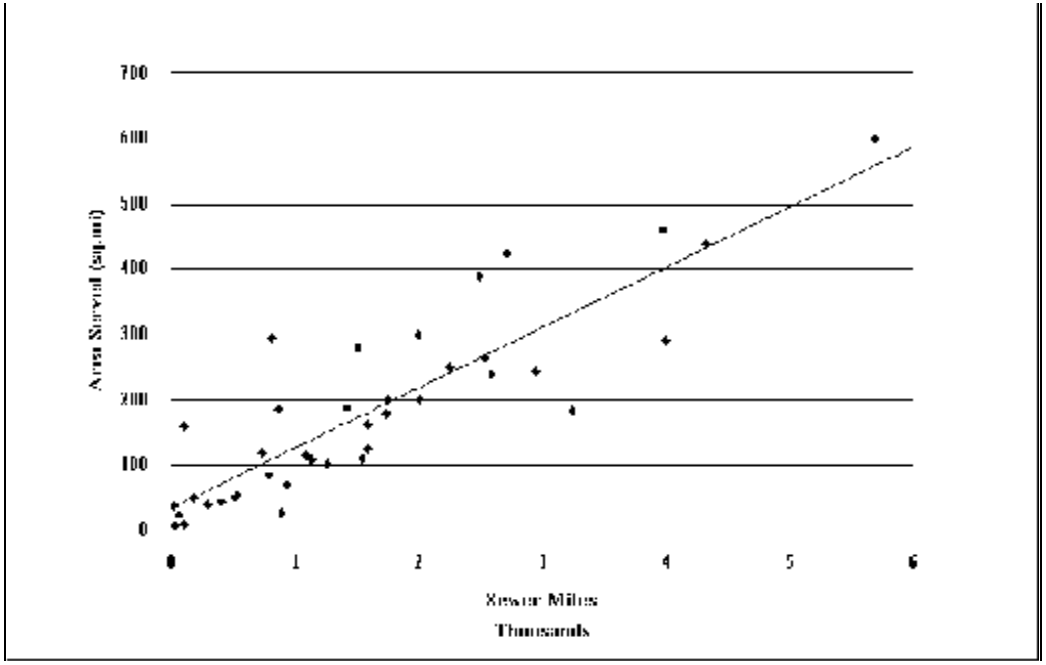
City/ Agency	Size	Region	Population Served	Miles of Sewer	Number of Manholes	Number of Connections	Area Served (sq mi)	Average Age	Average Annual Daily Flow (mgd)	System in Groundwater (%)	System > 24" (%)	Number of Pump Stations	Total Installed (hp)	Energy Per Year (kWh)	Miles of Force Mains	Industrial/ Commercial (%)	Typical Velocity (fps)
1	Large	Northeast	1,400,000	4,891	128,691	388,238	1,000	28.0	192.0	30	5.5	43	22,925	22,362,361	40.1	19	2.0
2	Small	Central	75,561	418	8,129	29,144	44	38.1	14.6	10.0	6.0	11	495	500,000	4.0	5.0	3.0
3	Small	Central	56,000	190	3,855	18,000	50	40.0	7.7	30.0	12.9	16	3,000	45,000	12.9	15.0	15.0
4	Large	Central	2,500,000	511	6,535	n/a	1,650	44.2	213.3	n/a	68.0	61	11,660	n/a	95.1	n/a	n/a
5	Large	Central	900,000	1,520	32,108	300,000	280	30.7	88.6	75.0	8.0	214	30,000	n/a	40.0	20.0	n/a
6	Medium	Central	180,000	900	27,000	60,000	26	39.2	34.6	n/a	8.0	23	5,700	4,000,000	20.0	n/a	2.5
7	Medium	Central	280,000	119	1,200	n/a	161	39.0	39.6	50.0	70.0	17	9,350	7,413,000	31.0	0.0	3.0
8	Medium	Central	465,000	2,000	35,000	160,000	300	42.0	70.5	15.0	20.0	60	n/a	n/a	n/a	10.0	4.0
9	Small	Central	78,000	300	7,243	24,000	39	31.1	12.1	n/a	7.0	4	305	n/a	1.0	59.0	n/a
10	Large	Central	850,000	2,953	82,900	220,000	244	63.0	216.0	n/a	n/a	131	4,593	5,800,000	n/a	40.0	n/a
11	Large	Central	632,958	2,017	60,000	176,004	201	34.8	160.6	n/a	12.0	11	1,210	1,421,500	6.5	15.0	4.0
12	Large	Central	875,000	2,500	44,000	212,000	390	51.0	113.0	n/a	n/a	202	14,472	14,700,000	140.0	n/a	n/a
13	Large	Northwest	700,000	3,250	43,500	182,386	183	18.5	160.5	10.0	3.0	71	2,654	2,834,228	12.4	9.0	2.0
14	Large	Southwest	4,770,000	1,250	20,400	1,143,980	770	47.9	520.0	n/a	38.0	48	7,388	1,280,000	20.0	20.0	3.0
15	Large	Northwest	525,000	1,550	36,000	136,814	110	59.5	50.0	5.0	4.0	4	n/a	n/a	3.0	n/a	3.0
16	Large	Central	619,320	2,255	35,000	138,975	250	21.0	76.9	n/a	8.7	82	n/a	8,275,000	1.8	n/a	3.0
17	Large	Central	1,070,168	4,010	30,493	285,000	290	24.5	177.0	25.0	21.5	16	477	122,500	2.0	10.0	3.5
18	Medium	Southeast	200,000	1,100	18,000	66,000	115	42.0	28.0	50.0	20.0	90	1,800	15,000	50.0	10.0	2.1
19	Medium	Central	180,000	800	18,000	57,000	85	31.0	31.0	25.0	12.0	35	1,700	2,100,000	15.0	30.0	2.0
20	Large	Southeast	950,000	2,543	59,150	258,152	266	19.2	307.0	75.0	1.2	930	90,000	100,000,000	735.0	20.0	2.0
21	Medium	Southeast	136,500	32	160	390	38	17.0	9.6	90.0	26.0	27	2,900	n/a	22.0	99.0	2.0
22	Medium	Southwest	456,445	1,435	19,346	127,578	187	11.4	68.3	10.0	4.0	32	1,125	1,586,836	12.4	1.0	4.0
23	Large	Southwest	1,000,000	3,986	63,837	348,973	460	26.0	59.2	n/a	5.6	19	1,840	n/a	12.8	20.0	2.0
24	Medium	Central	373,644	1750	51,042	121,880	180	30.0	55.0	n/a	5.0	57	n/a	n/a	32.0	n/a	n/a
25	Medium	Central	310,000	1,600	40,000	125,000	125	49.0	42.0	20.0	n/a	40	n/a	n/a	n/a	25.0	n/a
26	Medium	Southwest	183,000	875	13,000	60,000	185	22.5	15.1	0.0	5.0	27	700	40,000	43.8	6.7	2.5
27	Medium	Central	335,000	1,766	29,026	93,060	200	42.1	98.0	70.0	15.0	35	12,000	n/a	128.0	15.0	2.5
28	Medium	Southwest	405,517	1,141	23,281	114,857	108	20.3	49.3	0.0	6.3	2	140	n/a	0.7	6.6	n/a
29	Medium	Northeast	200,000	820	17,300	60,000	296	30.0	18.2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.0
30	Medium	Southwest	475,000	2,729	45,626	187,000	425	25.7	60.0	0.0	3.5	36	1,553	550,000	23.0	12.5	2.5
31	Large	Southeast	560,000	2,600	55,000	140,000	240	25.1	64.5	20.0	20.0	50	3,500	6,000,000	n/a	25.0	3.0
32	Small	Northeast	86,900	72	1,500	2,500	25	12.5	19.2	n/a	20.0	55	4,760	n/a	17.3	10.0	2.5
33	Large	Central	906,885	4,332	91,365	301,545	440	48.2	55.9	n/a	n/a	220	22,387	n/a	73.1	6.0	n/a
34	Large	Central	1,720,000	5,700	100,000	368,000	600	22.0	236.0	30.0	5.0	377	n/a	n/a	n/a	n/a	n/a
35	Medium	Southwest	191,000	548	10,863	41,650	54	17.9	15.0	n/a	2.7	5	450	n/a	2.0	20.0	2.0
36	Medium	Central	150,000	949	21,100	67,693	70	29.4	40.7	25.0	11.0	32	1,020	2,750,000	33.0	53.0	4.0
37	Medium	Southwest	450,000	1,600	29,000	141,000	162	29.0	57.1	5.0	6.0	14	n/a	5,504,196	8.0	20.0	3.0
38	Small	Southwest	14,000	40	836	4,022	7	42.7	1.6	70.0	0.0	5	212	24	1.4	2.0	3.0
39	Medium	Northwest	200,000	747	6,333	62,000	120	26.7	63.6	60.0	12.0	36	2,096	n/a	n/a	n/a	n/a
40	Small	Northwest	23,485	120	1,590	11,150	10	29.7	6.0	90.0	4.0	10	2,240	585,471	5.3	25.0	n/a
41	Medium	Southwest	396,011	1,274	18,190	104,000	102	34.6	63.0	n/a	19.0	16	372	158,000	2.6	7.0	n/a
42	Medium	Southwest	180,000	525	10,000	52,000	50	50.5	24.0	0.0	14.0	55	800	n/a	0.3	30.0	2.0
Total			26,030,394	69,718	1,345,599	6,389,991	10,536	1,387.0	3,464.0	860.0	509.9	3,220	242,898	177,200,755	164.7	646.8	89.0
Average			619,771	1,660	32,038	159,750	251	33.0	82.0	33.1	13.8	79	7,361	7,704,381	47	20.2	3.0
Maximum			4,770,000	5,700	128,691	1,143,980	1,650	63.0	520.0	90.0	70.0	930	90,000	100,000,000	735	99.0	15.0
Minimum			14,000	32	160	390	7	11.4	1.6	0.0	0.0	2	140	24	0	0.0	2.0

Region	Number of Respondents	Feet of Sewer/Capita	Feet of Sewer/sq. mi.
Central	17	23	58,184
Northeast	2	20	20,226
Northwest	4	22	66,100
Southeast	3	23	52,727
Southwest	10	19	45,805
Size			
Large	13	19	35,457
Medium	18	23	54,725
Small	5	22	40,844
Overall Average	36	21	53,062

Figure 3-1 Sewer Miles vs. Population



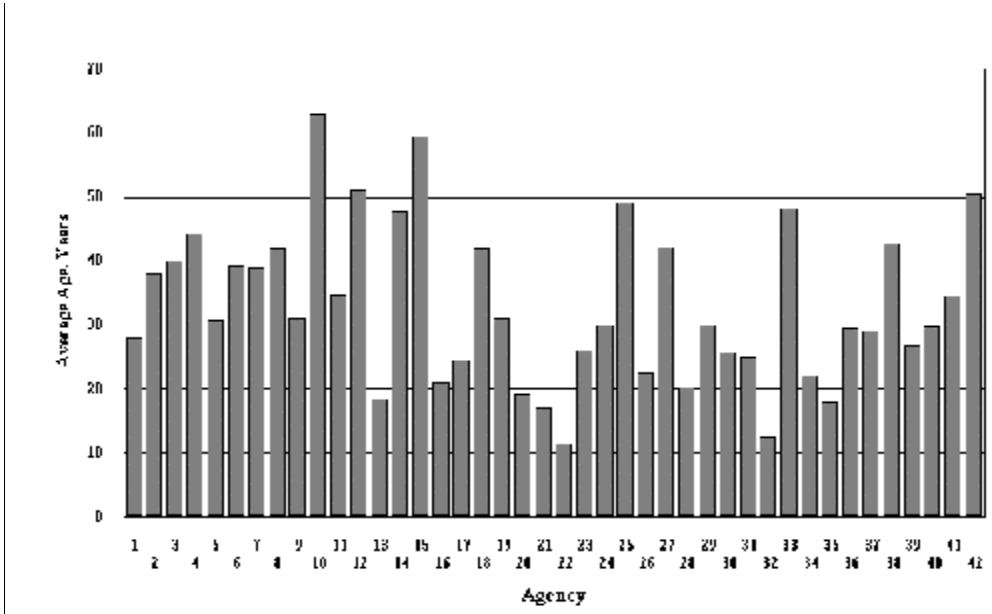
The overall average sewer density in this survey is 21 feet of sewer per capita, or 53,062 feet per square mile. Large systems have the average sewer density of 19 feet per capita, medium-sized systems have 23 feet per capita, and small systems, 22 feet per capita.



The age distribution of sewers in a system will vary depending on when development occurred. Age is an important factor in assessing system needs since systems deteriorate over time. The oldest collection system in this survey was constructed in 1880. The system age for each agency was estimated based on the reported percentage of their system within the following age categories:

- 0 - 10 years (use 5 years as midpoint)
- 11 - 20 years (use 15 years as midpoint)
- 21 - 50 years (use 35 years as midpoint)
- 51- 100 years (use 75 years as midpoint)
- > 100 years (use 125 years as midpoint)

The average system age ranged from 11.4 to 63 years. The overall average was 33 years. Average system age for each agency is shown on Figure 3-3

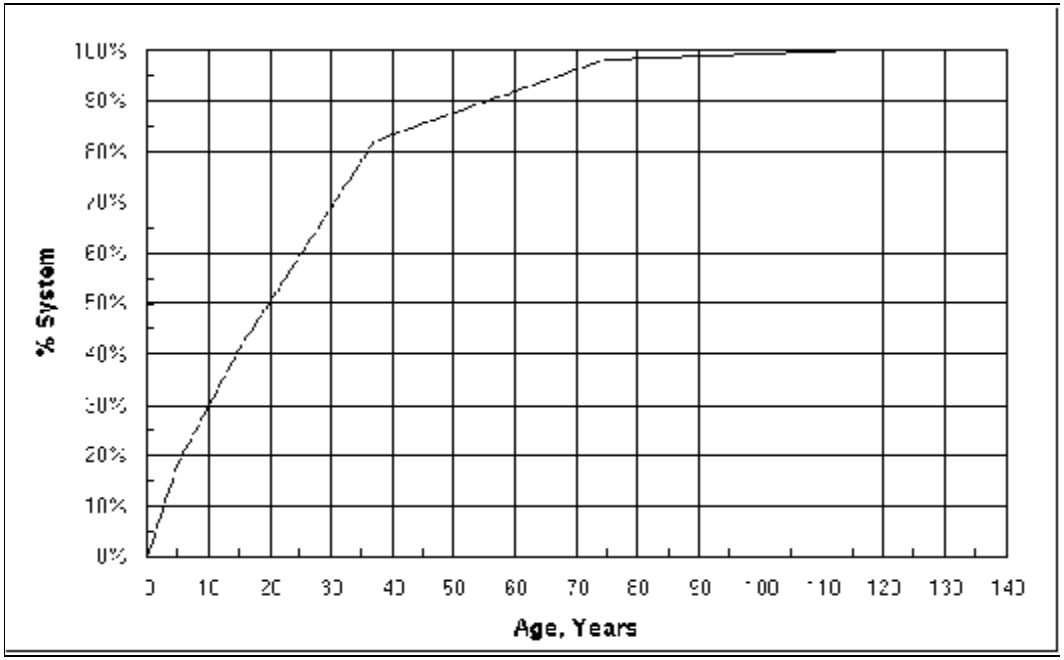


Averaging the cumulative percentages within each class of the age distribution shows that about 18 percent of sewers were built in the last 10 years, 41 percent in the last 20 years, 82 percent in the last 50 years, and 98 percent in the last 100 years as summarized on Table 3-3 and shown on Figure 3-4. The average rate of system growth, based upon the age distribution, is estimated to be about 2.1% per year.

Table 3-3

Percentage of System vs. Average Age

Region	Number of Respondents	0-10 Years (%)	11-20 Years (%)	21-50 Years (%)	51-100 Years (%)	>100 Years (%)
Central	20	13.4	19.7	43.5	21.2	2.2
Northeast	3	21.5	40.4	30.4	7.6	0.0
Northwest	4	19.5	19.0	45.3	12.8	3.5
Southeast	4	27.5	27.3	34.3	10.8	0.3
Southwest	11	21.9	23.4	40.5	13.3	0.9
Size						
Large	16	16.3	22.9	39.2	19.5	2.1
Medium	20	20.3	21.5	43.0	13.7	1.5
Small	6	16.0	26.7	39.7	16.8	0.8
Overall	42	18.2	22.8	41.1	16.4	1.6
Cumulative		18.2	40.9	82.0	98.4	100.0



3.3 Flow Information

3.3.1 Summary of Flow Information

Each agency was requested to provide flow information, such as average annual daily flow, maximum daily flow, peak hourly flow, and maximum and minimum month daily flow.

Average annual daily flows (ADF) reported in the survey ranged from 1.6 to 520 mgd. The ADF listed in Table 3-4 vary widely, reflecting the differences in the industrial component and the I/I of flow of each system. Generally, ADF increases with increasing population although the data shows that ADF cannot be accurately predicted by population estimates alone. The average per capita ADF is 140 gpcd. Figure 3-5 shows the relationship between ADF and population.

Region	Number of Respondents	Average ADF (mgd)	Average Population	Average (gpcd)
Central	20	89.2	626,377	142
Northeast	3	76.5	562,300	136
Northwest	4	70.0	362,121	193
Southeast	4	102.3	461,625	222
Southwest	11	84.8	774,634	109
Size				
Large	16	168.2	1,248,708	135
Medium	20	44.1	285,856	170
Small	6	10.2	55,658	183
Overall Average	42	86.5	619,771	140

Figure 3-5 ADF vs. Population

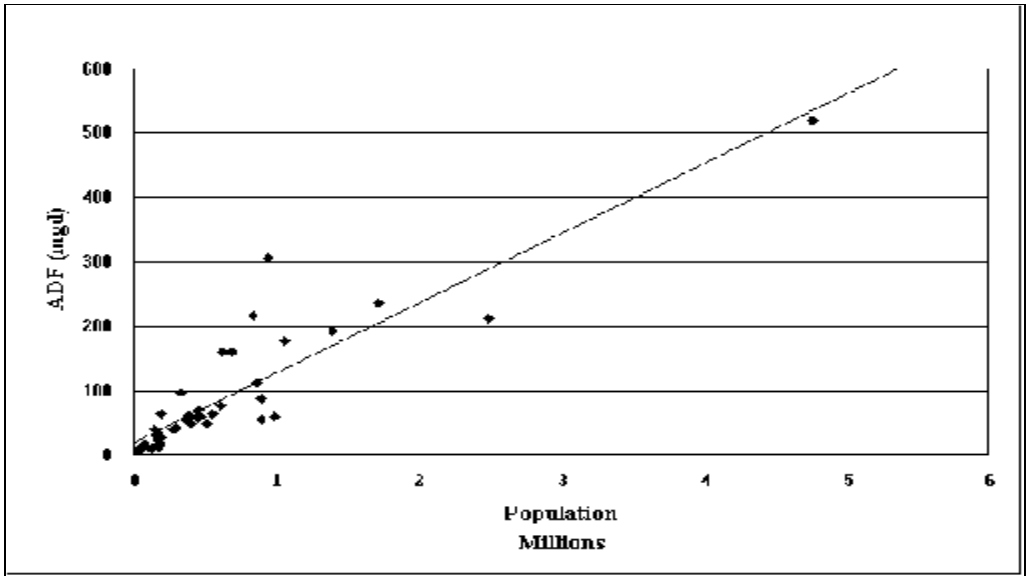


Table 3-5 summarizes the peak hourly/ADF flow ratio by region and by size. The overall average peaking factor is 2.24. The Northwest region has the highest ratio of 3.81 as expected, since this region has a wetter climate than other parts of the country. The Southwest region has the lowest peaking factor of 1.77, also as expected, since this region has a drier climate than rest of the country.

Region	Number of Respondents	Average Peak Hourly Flow/ADF
Central	18	2.47
Northeast	2	2.27
Northwest	2	3.81
Southeast	3	2.05
Southwest	10	1.77
Size		
Large	12	2.20
Medium	17	2.34
Small	6	2.95
Overall Average	35	2.24

3.4 Information on System Characteristics

Characteristic information includes the number of pump stations, total installed horsepower of pumps in the pump stations, total energy consumed by all pump stations, total length of force mains, typical velocity of flow, etc.

3.4.1 Summary of Characteristic Information

The percentage of larger than 24-inch diameter sewers in each system ranged from 0 to 70%. Total number of pump stations in each agency's system ranged from 2 to 930. The total installed horsepower for all regions ranged from 140 to 90,000 hp, the total energy consumed per year ranged from 24 kWh to 100 million kWh. The percentage of industrial/commercial flow ranged from 0 to 99% of the system. The typical flow velocity in the system ranged from 2 to 15 fps.

Table 3-6 summarizes the percentage of greater than 24-inch diameter sewers in each system by region and by system size. The overall average is 13.8%.

Table 3-6 Percentage of System Greater than 24 Inches in Diameter		
Region	Number of Respondents	Percentage of System
Central	16	18.1
Northeast	2	12.8
Northwest	4	5.8
Southeast	4	16.8
Southwest	11	9.5
Size		
Large	13	15.4
Medium	18	14.4
Small	6	8.3
Overall Average	37	13.8

All 42 agencies have pump stations. The number of pump stations ranged from 2 to 930. Table 3-7 summarizes the number of pump stations per mile of sewer by region and by system size. The overall average is 0.09 pump stations per mile of sewer. As expected, the Southeast region has the highest number of pump station rates of 0.33 per mile of sewer. Small systems have the highest pump station rate of 0.18 per mile of sewer, medium-sized systems have 0.08 pump stations per mile of sewer, and large systems, 0.06 pump stations per mile of sewer.

Table 3-7 Number of Pump Stations		
Region	Number of Respondents	Number of Pump Stations/ Miles of Sewer
Central	20	0.05
Northeast	2	0.26
Northwest	4	0.04
Southeast	4	0.33
Southwest	11	0.03
Size		
Large	16	0.06
Medium	19	0.08
Small	6	0.18
Overall Average	41	0.09

Each agency was requested to provide information on the total horsepower of the pump stations. Although all 42 agencies reported having pump station installed, only 34 agencies reported total horsepower of the pump stations.

Table 3-8 summarizes the total installed horsepower per pump station by region and by system size. The Northeast region has the largest horsepower installed. The Southwest has the

smallest horsepower installed. Small systems have larger horsepower installed than large and medium-seized systems.

Table 3-8
Total Installed Horsepower of Pump Stations

Region	Number of Respondents	Horsepower/Pump Station
Central	15	110
Northeast	2`	310
Northwest	3	80
Southeast	4	74
Southwest	10	54
Size		
Large	13	104
Medium	15	90
Small	6	110
Overall Average	34	98

The average of the total length of force main per pump station is 0.56 miles as summarized in Table 3-9. The Central region has the highest rates of 0.67 miles of force main per pump station, and the Northwest region has the lowest rate of 0.36 miles of force main per pump station. Medium-sized systems have the highest rate of 0.69 miles of force main per pump station, large systems have 0.45 miles of force main per pump station, and small systems, 0.42 miles of force main per pump station.

Table 3-9
Ration-Force Main Length/Pump Station

Region	Number of Respondents	miles/ps
Central	16	0.67
Northeast	2	0.42
Northwest	3	0.36
Southeast	3	0.54
Southwest	11	0.50
Size		
Large	13	0.45
Medium	16	0.69
Small	6	0.42
Overall Average	35	0.56

Table 3-10 summarizes the percentages of systems in industrial/commercial flows. The overall average is 20.2%. The Southeast region has the highest percentage, 38.5%, the Central region has 21.6%, the Northwest region 17%, the Northeast region 14.5%, and the Southwest region 13.3%. The medium-sized systems, 21.6%, the small systems 13.3% and, large systems 18.6%.

Table 3-10
Percentage of System Industrial/Commercial Flow

Region	Number of Respondents	Percentage of System
Central	14	21.6
Northeast	2	14.5
Northwest	2	17.0
Southeast	4	38.5
Southwest	11	13.3
Size		
Large	11	18.6
Medium	16	21.6
Small	6	19.3
Overall Average	33	20.2

Table 3-11 summarizes the minimum, maximum, and typical velocities by regions and system sizes. The overall average in minimum velocity is 1.4 ft/s, maximum velocity is 8.4 ft/s.

Table 3-11
Typical Velocity of Flow

Region	Min (ft/s)	Max (ft/s)	Typical (ft/s)
Central	1.7	8.4	4.2
Northeast	0.3	7.5	2.2
Northwest	1.5	7.5	2.5
Southeast	1.2	4.7	2.3
Southwest	1.4	10.1	2.7
Size			
Large	1.3	7.3	2.8
Medium	1.5	9.3	2.7
Small	1.3	8.3	5.9
Overall Average	1.4	8.4	3.1

4.0 Maintenance Data

4.1 Introduction

Maintenance typically refers to the specific procedures, tasks, instructions, personnel, qualifications, equipment, and resources needed to satisfy the maintainability requirement within a specific use environment. AMaintenance is that set of activities required to keep a component, system, infrastructure asset, or facility functioning as it was originally designed and constructed to function.@[1] For our purpose, any reinvestment in the system, including routine maintenance, capital improvements for repair or rehabilitation, inspection activities, and monitoring activities are classified as maintenance. Capital improvements for system expansion are not classified as maintenance reinvestment.

4.2 Routine Maintenance

Routine maintenance includes sewer cleaning, root removal/treatment, cleaning of mainline stoppages, cleaning of house service stoppages, and inspections and servicing of pump stations. Each agency was requested to provide 5 years of data (from 1992 to 1996) to establish routine maintenance rates. These routine maintenance rates by region and by size are presented in Table 4-1 through 4-5.

Forty-one out of 42 agencies reported having a cleaning maintenance program. Table 4-1 summarizes the sewer maintenance for each year from 1992 to 1996 by region and system size. The cleaning rates represented the reported total miles cleaned annually compared to the total miles in the agency=s system. Overall, the Northwest region has the highest cleaning rates in miles per mile per year, and the Northeast has the lowest rate in miles per mile per year. Small systems have the highest cleaning rate, followed by medium and large systems. Overall, the annual cleaning rate varied from about 0.29 miles per mile per year to about 0.32 miles per mile per year. The overall average cleaning rate is 0.30 miles per mile per year.

[1]Ronald Hudson, *Infrastructure Management*.

Table 4-1

Routine Maintenance - Average Sewer 5-Year Cleaning

(miles cleaned/mile of system$yr)

Region	Number of Respondents	1992	1993	1994	1995	1996	5-Year Average miles cleaned/ mile of system$yr
Central	20	0.23	0.23	0.22	0.22	0.21	0.22
Northeast	2	0.08	0.09	0.09	0.09	0.08	0.09
Northwest	4	0.76	0.57	0.56	0.58	0.56	0.61
Southeast	4	0.32	0.37	0.26	0.26	0.24	0.29
Southwest	11	0.35	0.36	0.37	0.42	0.41	0.38
Size							
Large	16	0.27	0.31	0.27	0.27	0.24	0.27
Medium	20	0.27	0.28	0.29	0.33	0.32	0.30
Small	5	0.51	0.34	0.35	0.42	0.37	0.40
Overall Average	41	0.30	0.30	0.29	0.32	0.29	0.30

Thirty-six out of 42 agencies reported having a root removal maintenance program. Table 4-2 summarizes miles of root removal by region and by system size. The Central region shows a decrease in root removal from 1992 to 1995, followed by a huge increase in 1996. The Southeast region has shown a slight increase between 1992 and 1993, then a significant decrease from 1993 to 1996. The overall average root removal during this 5-year period was 0.04 miles per mile of systems per year.

Table 4-2

Routine Maintenance - Average Root Removal

(miles/mile of system$yr)

Region	Number of Respondents	1992	1993	1994	1995	1996	5-Year Average mile/mile of system$yr
Central	18	0.02	0.02	0.02	0.02	0.03	0.02
Northeast	2	0.01	0.01	0.01	0.01	0.01	0.01
Northwest	4			0.02	0.02	0.02	0.01
Southeast	4	0.22	0.24	0.10	0.11	0.07	0.15
Southwest	8	0.08	0.06	0.06	0.06	0.05	0.06
Size							
Large	13	0.06	0.05	0.03	0.03	0.02	0.04
Medium	17	0.05	0.05	0.04	0.05	0.06	0.05
Small	6	0.00	0.07	0.02	0.03	0.03	0.03
Overall Average	36	0.05	0.05	0.03	0.04	0.04	0.04

Note: Blank cells indicate that data were unreported or required data to convert values to rates was unreported.

Thirty-eight out of 42 agencies reported main line stoppages cleaned data. Only 27 agencies provided house service stoppages cleared data between 1992 and 1996. Tables 4-3 and 4-4 summarize the main line stoppages and house service stoppages cleared per sewer mile between 1992 and 1996. Both large and medium systems show an increase of main line stoppages cleared annually. In general, as shown in Table 4-3, main line stoppages in both large and medium systems have been increasing annually and have decreased in small systems. Large systems reported a 35% increase of stoppages cleared between 1994 and 1995. The Central, Northeast, Northwest and Southwest areas reported an average increase of 10% to 20% each year, while the Southeast reported more than a 62% increase between 1995 and 1996. The overall rate of mainline stoppages cleared is about 0.23 per mile per year.

Table 4-3
Routine Maintenance - Average Main Line Stoppages Cleared
(stoppages/mi)

Region	Number of Respondents	1992	1993	1994	1995	1996	5-Year Average stoppages/mile
Central	18	0.30	0.31	0.30	0.28	0.25	0.29
Northeast	3	0.19	0.17	0.19	0.24	0.23	0.20
Northwest	4	0.19	0.13	0.11	0.07	0.07	0.11
Southeast	4	0.26	0.28	0.26	0.39	0.63	0.36
Southwest	9	0.09	0.09	0.16	0.15	0.15	0.13
Size							
Large	13	0.17	0.18	0.17	0.23	0.23	0.20
Medium	19	0.27	0.28	0.31	0.26	0.31	0.29
Small	6	0.16	0.13	0.14	0.12	0.10	0.13
Overall Average	38	0.22	0.21	0.23	0.23	0.25	0.23

As shown in Table 4-4, large systems reported an increase in house service stoppages cleared annually, while medium and small systems reported a decrease each year. Overall, the rate of stoppages cleared increased by an average 10 to 20% each year. Increasing numbers of stoppages indicate decreasing performance of the systems. The overall average for house service stoppages cleared is 0.29 stoppages per mile per year.

Table 4-4

Routine Maintenance - Average House Service Stoppages Cleared

(stoppages/mi$yr)

Region	Number of Respondents	1992	1993	1994	1995	1996	5-Year Average stoppage/mi$yr
Central	13	0.47	0.46	0.49	0.48	0.40	0.46
Northeast	3	0.20	0.20	0.17	0.19	0.24	0.20
Northwest	3	0.22	0.26	0.25	0.14	0.14	0.20
Southeast	2	0.26	0.33	0.35	0.63	0.68	0.45
Southwest	6	0.06	0.05	0.05	0.02	0.04	0.04
Size							
Large	13	0.21	0.22	0.25	0.30	0.32	0.26
Medium	10	0.35	0.35	0.35	0.31	0.26	0.32
Small	4	0.38	0.35	0.33	0.27	0.29	0.32
Overall Average	27	0.29	0.29	0.30	0.30	0.29	0.29

Thirty-one agencies reported having routine inspection and service on pump stations between 1992 and 1996. Table 4-5 summarizes the inspections and servicing of pump stations by region and by size. Although the Southeast region has the largest number of pump stations installed, it has the lowest number of inspections between 1994 and 1996. The small systems have the highest inspection and servicing rate.

Table 4-5

Routine Maintenance - Average Inspections & Service of Pump Stations

(inspection/pump stations$yr)

Region	Number of Respondents	1992	1993	1994	1995	1996	5-Year Average inspection/ps$yr
Central	13	140	155	143	144	125	141
Northeast	1	331	340	340	340	365	353
Northwest	4	18	18	18	14	14	16
Southeast	4	1	1	41	44	28	23
Southwest	9	140	74	75	72	73	87
Size							
Large	11	92	87	92	93	90	91
Medium	15	72	84	78	71	65	74
Small	5	30	220	328	184	184	229
Overall Average	31	122	107	106	98	92	105

4.3 Inspection Maintenance

An inspection program is vital to proper maintenance of a wastewater collection system. Without inspections, a maintenance program is difficult to define, since problems cannot be solved if they are not identified. The elements of an inspection program include flow monitoring, manhole inspections, smoke/dye testing, closed circuit television inspection, and private sector inspections. Inspections provide the data necessary for managers to make informed decisions on all maintenance, repair, and rehabilitation actions.

Information regarding the inspection methods and status for the most recent 1-year, 5-year, 10-year, and 20-year time intervals was obtained for each agency. Cumulative numbers of inspections completed for each type of activity were obtained. The inspection maintenance methods by region and by size are summarized in Tables 4-6 through 4-10.

The frequency and types of inspections vary widely from agency to agency.

Table 4-6 summarizes the flow evaluations performed by region and by size in the last 1 year, 5 years, 10 years, and 20 years. The Northwest and Southwest regions reported greater flow monitoring activities than the other regions. Large systems reported more flow monitoring than medium or small systems. Overall, flow monitoring has increased from 8% per year 20 years ago to 33% per year today. Some areas have been monitored more than once and therefore, have been reported as being flow monitored more than once resulting in reported values exceeding 100%.

Table 4-6
Inspection Methods - Flow Evaluation
(cumulative % of system)

Region	Number of Respondents	1-Year	5-Year	10-Year	20-Year
Central	15	26%	53%	74%	83%
Northeast	3	63%	67%	67%	67%
Northwest	3	67%	367%	533%	733%
Southeast	4	15%	43%	43%	43%
Southwest	8	32%	67%	106%	170%
Size					
Large	10	53%	143%	220%	331%
Medium	17	33%	68%	76%	77%
Small	6	2%	35%	74%	91%
Overall Average	33	33%	85%	119%	157%
Average %/Year		33%	17%	12%	8%

Table 4-7 summarizes the manhole inspections status. The Northeast and Southwest regions reported relatively high manhole inspection rates over the past 20 years. The Central region is below the average manhole inspection rate. Large, medium and small systems all reported an average inspection rate greater than 100% over the past ten years. Most regions reported more than 100% manhole inspections during last 5 years. Reported values that exceed 100% indicated that manhole inspections have been conducted more than once in the same area. The overall average reported shows that manhole inspection activity has increased from 10%, 20 years ago, to 26%, 1 year ago.

Table 4-7
Inspection Methods - Manhole Inspection
(cumulative % of system)

Region	Number of Respondents	1-Year	5-Year	10-Year	20-Year
Central	17	17%	48%	73%	76%
Northeast	3	35%	88%	125%	163%
Northwest	4	34%	55%	61%	67%
Southeast	4	19%	144%	144%	145%
Southwest	7	44%	186%	334%	598%
Size					
Large	13	27%	115%	177%	289%
Medium	16	27%	80%	113%	142%
Small	6	24%	70%	109%	130%
Overall Average	35	26%	91%	136%	195%
Average/Year		26%	18%	14%	10%

Table 4-8 summarizes the smoke/dye test by region and by system size. The Southeast region reported the greatest average percentage system smoke/dye testes. Small systems reported the greatest overall smoke/dye testing over the past 20 years but the lowest activity in the past year. The smoke/dye test activity has been increased from 2% per year, 20 years ago, to 8%, 1 year ago.

Table 4-8
Inspection Methods - Smoke/Dye Testing
(cumulative % of system)

Region	Number of Respondents	1-Year	5-Year	10-Year	20-Year
Central	18	12%	21%	31%	38%
Northeast	3	1%	3%	3%	5%
Northwest	4	2%	8%	15%	21%
Southeast	4	13%	123%	123%	123%
Southwest	9	1%	17%	23%	34%
Size					
Large	14	10%	33%	35%	37%
Medium	18	7%	20%	27%	33%
Small	6		33%	42%	60%
Overall Average	38	8%	26%	32%	39%
Average/Year		8%	5%	3%	2%

Note: Blank cells indicate that data were unreported or required data to convert values to rates was unreported.

Table 4-9 summarizes TV inspection activity. Overall, TV inspection has increased from 2% per year 20 years ago to 7% per year a year ago. The Southeast region has shown the highest percentage of TV inspection within the past 5 years.

Table 4-9
Inspection Methods - Television Inspection
(cumulative % of system)

Region	Number of Respondents	1-Year	5-Year	10-Year	20-Year
Central	19	6%	19%	29%	32%
Northeast	3	8%	15%	17%	24%
Northwest	4	7%	36%	45%	55%
Southeast	4	9%	105%	107%	111%
Southwest	9	10%	27%	35%	43%
Size					
Large	15	7%	41%	47%	54%
Medium	18	6%	25%	30%	34%
Small	6	11%	25%	48%	54%
Overall Average	39	7%	31%	39%	44%
Average %/Year		7%	6%	4%	2%

The private sector building inspection activities include area drains, downspouts, cleanouts, sump discharges and other private sector inflow sources into the system. Only twenty-two out of 42 agencies provided private sector building inspection data. Table 4-10 summarizes the cumulative percentage of private sector building inspection. The overall average activity for the private sector building inspection has been increased from 1 percent per year, 20 years ago, to 5 percent, 1 year ago.

Table 4-10
Inspection Methods - Private Sector Building Inspection
(cumulative % of system)

Region	Number of Respondents	1-Year	5-Year	10-Year	20-Year
Central	12	7%	17%	27%	27%
Northeast	1	0%	0.5%	1%	1%
Northwest	2	0%	0%	0%	0%
Southeast	2	12%	50%	50%	50%
Southwest	5	0.2%	20%	20%	20%
Size					
Large	9	4%	15%	16%	17%
Medium	9	8%	18%	18%	18%
Small	4	0.3%	25%	50%	50%
Overall Average	22	5%	18%	24%	24%
Average %/Year		5%	4%	2%	1%

Note: Blank cells indicate that data were unreported or required data to convert values to rates was unreported.

4.4 Rehabilitation Maintenance

A rehabilitation maintenance program is essential to maintaining a wastewater collection system. The percentage of system manholes, sewer lines, relief sewers, and private sector defects which have been rehabilitated (rehabilitation maintenance and status) was summarized. The rehabilitation maintenance status by region and by size is shown in Table 4-11.

Thirty-eight out of 42 agencies reported the rehabilitation maintenance status. The national average for manhole rehabilitation is 42% from this survey. Both large and medium-sized systems are above the average. Central and Northwest region are below the national average in manhole rehabilitation maintenance. The national average for main line or public service connection repairs is 38%. Northeast region has shown a high percentage of repairing rate in main line or public

service connection. The national average relief sewer rehabilitation maintenance is 47%. The small systems have the highest maintenance rate of 81%. The national average for private sector maintenance is 28%. Southwest region and small systems have the highest maintenance rate.

Table 4-11
Rehabilitation Maintenance Status

Region	Number of Respondents	Manhole	Main Line or Public Service Connection Repairs	Relief/Equalization	Private Sector
Central	18	35%	33%	42%	21%
Northeast	2	83%	73%	80%	0 %
Northwest	4	35%	28%	50%	34%
Southeast	4	51%	41%	32%	32%
Southwest	10	45%	40%	55%	49%
Size					
Large	14	46%	36%	44%	26%
Medium	18	43%	39%	44%	26%
Small	6	32%	39%	81%	44%
Overall Average	38	42%	38%	47%	28%

Note: Blank cells indicate that data were unreported or required data to convert values to rates was unreported.

4.5 System Maintenance Costs

System maintenance costs were reported by the following categories: relief, equalization, rehabilitation/replacement, routine O&M, equipment replacement, and other costs. Information regarding the total dollars reinvested on system maintenance was obtained for the following time periods:

- $ 1990 - 1996
- $ 1980 - 1989
- $ 1970 - 1979
- $ pre - 1970

The dollar values listed are as reported and are not adjusted for inflation.

The average cumulative dollars spent on system maintenance is listed in Tables 4-12 through 4-15. The data show a large increase in spending in the 1990s. The rate of spending has increased from $5 per mile per year in pre-1970s to $8,000 per mile per year in the 1990s as indicated in Table 4-16.

Table 4-12

Relief Maintenance Costs by Period

Region	Number of Respondents	Pre-1970 ($/mi$yr)	Number of Respondents	1970-1979 ($/mi$yr)	Number of Respondents	1980-1989 ($/mi$yr)	Number of Respondents	1990-1996 ($/mi$yr)
Central	3	3	5	6,206	9	1,906	17	1,467
Northeast	1	0	1	0	1	0	2	1,730
Northwest	1	0	1	0	1	0	3	907
Southeast	1	0	2	1,057	2	1,216	4	0
Southwest	1	0	2	1,648	7	476	7	1,640
Size								
Large	4	0	4	7,597	6	2,480	13	1,980
Medium	2	5	5	1,093	12	577	15	572
Small	1	0	2	294	2	554	5	1,656
Overall Average		1		3,313		1,146		1,291

Note: Blank cells indicate that data were unreported or required data to convert values to rates was unreported.

Table 4-13

Equalization Costs

Region	Number of Respondents	Pre-1970 ($/mi yr)	Number of Respondents	1970-1979 ($/mi$yr)	Number of Respondents	1980-1989 ($/mi$yr)	Number of Respondents	1990-1996 ($/mi$yr)
Central	7	0	8	0	8	17	10	257
Northeast								
Northwest								
Southeast	2	0	2	0	2	0	2	1,325
Southwest	4	0	7	130	6	68	6	97
Size								
Large	3	0	4	0	4	0	4	1
Medium	8	0	11	82	10	53	12	482
Small	2	0	2	0	2	6	2	7
Overall Average		0		53		34		322

Note: Blank cells indicate that data were unreported or required data to convert values to rates was unreported.

Table 4-14

Rehabilitation/Replacement Costs by Period

Region	Number of Respondents	Pre-1970 ($/mi yr)	Number of Respondents	1970-1979 ($/mi$yr)	Number of Respondents	1980-1989 ($/mi$yr)	Number of Respondents	1990-1996 ($/mi$yr)
Central	3	2	6	1,209	9	1,176	14	3,583
Northeast	1	3	1	143	1	1,718	1	1,270
Northwest	1	0	1	0	1	0	2	2,517
Southeast	2	0	3	106	3	65	3	1,098
Southwest	2	0	2	0	8	516	8	2,456
Size								
Large	2	0	5	593	6	1,269	9	3,229
Medium	5	1	6	39	13	260	15	1,317
Small	1	0	2	2,205	3	1,876	4	7,650
Overall Average		1		585		756		2,836

Note: Blank cells indicate that data were unreported or required data to convert values to rates was unreported.

Table 4-15
O&M Budget by Period

Region	Number of Respondents	Pre-1970 ($/mi yr)	Number of Respondents	1970-1979 ($/mi$yr)	Number of Respondents	1980-1989 ($/mi$yr)	Number of Respondents	1990-1996 ($/mi$yr)
Central	3	7	7	766	11	2,063	18	2,260
Northeast	1	0	1	0	1	488	2	7,350
Northwest			1	0	1	0	3	2,960
Southeast	1	0	1	0	2	0	3	2,988
Southwest			1	1,329	6	1,247	9	2,657
Size								
Large	2	0	5	695	10	1,481	13	3,945
Medium	3	4	5	302	9	1,273	17	1,548
Small			1	941	2	1,163	5	4,051
Overall Average		3		539		1,362		2,796

Note: Blank cells indicate that data were unreported or required data to convert values to rates was unreported.

Table 4-16
Rate of Spending

Reinvestment Category	Number of Respondents	Pre-1970 ($/mi yr)	Number of Respondents	1970-1979 ($/mi$yr)	Number of Respondents	1980-1989 ($/mi$yr)	Number of Respondents	1990-1996 ($/mi$yr)
Relief	7	1	11	3,313	20	1,146	33	1,291
Equalization	13	0	17	53	16	34	18	322
Rehabilitation	8	1	13	585	22	756	28	2,836
O&M	5	3	11	539	21	1,362	35	2,796
Equipment	5	0	6	9	8	34	15	117
Other	2	0	2	0	5	512	5	647
Total		5		4,499		3,844		8,009

Note: Blank cells indicate that data were unreported or required data to convert values to rates was unreported.

5.0 System Maintenance Frequency Determination

5.1 Introduction

Maintenance, as defined in the broad sense used in this study, includes any collection system reinvestment in the form of capital improvements, rehabilitation, inspection, and what is typically considered routine maintenance. All maintenance activities are not equally effective. Therefore, when evaluating how much maintenance an agency is doing, what is of real interest is how much *effective* maintenance it is doing. For example, if an agency was performing only CCTV inspections and nothing else, even though considerable time and effort may be going into the CCTV inspection, little system improvement would result. The CCTV is effective only if it is done in concert with other activities such as removing blockages and debris or repairing defects. In other words, an effective maintenance program requires a balance of activities. This chapter presents an evaluation of maintenance and a determination of a maintenance frequency for the agencies surveyed.

5.2 Weighting of Maintenance Activities

In order to evaluate the relative importance of activities necessary to develop a system maintenance frequency, each agency was requested to provide an opinion of the relative importance of twelve common maintenance activities. The most important maintenance activity, as selected by the agencies surveyed, is line cleaning, which averaged almost 18% of the total maintenance weight assigned. The next three activities, listed in descending order of importance, are pump station servicing (14.1%), main line rehabilitation (12.6%), and closed circuit television inspection (10.5%). The three least important activities, as selected by the agencies surveyed, are manhole rehabilitation (5.6%), smoke testing (3.3%), and private sector inspections (2.0%). These maintenance activities and their average weight of importance are listed in Table 5-1. Average percentages were adjusted proportionately, so that the total of all maintenance items was equal to 100 percent.

Table 5-1 Average Weight of Maintenance Activity		
Activity	Relative Importance (Weight)	Number of Responses
1. Cleaning	17.7%	36
2. Root removal	8.4%	36
3. Pump station service	14.1%	36
4. Flow monitoring	7.0%	33
5. Manhole inspection	6.4%	35
6. Smoke testing	3.3%	31
7. CCTV	10.5%	34
8. Private sector inspections	2.0%	32
9. Manhole rehabilitation	5.6%	37
10. Main line rehabilitation	12.6%	36
11. Relief construction	6.3%	35
12. Private sector I/I removal	6.1%	34
Total	100%	

The variations in weights by region and by size category are presented in Appendix C. The relative importance by region and size was similar for all regions except for the Southeast region which placed a higher importance on pump station servicing than other regions, and for the Central region which placed a higher importance on main line rehabilitation. Because of the small sample within each category (region and size), the overall average weights of maintenance activities were used in the analysis reported herein.

5.3 Development of Maintenance Frequency

The system maintenance frequency for each agency was developed using the maintenance activity weight (importance) as discussed in Section 5.2, a calculated standard rating based on a normal distribution of maintenance rates, and the assigned maintenance frequencies.

5.3.1 Determining Maintenance Rates

All maintenance activity quantities were converted into unit rates. For example, miles of sewer cleaned was converted into miles of sewer cleaned per year. For annual maintenance activities, data for the past five years were used as a basis for the analysis, since this period was considered representative of the best data. For Aone-time@ maintenance activities such as rehabilitation, an estimate of the needed rehabilitation completed was used. For example, if over the life a system, 50% of the manholes were identified as needing rehabilitation and no repairs had been made, 0% of manhole rehabilitation would have been completed. Likewise, if 25% of the total number of manholes in this same system had been repaired (50% of manholes needing rehabilitation), then 50% of manhole rehabilitation would have been completed, and so on. The

time interval during which rehabilitation was done was assumed to be the most recent 25 years, which approximates the life expectancy of many rehabilitation methods. The maintenance done by the agencies surveyed is presented in Table 5-2 and the maintenance rates are given in Table 5-3. To determine maintenance rates, the average miles of sewer installed were estimated over the maintenance period, based on the age information provided by each agency.

5.3.2 Developing the Standard Rating

A standardized table was developed using the maintenance data collected and a normal distribution. The mean, standard deviation, range, and number of responses for each maintenance activity are listed in Table 5-4. The rate of each maintenance activity was normalized using the normal distribution to develop a standard by which any maintenance rate, or group of maintenance rates from various maintenance activities, could be compared. The frequency of individual maintenance activities can be easily determined; however, the overall system maintenance frequency, considering all maintenance activities, requires a method to standardize and weight all maintenance activities. Once the maintenance data was normalized, a frequency was assigned to correspond to selected standard deviations from the mean. The assignment of the standard maintenance frequency was somewhat arbitrary; however, based on previous reports (Nelson) a 5 to 10 percent overall average frequency goal was assumed to be reasonable. Through trial and error, an average maintenance frequency of 6.7% for all agencies was chosen. This is discussed in more detail in Section 5.4. The selected frequencies corresponding to the normalized data are listed in Table 5-5.

Table 5-2
Maintenance Performed

Utility No.	Cleaning 1992 -1996, miles	Root Removal 1992 - 1996, miles	Lift Station Inspections 1992 - 1996	% Flow Monitoring Last 5 Yr	% Manhole Inspections Last 5 Yr.	% Smoke/Dye Test Last 5 Yr.	% CCTV Last 5 Yr.	% Private Sector Last 5 YR.	% Manhole Rehabbed	% Main Line Rehabbed	% Relief/ Equal Completed	% Private Sector Completed
1	1,282	280	75,900	100%	10%	5%	15%	1%	75%	50%	80%	
2	780	103	1,148		80%		10%		20%	50%		10%
3	204	0	45,500	10%	10%		15%		33%	29%	62%	69%
4	50	9	75,000	200%	40%	2%	20%		90%			
5			16,770		50%		5%		75%	75%		
6	2,280	0		17%	50%	17%	23%		20%	20%	5%	
7	42	0	9,000	100%	47%		47%		100%	100%	100%	100%
8				30%	20%	20%	10%		30%	40%	50%	
9	828		1,000	5%	4%	5%	48%		25%	50%		
10			29,912									
11	1,869			200%		3%	6%		10%	2%		1%
12	269	108			50%	3%	7%					
13	4,123		4,176	500%	1%	1%	15%		0%	1%		
14				250%	500%		37%		56%	56%	67%	
15	9,984	0	500		100%	1%	45%		100%	100%	100%	100%
16	953			20%	50%	50%	50%		5%	10%		5%
17	4,258	284	3,328	20%	20%	20%	18%	20%	40%	50%	80%	90%
18					18%	50%	8%		2%	2%	20%	
19	145	21	3,851	25%	32%	26%	25%		40%	30%	60%	
20			135,220	100%	100%	100%	100%	100%	96%	70%	25%	95%
21	50	0		30%	90%		90%		100%	90%		
22	1,111		14,104	100%	250%	50%	8%		100%	100%	100%	100%
23	5,417	2	9,360		200%	1%	65%		1%	1%		
24	3,851	29	39,182	45%	211%	84%	27%	70%	30%	30%	60%	30%
25									5%	1%		1%
26	991	118	970	100%	50%		75%			25%	10%	n/a
27	935	480	52,610	75%	50%	15%	8%	3%	20%	20%	10%	5%
28	3,565	5	676									
29	486			80%	54%		11%					
30	6,000			5%			6%		5%	5%	10%	
31	3,760	2,564			368%	218%	222%		5%	3%	50%	
32		0		20%	200%				90%	95%		
33												
34									40%	44%	35%	17%
35	739		260		100%		7%		25%	25%	50%	
36	1,075	30	20,800	55%	95%	60%	17%	85%	20%	15%		
37	2,814	39				3%	7%			31%		
38	124	0	8,700	75%	105%	101%	33%	101%	20%	2%	100%	95%
39	880			500%	100%		60%			5%		3%
40	75			100%	20%	25%	25%		5%	5%		
41	3,539	1,783							99%	100%	100%	100%
42	844	20		2%	100%		5%		95%	60%		
	32 count	23 count	22 count	27 count	33 count	23 count	35 count	7 count	34 count	36 count	21 count	17 count
	1979 avg	255 avg	24908 avg	102% avg	96% avg	37% avg	33% avg	54% avg	43% avg	39% avg	56% avg	48% avg
	2209 sd	614 sd	33367 sd	1.29 sd	1.07 sd	0.50 sd	0.41 sd	0.42 sd	0.37 sd	0.33 sd	0.33 sd	0.44 sd

Note: Blank cells indicate that data was unreported.

Table 5-3
Reported Maintenance Rates

Utility	Cleaning Rate, % system/year	Root Cutting, % System/yr	Lift Station Rate, no/ls/yr	Flow Monitoring Rate,% System/yr	Manhole Inspect. % System/yr	Smoke/dye Rate, % System/yr	CCTV Rate, % System/yr	Private Sector Inspection Rate, % System/yr	Manhole Rehab Status	Main Line Rehab Status	Sewer Relief Status	Private I/I Removal Rating
1	0.052	0.011	353	0.200	0.020	0.010	0.030	0.001	0.750	0.500	0.800	
2	0.373	0.049	21		0.160		0.020		0.200	0.500		0.100
3	0.214	0.000	569	0.020	0.020		0.030		0.330	0.290	0.620	0.690
4	0.020	0.003	246	0.400	0.080	0.004	0.040		0.900			
5			16		0.100		0.010		0.750	0.750		
6	0.507	0.000		0.034	0.100	0.034	0.046		0.200	0.200	0.050	
7	0.070	0.000	106	0.200	0.094		0.094		1.000	1.000	1.000	1.000
8				0.060	0.040	0.040	0.020		0.300	0.400	0.500	
9	0.552		50	0.010	0.008	0.010	0.096		0.250	0.500		
10			46									
11	0.185			0.400		0.006	0.012		0.100	0.020		0.010
12	0.022	0.009			0.100	0.006	0.014					
13	0.254		12	1.000	0.001	0.001	0.030		0.001	0.010		
14				0.500	1.000		0.074		0.560	0.560	0.670	
15	1.288	0.000	25		0.200	0.002	0.090		1.000	1.000	1.000	1.000
16	0.085			0.040	0.100	0.100	0.100		0.050	0.100		0.050
17	0.212	0.014	42	0.040	0.040	0.040	0.036	0.040	0.400	0.500	0.800	0.900
18					0.036	0.100	0.017		0.020	0.020	0.200	
19	0.036	0.005	22	0.050	0.064	0.052	0.050		0.400	0.300	0.600	
20			29	0.200	0.200	0.200	0.200	0.200	0.960	0.700	0.250	0.950
21	0.313	0.000		0.060	0.180		0.180		1.000	0.900		
22	0.155		88	0.200	0.500	0.100	0.016		0.999	1.000	1.000	1.000
23	0.272	0.000	99		0.400	0.002	0.130		0.010	0.010		
24	0.440	0.003	137	0.090	0.422	0.168	0.054	0.140	0.300	0.300	0.600	0.300
25									0.050	0.010		0.010
26	0.227	0.027	7	0.200	0.100		0.150			0.250	0.100	
27	0.106	0.054	301	0.150	0.100	0.030	0.016	0.006	0.200	0.200	0.100	0.050
28	0.625	0.001	68									
29	0.119			0.160	0.108		0.022					
30	0.440			0.010			0.012		0.050	0.050	0.100	
31	0.289	0.197			0.736	0.436	0.444		0.050	0.030	0.500	
32		0.000		0.040	0.400				0.900	0.950		
33												
34									0.400	0.440	0.350	0.170
35	0.270		10		0.200		0.014		0.250	0.250	0.500	
36	0.227	0.006	130	0.110	0.190	0.120	0.034	0.170	0.200	0.150		
37	0.352	0.005				0.007	0.014			0.310		
38	0.623	0.000	348	0.150	0.210	0.202	0.066	0.202	0.200	0.020	1.000	0.950
39	0.236			1.000	0.200		0.120			0.050		0.030
40	0.125			0.200	0.040	0.050	0.050		0.050	0.050		
41	0.556	0.280							0.990	0.999	1.000	1.000
42	0.322	0.008		0.004	0.200		0.010		0.950	0.600		
	29.9%	2.9%	123.781	0.205	0.192	0.075	0.067	0.108	0.434	0.387	0.559	0.513
	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg
	32	23	22	27	33	23	35	7	34	36	21	16
	count	count	count	count	count	count	count	count	count	count	count	count
	24.8%	6.7%	144.801	0.257	0.213	0.099	0.082	0.083	0.366	0.334	0.329	0.434
	sd	sd	sd	sd	sd	sd	sd	sd	sd	sd	sd	sd
	129%	28%	568.750	1.000	1.000	0.436	0.444	0.202	1.000	1.000	1.000	1.000
	max	max	max	max	max	max	max	max	max	max	max	max
	2%	0%	7.185	0.004	0.001	0.001	0.010	0.001	0.001	0.010	0.050	0.010
	min	min	min	min	min	min	min	min	min	min	min	min

Table 5-4

Maintenance Activity Statistics

Activity	Mean	Standard Deviation	Range	Number of Responses
1. Cleaning, % system/yr	29.9%	24.8%	2% - 129%	32
2. Root removal, % system/yr	2.9%	6.7%	0% - 28%	23
3. Pump station service, no/ps/yr	123.8	144.8	7.2-569	22
4. Flow monitoring, % system/yr	20.5%	25.7%	0.4% - 100%	27
5. Manhole inspection, %system/yr	19.2%	21.3%	0.1% - 100%	33
6. Smoke testing, %system/yr	7.5%	9.9%	0.1% - 43.6%	23
7. CCTV, % system/yr	6.7%	8.2%	1.0% - 44.4%	35
8. Private sector inspections, % system/yr	10.8%	8.3%	0.1% - 20.2%	7
9. Manhole rehabilitation, % complete	43.4%	36.6%	0.1% - 100%	34
10. Main line rehabilitation, % complete	38.7%	33.4%	0.1% - 100%	36
11. Relief construction, % complete	55.9%	32.9%	5% - 100%	21
12. Private sector I/I removal, % complete	51.3%	43.3%	0.1% - 100%	16

The relationship between maintenance activity rate and maintenance frequency was determined by setting a maintenance frequency of 10 percent equal to the mean value for each maintenance activity and assigning corresponding maintenance frequencies on either side of the mean based on the area under the normal curve. The selection of 10 percent maintenance frequency association with the mean maintenance rate assumes that on average, most systems will perform 100 percent of maintenance activities in a 10 year period. The maintenance frequencies assigned to each deviation from the mean are shown on Figure 5-1.

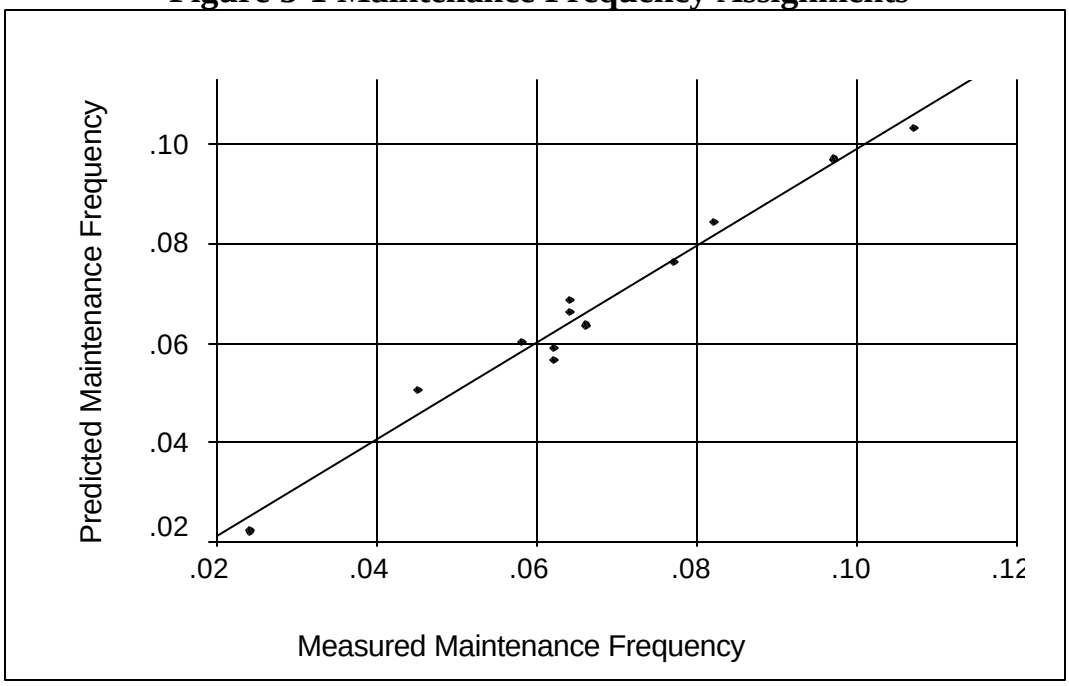
Table 6.5 Standardized Maintenance Frequency Table by Maintenance Rate

Activity	No. Reporting	Avg.	sd	-2sd -2	-1.5sd -1.5	-1.0sd -1	-0.75sd -0.75	-0.50sd -0.5	-0.25sd -0.25	x 0	+0.25sd 0.25	+0.50sd 0.5	+0.75sd 0.75	+1.00sd 1	+1.25sd 1.25	+1.50sd 1.5	+1.75sd 1.75	+2.0sd 2	+3.00sd 3
Cleaning	32	0.299	0.248	-0.20	-0.07	0.05	0.11	0.18	0.24	0.30	0.36	0.42	0.48	0.55	0.61	0.67	0.73	0.79	1.04
Root Removal	23	0.029	0.067	-0.11	-0.07	-0.04	-0.02	-0.00	0.01	0.03	0.05	0.06	0.08	0.10	0.11	0.13	0.15	0.16	0.23
LS Service	22	123.781	144.801	-165.82	-93.42	-21.02	15.18	51.38	87.58	123.78	159.98	196.18	232.38	268.58	304.78	340.98	377.18	413.38	558.18
Flow Monitoring	27	0.205	0.257	-0.31	-0.18	-0.05	0.01	0.08	0.14	0.20	0.27	0.33	0.40	0.46	0.53	0.59	0.65	0.72	0.98
Manhole Inspection	33	0.192	0.213	-0.23	-0.13	-0.02	0.03	0.09	0.14	0.19	0.25	0.30	0.35	0.41	0.46	0.51	0.57	0.62	0.83
Smoke/Dye Test	23	0.075	0.099	-0.12	-0.07	-0.02	0.00	0.03	0.05	0.07	0.10	0.12	0.15	0.17	0.20	0.22	0.25	0.27	0.37
CCTV	35	0.067	0.082	-0.10	-0.06	-0.01	0.01	0.03	0.05	0.07	0.09	0.11	0.13	0.15	0.17	0.19	0.21	0.23	0.31
Private Sector Inspections	7	0.108	0.083	-0.06	-0.02	0.03	0.05	0.07	0.09	0.11	0.13	0.15	0.17	0.19	0.21	0.23	0.25	0.28	0.36
Manhole Rehabilitation	34	0.434	0.366	-0.30	-0.12	0.07	0.16	0.25	0.34	0.43	0.53	0.62	0.71	0.80	0.89	0.98	1.08	1.17	1.53
Main Line Rehabilitation	36	0.387	0.334	-0.28	-0.11	0.05	0.14	0.22	0.30	0.39	0.47	0.55	0.64	0.72	0.80	0.89	0.97	1.05	1.39
Sewer Relief	21	0.559	0.329	-0.10	0.07	0.23	0.31	0.39	0.48	0.56	0.64	0.72	0.81	0.89	0.97	1.05	1.14	1.22	1.55
Private I/I Removal	16	0.513	0.434	-0.35	-0.14	0.08	0.19	0.30	0.40	0.51	0.62	0.73	0.84	0.95	1.06	1.16	1.27	1.38	1.82
Standardized Maintenance Frequency:				0%	1%	3%	5%	6%	8%	10%	12%	14%	15%	17%	18%	19%	19%	20%	20%
Areas Under Normal Curve (=1.00):				0.0228	0.0668	0.1587	0.2266	0.3085	0.4013	0.5	0.5987	0.6915	0.7734	0.8413	0.8944	0.9332	0.9599	0.9772	0.9987

sd = standard deviation

x = mean

Figure 5-1 Maintenance Frequency Assignments



5.4 Determination of Maintenance Frequency

An overall maintenance frequency for each agency was determined by applying the actual maintenance rates reported from Table 5-3, the relative weight for each maintenance activity from Table 5-1, and the corresponding standard activity maintenance frequency using Table 5-5. Average maintenance activity rates were used for missing data to estimate the maintenance frequency for each agency. The range and mean of the maintenance frequencies derived is presented in Table 5-6 and shown on the distribution curve on
Figure 5-2. The system maintenance frequency determined for each agency is presented in Table 5-7.

Table 5-6 Calculated Maintenance Frequencies

Utility No. 5	Cleaning Rating	Root Cutting Rating	Lift Station Rating	Flow Monitoring Rating	Manhole Inspect Rating	Smoke/dye Rating	CCTV Rating	Private Sector Inspection Rating	Manhole Rehab Rating	Main Line Rehab Rating	Sewer Relief Rating	Private I/I Removal Rating	Total Maintenance Frequency Rating
	17.7%	8.4%	14.1%	7.0%	6.4%	3.3%	10.5%	2.0%	5.6%	12.6%	6.3%	6.1%	100.0%
1	0.6%	0.5%	2.6%	0.6%	0.2%	0.1%	0.6%	0.0%	0.9%	1.5%	0.9%	0.1%	8.6%
2	2.1%	1.0%	0.6%	0.2%	0.5%	0.1%	0.5%	0.0%	0.3%	1.5%	0.0%	0.2%	7.1%
3	1.1%	0.5%	2.8%	0.3%	0.2%	0.1%	0.6%	0.0%	0.3%	0.8%	0.6%	0.7%	8.2%
4	0.2%	0.5%	2.2%	1.1%	0.3%	0.1%	0.6%	0.0%	1.0%	0.2%	0.0%	0.1%	6.4%
5	0.2%	0.5%	0.6%	0.2%	0.4%	0.1%	0.5%	0.0%	0.9%	2.1%	0.0%	0.1%	5.7%
6	2.7%	0.5%	0.4%	0.3%	0.4%	0.2%	0.6%	0.0%	0.3%	0.6%	0.0%	0.1%	6.2%
7	0.6%	0.5%	1.1%	0.6%	0.4%	0.1%	1.3%	0.0%	1.0%	2.4%	1.1%	1.0%	10.2%
8	0.2%	0.5%	0.4%	0.3%	0.3%	0.2%	0.5%	0.0%	0.3%	1.3%	0.5%	0.1%	4.7%
9	3.0%	0.5%	0.6%	0.2%	0.2%	0.1%	1.3%	0.0%	0.3%	1.5%	0.0%	0.1%	7.9%
10	0.2%	0.5%	0.6%	0.2%	0.2%	0.1%	0.3%	0.0%	0.1%	0.2%	0.0%	0.1%	2.6%
11	1.1%	0.5%	0.4%	1.1%	0.2%	0.1%	0.5%	0.0%	0.2%	0.2%	0.0%	0.1%	4.5%
12	0.2%	0.5%	0.4%	0.2%	0.4%	0.1%	0.5%	0.0%	0.1%	0.2%	0.0%	0.1%	2.8%
13	1.4%	0.5%	0.4%	1.4%	0.2%	0.1%	0.6%	0.0%	0.1%	0.2%	0.0%	0.1%	5.2%
14	0.2%	0.5%	0.4%	1.2%	1.3%	0.1%	1.1%	0.0%	0.7%	1.7%	0.8%	0.1%	8.1%
15	3.5%	0.5%	0.6%	0.2%	0.6%	0.1%	1.3%	0.0%	1.0%	2.4%	1.1%	1.0%	12.6%
16	0.6%	0.5%	0.4%	0.3%	0.4%	0.4%	1.3%	0.0%	0.1%	0.4%	0.0%	0.1%	4.5%
17	1.1%	0.7%	0.6%	0.3%	0.3%	0.2%	0.6%	0.1%	0.4%	1.5%	0.9%	0.9%	7.7%
18	0.2%	0.5%	0.4%	0.2%	0.3%	0.4%	0.5%	0.0%	0.1%	0.2%	0.1%	0.1%	3.0%
19	0.2%	0.5%	0.6%	0.3%	0.3%	0.3%	0.8%	0.0%	0.4%	0.8%	0.6%	0.1%	5.1%
20	0.2%	0.5%	0.6%	0.6%	0.6%	0.6%	2.0%	0.3%	1.0%	1.9%	0.2%	1.0%	9.7%
21	1.8%	0.5%	0.4%	0.3%	0.5%	0.1%	1.9%	0.0%	1.0%	2.4%	0.0%	0.1%	9.1%
22	0.8%	0.5%	1.1%	0.6%	1.1%	0.4%	0.5%	0.0%	1.0%	2.4%	1.1%	1.0%	10.7%
23	1.4%	0.5%	1.1%	0.2%	1.0%	0.1%	1.6%	0.0%	0.1%	0.2%	0.0%	0.1%	6.4%
24	2.4%	0.5%	1.4%	0.4%	1.1%	0.5%	0.8%	0.2%	0.3%	0.8%	0.6%	0.4%	9.6%
25	0.2%	0.5%	0.4%	0.2%	0.2%	0.1%	0.3%	0.0%	0.1%	0.2%	0.0%	0.1%	2.4%
26	1.1%	0.7%	0.4%	0.6%	0.4%	0.1%	1.8%	0.0%	0.1%	0.8%	0.1%	0.1%	6.1%
27	0.6%	1.0%	2.4%	0.6%	0.4%	0.2%	0.5%	0.0%	0.3%	0.6%	0.1%	0.1%	6.6%
28	3.2%	0.5%	0.9%	0.2%	0.2%	0.1%	0.3%	0.0%	0.1%	0.2%	0.0%	0.1%	5.8%
29	0.8%	0.5%	0.4%	0.6%	0.4%	0.1%	0.5%	0.0%	0.1%	0.2%	0.0%	0.1%	3.7%
30	2.4%	0.5%	0.4%	0.2%	0.2%	0.1%	0.5%	0.0%	0.1%	0.2%	0.1%	0.1%	4.9%
31	1.4%	1.6%	0.4%	0.2%	1.3%	0.7%	2.1%	0.0%	0.1%	0.2%	0.5%	0.1%	8.6%
32	0.2%	0.5%	0.4%	0.3%	1.0%	0.1%	0.3%	0.0%	1.0%	2.4%	0.0%	0.1%	6.4%
33	0.2%	0.5%	0.4%	0.2%	0.2%	0.1%	0.3%	0.0%	0.1%	0.2%	0.0%	0.1%	2.4%
34	0.2%	0.5%	0.4%	0.2%	0.2%	0.1%	0.3%	0.0%	0.4%	1.3%	0.3%	0.2%	4.3%
35	1.4%	0.5%	0.4%	0.2%	0.6%	0.1%	0.5%	0.0%	0.3%	0.8%	0.5%	0.1%	5.5%
36	1.1%	0.5%	1.4%	0.4%	0.5%	0.4%	0.6%	0.3%	0.3%	0.6%	0.0%	0.1%	6.2%
37	1.8%	0.5%	0.4%	0.2%	0.2%	0.1%	0.5%	0.0%	0.1%	1.0%	0.0%	0.1%	5.0%
38	3.2%	0.5%	2.6%	0.6%	0.6%	0.6%	0.8%	0.3%	0.3%	0.2%	1.1%	1.0%	11.9%
39	1.1%	0.5%	0.4%	1.4%	0.6%	0.1%	1.5%	0.0%	0.1%	0.2%	0.0%	0.1%	6.0%
40	0.8%	0.5%	0.4%	0.6%	0.3%	0.3%	0.8%	0.0%	0.1%	0.2%	0.0%	0.1%	4.1%
41	3.0%	1.7%	0.4%	0.2%	0.2%	0.1%	0.3%	0.0%	1.0%	2.4%	1.1%	1.0%	11.6%
42	1.8%	0.5%	0.4%	0.2%	0.6%	0.1%	0.5%	0.0%	1.0%	1.7%	0.0%	0.1%	7.1%
	1.2% avg	0.6% avg	0.8% avg	0.4% avg	0.5% avg	0.2% avg	0.8% avg	0.1% avg	0.4% avg	1.0% avg	0.3% avg	0.3% avg	6.6% avg
	42 count	42 count	42 count	42 count	42 count	42 count	42 count	42 count	42 count	42 count	42 count	42 count	42 count
	1.0% sd	0.3% sd	0.7% sd	0.3% sd	0.3% sd	0.2% sd	0.5% sd	0.1% sd	0.4% sd	0.8% sd	0.4% sd	0.4% sd	2.6% Sd
													2.4% min
													12.6% max

Figure 5-2 Collection System Maintenance Frequency Distribution

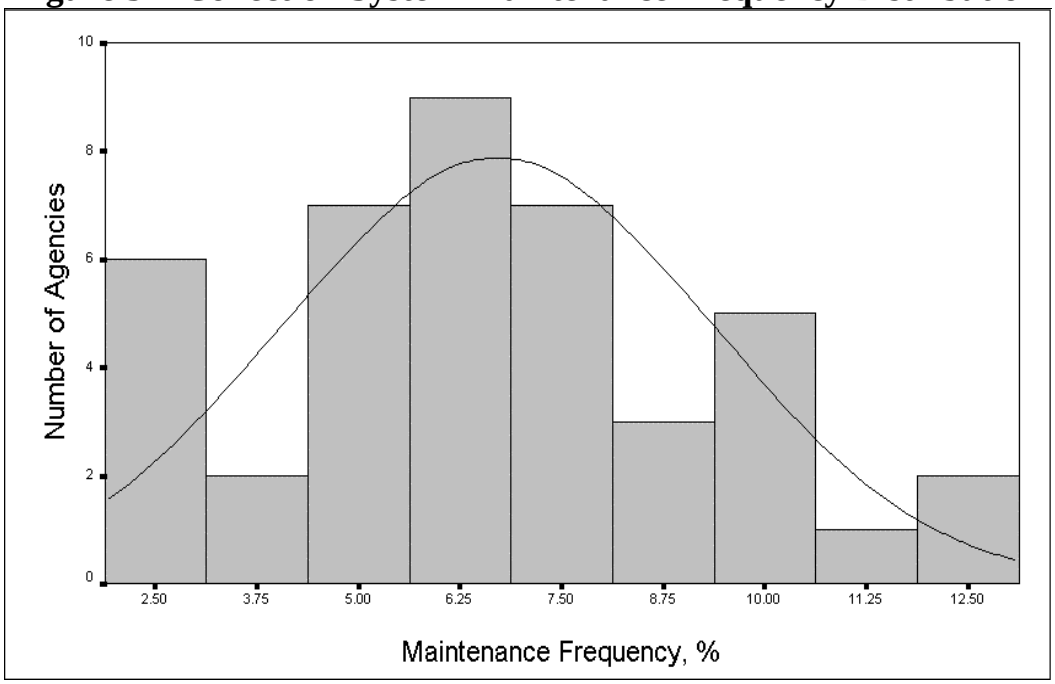


Table 5-7
Range and Mean of System Maintenance Frequencies

Estimate	Value
Mean	.6%
Minimum	2.4%
Maximum	12.6%

5.5 Performance Indicators

The objective of system maintenance is to provide a properly operating collection system. The effectiveness of maintenance can be evaluated by improvement in system performance. Performance measures considered in this study include customer complaints, manhole overflows, pipe failures, pump station failures, and the ratio of peak hourly flow to average daily flow (ADF), and peak monthly flow to ADF. The relationship between system maintenance frequency and performance is explored in the next section.

5.6 Regression Analysis for Maintenance Frequency

Multiple linear regression analysis involves determining and measuring the relationship between three or more variables. In this respect, regression deals with determining a quantitative expression to describe the relationship, while correlation deals with the measurement of the extent

of the relationship. Linear regression is a procedure of estimating a linear relationship between a dependent variable, and one or more independent variables. The general form of a multiple regression equation is:

$$Y = B1 + B2X1 + ...BnXn\text{-}1 + e$$

Where:

Y = dependent variable

Xi = ith independent variable for I=1...n

Bi = ith coefficient for Xi

e = random error

The variable Ae@ is a random error parameter and is assumed to have a normal distribution with a mean of zero and a constant variance for all values of independent variables. The multiple regression used in the model building process uses the least square method to estimate the coefficients. All regression analyses were performed using the SPSS statistical software package for Windows Release 6.0 .

Regression analyses were performed using the derived maintenance frequency as the dependent variable and various sets of independent variables. The purpose of this analysis was to explore the relationship, if any, between calculated maintenance frequency and key independent variables, including performance measures, the number of pump stations, the size of the agency, and the regional location of the agency, which may tend to result in the need for maintenance. The independent variables considered for analysis, were selected from the list of data requested from the agencies and are summarized in Table 5-8.

Table 5-8

Potential Independent Variables Related to Maintenance Frequency

Variable	Unit	Code
Customer Complaints - last 5 years	Complaints/mile$year	CUSTC_5
Manhole and Treatment Overflows last 5 years	Overflows/mile$year	MHOF_5
Pipe Failures - last 5 years	Failures/mile$year	PIPEF_5
Pump Station Failures - last 5 years	Failures/pump station$year	PSF_5
Pump Station Number	Number of pump stations	PS_NO
Size of Agency	Based on size designation - small, medium, large	SIZE_CD
Location of Agency	Based on regional codes established for this project	REG_CD
Ratio of Peak Hourly Flow to Annual Average Flow	Ratio	PH_ADF
Ratio of Peak Monthly Flow to Annual Average Flow	Ratio	PM_ADF

Note: The code is used in the SPSS statistical software package and is listed here for reference.

A number of regression analyses were performed to evaluate possible relationships. Out of the many analyses performed, nine are documented in this report. The coefficients of determination (R^2) for the nine documented analyses are presented in Table 5-9. The analyses show that the best R^2 is obtained when all nine independent variables are considered. The R^2 values show that the estimate of the maintenance frequency is highly dependent on customer complaints, manhole overflows, size characteristics, regional characteristics, peak hour/ADF ratio, and pump station failure rates. The Size Code is 1 = small, 2 = medium, 3 = large, and the Regional Code is 1 = central, 2 = northeast, 3 = northwest, 4 = southeast, and 5 = southwest. The regression equation coefficients for the four best relationships (R^2 greater than 0.80) are presented in Table 5-10. These regression coefficients were used to estimate the maintenance frequency from those agencies that provided complete information. Only 12 agencies provided all the data necessary for the regression analysis. The results presented on Figure 5-3 show good agreement between the calculated (from Table 5-7) and the predicted maintenance frequency using Equation MF1 in Table 5-10. The results on Figure 5-3 indicate that system performance measures and system maintenance frequencies may be related.

Table 5-9

Regression Analysis for Maintenance Frequency

No. Var	Independent Variables: Customer Complaints	Manhole Overflows	Pipe Failures	Size Code	Region Code	Peak Hour/ADF	Peak Month/ADF	Pump Station Failure	Pump Station Quantity	Coefficient of Determination: R^2	Adjusted $R^{2\,(1)}$	Selected Regression Analyses R^2>0.80	Equation Name
9	X	X	X	X	X	X	X	X	X	0.975	0.863	X	MF1
8	X	X	X	X	X	X		X	X	0.896	0.619	X	MF2
7	X	X	X	X	X	X		X		0.827	0.523	X	MF3
7	X	X	X	X	X	X			X	0.495	0.053		
6	X	X	X	X	X			X		0.593	0.276		
6	X	X	X	X		X		X		0.609	0.140		
6		X	X	X	X	X		X		0.318	-0.054		
6	X		X	X	X	X		X		0.639	0.422		
6	X	X		X	X	X		X		0.826	0.618	X	MF5

(1) The adjusted R^2 statistic attempts to model R^2 to more closely reflect the goodness of fit of the model in the population. (pg. 318 SPSS Manual)

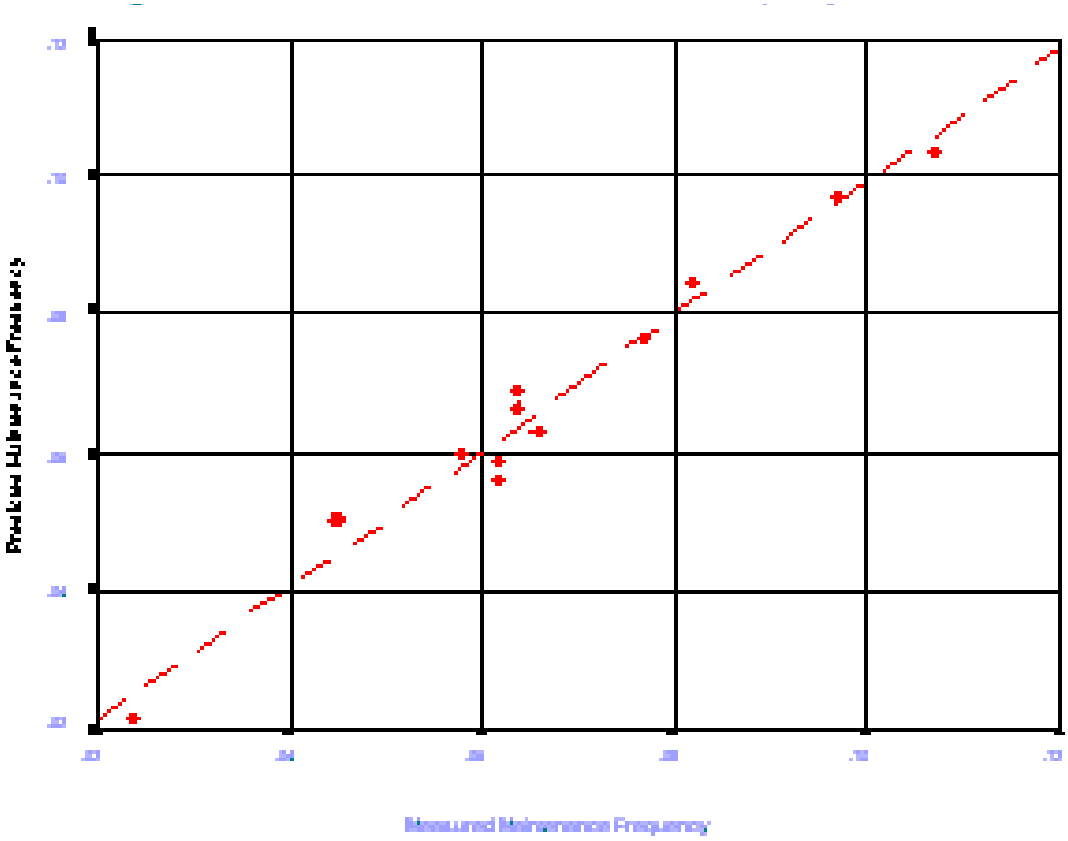
$$R^2 = R^2 - \frac{P(1-R^2)}{N-P-1}$$

Table 5-10

Regression Coefficients for Maintenance Frequencies

Item	Linear Regression Equation Coefficients			
	Equation MF1	Equation MF2	Equation MF3	Equation MF4
Constant	-0.107	-0.123	0.0796	0.0804
Customer Complaints	-0.0484	-.00041	-0.00156	0.00152
Manhole Overflows	-0.340	-0.139	-0.190	-0.189
Pipe Failures	-0.422	-0.0760	-0.00359	----
Size Code	-0.00978	-0.0103	-0.00658	-0.0065
Region Code	-0.0129	0.0031	0.00849	0.00841
Peak Hour/ADF	-0.0920	-0.0093	-0.000785	-0.001
Peak Month/ADF	0.430	----	----	---
Pump Station Failure	0.344	-0.839	-0.826	-0.828
Pump Station Number	0.00004	0.000038	----	----

Figure 5-3 Calculated vs. Predicted Maintenance Frequency



5.7 Conclusions

The maintenance frequency for a system can be expressed as a single measurement using a standard rating frequency and weighting factor for each activity. The maintenance frequency appears to be related to a number of independent variables, including customer complaints, manhole overflows, pipe failures, system size, number of pump stations, system size, regional locations, peak hour/ADF ratio, peak month/ADF ratio, and pump station failures. These independent variables can be used to derive a suggested system maintenance frequency using one of the equations in Table 5-10.

6.0 Determination of System Performance Rating

6.1 Introduction

System performance measurements should indicate how well or how poorly a collection system is providing the intended service. The measurement of system performance is crucial to the optimization of maintenance, for without a proper Ayardstick@, it is not possible to tell how effective the maintenance program is. All performance measures are not necessarily equal in importance. Therefore, when evaluating an agency=s performance, the most important question is how the system as a whole is performing based on a number of significant factors. It does little good for an agency to have zero pipe failures and yet have a large number of complaints about sewage backing up into homes. Just as with maintenance activities, an effective performance evaluation requires consideration of a number of factors. This chapter presents the evaluation of performance, the determination of a performance rating for the agencies surveyed, and the procedures to follow in determining the performance rating.

6.2 Performance Data Weighting

In order to develop an overall performance rating, each agency was requested to provide its opinion of the relative importance of six commonly used collection system performance measures as described below:

Pipe Failure - a pipe which has lost its structural integrity as evidenced by total or partial collapse (loss of 50% of pipe area or 25% of pipe wall around any circumference. Measured by failures per mile per year.

Sanitary Sewer Overflow (SSO) - a discharge of wastewater from the collection system with the potential to enter surface water courses occurring either in the collection system or in the headworks of the wastewater treatment plant.

Complaints - a customer complaint related to the performance of the collection system, including issues such as overflows, odors, and loose manhole covers.

Pump Station Failure - a condition that results in station overflows or an unacceptable surcharge of the system.

Peak Hour/ADF Ratio - The ratio of peak hour flow at a selected design condition to the average annual daily flow. This calculation may require extrapolation of monitored storm events.

Peak Month/ADF Ratio - The ratio of the peak monthly flow at the WWTP to the average annual daily flow.

The performance measures described above and the average weight assigned by the surveyed agencies are presented in Table 6-1. Average percentages were adjusted proportionately so the total of all maintenance items was equal to 100 percent.

Table 6-1
Performance Measure Weight

Measure	Relative Importance (Weight)
1. Pipe failure	22.6%
2. Sanitary sewer overflow (SSOs) (Manhole and Treatment Overflows)	23.6%
3. Complaints (basement backups and customer complaints)	20.8%
4. Pump station failure	17.8%
5. Peak Hour/ADF ratio	9.7%
6. Peak Month/ADF ratio	5.5%
Total	100.0%

The most important performance measures, according to the agencies surveyed, is pipe failure, SSOs, customer complaints, and pump station failures, which account for approximately 88 percent of the performance importance. The average performance weights of all agencies are used for the analysis presented herein.

6.3 Development of Performance Rating

Overall performance ratings for each agency were developed using an approach similar to that used to standardize maintenance frequencies. Standard performance ratings were developed based on normal distribution of performance measures, assigned performance rating, and the importance of the performance measure.

6.3.1 Determining Performance Rating

All performance measures were converted into unit rates, such as pipe failures per mile per year. Performance measures over the past 5 years were used as the basis for the analysis, since this data period provided more complete information than longer periods. Performance data for each agency is presented in Table 6-2. Blank cells indicate that the data was not provided by the agency. Performance rates for each agency were determined using the performance data and appropriate measures, such as miles of sewer. To determine performance, adjustments to miles of sewer were made based on the age information provided by each agency to more accurately estimate the true rate of each performance data. The performance rates for each agency are presented in Table 6-3.

6.3.2 Developing the Standard Rating

The mean, standard deviation, range, and number of responses for each performance measure are listed in Table 6-4. The rate of each performance measure was then normalized using the normal distribution to develop a standard by which any performance rate, or group of performance rates from various performance measures could be compared. Once the performance data was normalized, a standard performance rating was assigned to selected deviations from the mean. The assignment of the standard performance rating was somewhat arbitrary; however, based on the initial hypothesis, an average rating of 65 to 75% for the age of the systems investigated was assumed to be reasonable. Through trial and error, an average performance rating of 71.1% was determined, as discussed in more detail in Section 6.4. The standardized performance ratings assigned to each deviation from the mean for each performance measured data are given in Table 6-5. The weights used for analysis are also given in Table 6-5. It should be noted that the performance weight suggested by agencies for complaints was split 50/50 between basement backups and customer complaints.

Table 6-2 Utility Performance Data

Utility No.	Pipe Failures Last 5 Yrs.	SSOs Last 5 Yr. (1)	Complaints Last 5 years (2)	Pump Station Failures Last 5 Yrs.	Peak Hr/ADF	Peak Mo/ADF
1	270	1,102	2,860	123	2.08	1.13
2					2.05	1.25
3	20	2	1,675	3	1.83	1.10
4	15	20	60	1	2.81	1.11
5					2.26	1.58
6					3.36	1.29
7	0	13	22	4	3.36	1.24
8					2.55	1.77
9	1	5	110	0	2.31	1.08
10					2.70	1.83
11	986				1.80	1.16
12	562	345	21,705	623	2.21	1.19
13	2	924	30,284	0		1.24
14	11	27	105	1	1.81	1.02
15	1,000		4,150			1.32
16	846	651	34,901	36		1.00
17	27	72	44,955	28	2.15	1.25
18	500	250		3	3.21	2.14
19	500		100	25	2.29	1.32
20	1,200	251	23,000	70	1.95	1.33
21	7	5	1	0	1.69	1.11
22	1	184	2,999	5	1.39	1.05
23					1.32	1.03
24	761	1,486	13,656	20		1.28
25					2.80	1.03
26	5	20	1,500	2		1.22
27	2,200	560	7,970	35	1.28	1.12
28	5	640	3,375	100	1.83	1.10
29						1.15
30	12		2,215	30	2.05	1.03
31						1.12
32	2	25	20	5	4.16	1.41
33					2.95	1.38
34					2.75	
35	1	9	4	0	2.27	
36	5	9	6,510	5	3.44	1.35
37	355	275	161	1	1.27	1.03
38	2	13	1		1.97	1.07
39						
40	5	100	120	5	4.26	2.43
41						1.02
42	3	76	3,805	60	3.00	2.50
	9,304 sum	7,064 sum	206,264 sum	1,185 sum	2.40 avg.	1.30 avg.
	29 Count	26 Count	28 Count	26 Count	33 Count	39 Count

(1) Includes manhole and treatment headworks SSOs.
(2) Includes Complaints, basement backups, and "other" category on questionnaire.
Note: Blank cells indicate that data is unreported or required data to convert values to rates was unreported.

Table 6-3 Performance Rates

Utility No.	Pipe Failure Rate Last 5 yrs, no/yr/mi	SSO Rate Last 5 Yrs., no/mi/yr (1)	Complaints Last 5 Yrs., no/mi/yr (2)	Pump St. Failures Last 5 Yrs., no/mi/yr	Peak Hr/ADF	Peak Mo/ ADF
1	0.012	0.047	0.114	0.005	2.08	1.13
2					2.05	1.25
3	0.021	0.002	0.294	0.003	1.83	1.10
4	0.006	0.008	0.005	0.000	2.81	1.11
5			0.179		2.26	1.58
6			1.001		3.36	1.29
7	0.000	0.022	1.027	0.007	3.36	1.24
8			0.116		2.55	1.77
9	0.001	0.003	0.043	0.000	2.31	1.08
10			0.962		2.70	1.83
11	0.102		0.518		1.80	1.16
12	0.046	0.028	69.107	0.051	2.21	1.19
13	0.000	0.061	0.027	0.000		1.24
14	0.002	0.004	0.963	0.000	1.81	1.02
15	0.130		0.019			1.32
16	0.080	0.062	1.000	0.003		1.00
17	0.001	0.004	0.460	0.001	2.15	1.25
18	0.093	0.046		0.001	3.21	2.14
19	0.132			0.007	2.29	1.32
20	0.101	0.021	0.200	0.006	1.95	1.33
21	0.047	0.033	0.011	0.000	1.69	1.11
22	0.000	0.028	1.005	0.001	1.39	1.05
23					1.32	1.03
24	0.091	0.177	0.034	0.002		1.28
25			2.079		2.80	1.03
26	0.001	0.005	0.750	0.000		1.22
27	0.257	0.066	25.394	0.004	1.28	1.12
28	0.001	0.119	0.357	0.019	1.83	1.10
29						1.15
30	0.001		0.074	0.002	2.05	1.03
31						1.12
32	0.006	0.077	1.615	0.015	4.16	1.41
33			9.821		2.95	1.38
34					2.75	
35	0.000	0.004	0.202	0.000	2.27	
36	0.001	0.002	0.059	0.001	3.44	1.35
37	0.046	0.035	0.022	0.000	1.27	1.03
38	0.010	0.067	0.106		1.97	1.07
39			0.051			
40	0.009	0.174	17.182	0.009	4.26	2.43
41						1.02
42	0.001	0.030	1.552	0.023	3.00	2.50
	0.041	0.045	4.010	0.006	2.399	1.302
	avg	avg	avg	avg	avg	avg
	29	25	34	26	33	39
	count	count	count	count	count	count
	0.059	0.048	12.464	0.011	0.756	0.360
	sd	sd	sd	sd	sd	sd
	0	0.00197989	0.00542603	0	1.27081507	0.99890744
	min	min	min	min	min	min
	0.257	0.177	69.107	0.051	4.257	2.500
	max	max	max	max	max	max

(1) Includes manhole and treatment headworks SSOs.
(2) Includes complaints, basement backups and "other" category on questionnaire.
Note: Blank cells indicate that data was unreported or required data to convert values to rates was unreported.

Table 6-4
Performance Data Statistics
(Last 5 years)

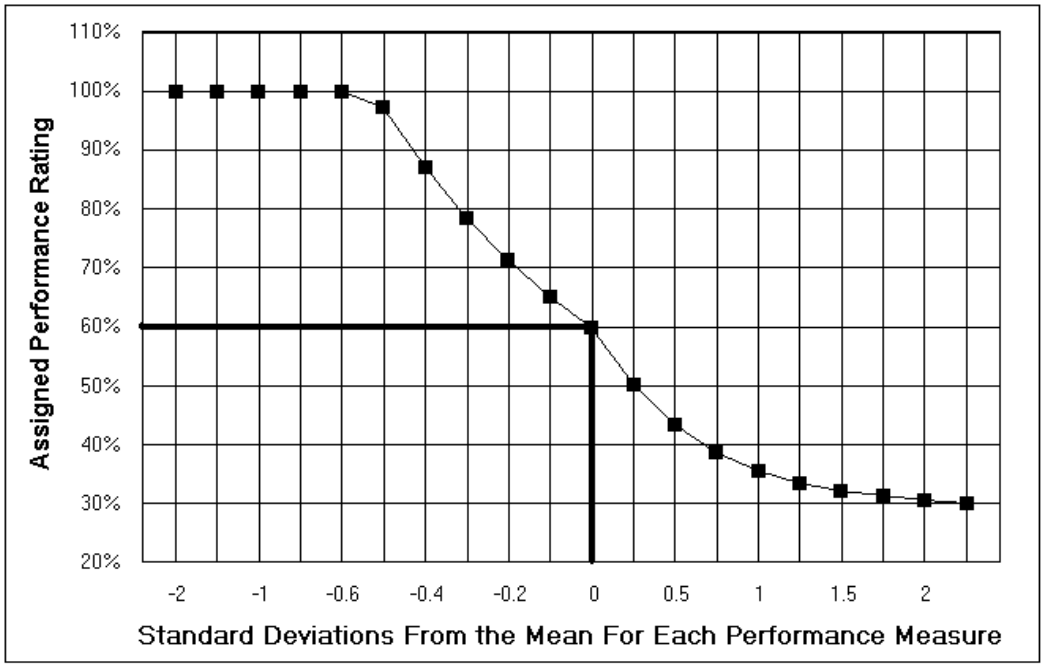
Performance Measure	Mean	Standard Deviation	Range	Number of Responses
1. Pipe failures, number/mi$yr	0.041	0.059	0.025	29
2. Sanitary Sewer Overflows (SSOs,) number/mi$yr	0.045	0.048	0.002-0.17	25
3. Complaints, number/mi$yr	4.010	12.464	0.005-69.1	34
4. Pump station failure, number/ps$yr	0.006	0.011	0-0.051	26
5. Peak hour flow/ADF Ratio	2.409	.756	1.27 - 4.26	33
6. Peak month flow/ ADF Ratio	1.30	0.360	1.0 - 2.50	39

The relationship between measured performance and assigned performance rating was determined by setting a performance rating of 50 percent equal to the mean value of each performance measure, and assigning corresponding performance ratings on either side of the mean based on the area under the normal curve. The selection of 50 percent association with the mean performance measure was by trial and error, so that the average performance rate of all agencies was between 65 and 75%. The performance rating assigned to each deviation from the performance mean is shown on Figure 6-1.

Table 6-5 Standardized Performance Rating Table by Performance Measure

Performance Measure	Weight	No.	Avg.	sd	-2sd	-1.5sd	-1sd	-0.75sd	-0.6sd	-0.5sd	-0.4sd	-0.3sd	-0.2sd	-.1sd	**x**	+.25sd	+0.50sd	+.75sd	+1sd	+1.25sd	+1.50sd	+1.75sd	+2sd	+3.0sd
					-2	-1.5	-1	-0.75	-0.6	-0.5	-0.4	-0.3	-0.2	-0.1	0	0.25	0.5	0.75	1	1.25	1.5	1.75	2	3
Pipe Failures	22.6%	29	0.0413	0.0593	-0.077	-0.048	-0.018	-0.003	0.006	0.012	0.018	0.024	0.029	0.035	0.041	0.056	0.071	0.086	0.101	0.115	0.130	0.145	0.160	0.219
SSO's	23.6%	25	0.0450	0.0480	-0.051	-0.027	-0.003	0.009	0.016	0.021	0.026	0.031	0.035	0.040	0.045	0.057	0.069	0.081	0.093	0.105	0.117	0.129	0.141	0.189
Customer Complaints	20.8%	34	4.0103	12.4642	-20.918	-14.686	-8.454	-5.338	-3.468	-2.222	-0.975	0.271	1.517	2.764	4.010	7.126	10.242	13.358	16.475	19.591	22.707	25.823	28.939	41.403
PS Failures	17.8%	26	0.0062	0.0107	-0.015	-0.010	-0.004	-0.002	-0.000	0.001	0.002	0.003	0.004	0.005	0.006	0.009	0.012	0.014	0.017	0.020	0.022	0.025	0.028	0.038
PH/ADF	9.7%	33	2.3992	0.3598	1.000	1.859	2.039	2.129	2.183	2.219	2.255	2.291	2.327	2.363	2.399	2.489	2.579	2.669	2.759	2.849	2.939	3.029	3.119	3.479
PM/ADF	5.5%	39	1.3023	0.3598	0.583	0.763	0.942	1.032	1.086	1.122	1.158	1.194	1.230	1.266	1.302	1.392	1.482	1.572	1.662	1.752	1.842	1.932	2.022	2.382
Standardized Performance Rating:					100%	100%	100%	100%	109%	97%	87%	79%	71%	65%	60%	50%	43%	39%	36%	34%	32%	31%	31%	30%
Areas Under the Normal curve (+1.00): X = mean					0.0228	0.0668	0.1587	0.2266	0.2743	0.3085	0.3446	0.3821	0.4207	0.4602	0.5	0.5987	0.6915	0.7734	0.8413	0.8944	0.9332	0.9599	0.9772	0.9987

Figure 6-1 Assignment of Performance Rating



6.4 Determination of Performance Rating

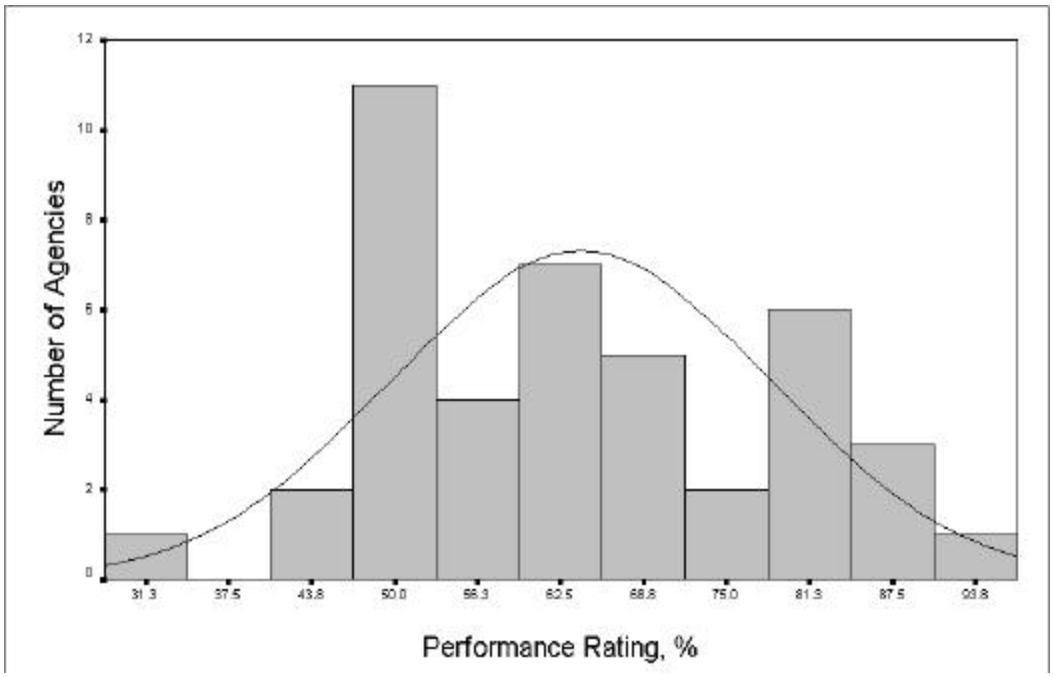
An overall performance rating for each agency, presented in Table 6-6, was determined by applying the actual performance measures reported, the relative weight for each performance measure, and the standard performance rating. A summary of the performance ratings derived is presented in Table 6-7 and shown on the distribution curve on Figure 6-2. For missing data points, where a performance measure was not provided, the average overall rating was used to calculate a performance rating.

Table 6-6 Calculated Performance Ratings

Utility No.	Pipe Failure Rating	SSO Rating	Complaint Rating	Pump St. Failure Rating	Peak Hr/ADF Rating	Peak Mo/ ADF Rating	System Performance Rating
(Weighting-->)	22.6%	23.6%	20.8%	17.8%	9.7%	5.5%	1.000
1	24.7%	14.2%	18.1%	11.6%	9.7%	5.4%	0.837
2	13.6%	14.2%	12.5%	10.7%	9.7%	3.9%	0.645
3	19.7%	23.6%	16.3%	13.9%	9.7%	6.1%	0.893
4	24.7%	23.6%	18.1%	10.7%	3.5%	6.1%	0.866
5	13.6%	14.2%	18.1%	10.7%	8.5%	2.1%	0.671
6	13.6%	14.2%	16.3%	10.7%	3.0%	3.6%	0.613
7	13.6%	22.9%	16.3%	10.7%	3.0%	3.9%	0.704
8	13.6%	14.2%	18.1%	10.7%	4.9%	1.9%	0.632
9	22.6%	23.6%	18.1%	10.7%	7.6%	5.5%	0.881
10	13.6%	14.2%	16.3%	10.7%	3.8%	1.9%	0.603
11	8.1%	14.2%	16.3%	10.7%	9.7%	4.8%	0.637
12	13.6%	20.5%	6.2%	5.3%	10.6%	4.3%	0.607
13	22.6%	11.8%	18.1%	10.7%	5.8%	3.9%	0.730
14	22.6%	23.6%	16.3%	19.4%	9.7%	5.5%	0.972
15	7.6%	14.2%	18.1%	10.7%	5.8%	3.3%	0.597
16	9.8%	11.8%	16.3%	13.9%	5.8%	5.5%	0.633
17	22.6%	23.6%	16.3%	17.3%	9.7%	3.9%	0.935
18	8.8%	14.2%	12.5%	19.4%	3.0%	1.7%	0.595
19	7.3%	14.2%	12.5%	10.7%	8.5%	3.3%	0.563
20	8.1%	22.9%	18.1%	11.6%	9.7%	3.3%	0.737
21	13.6%	18.5%	18.1%	10.7%	9.7%	6.1%	0.766
22	22.6%	20.5%	16.3%	19.4%	9.7%	5.5%	0.942
23	13.6%	14.2%	12.5%	10.7%	9.7%	5.5%	0.661
24	8.8%	7.2%	18.1%	15.5%	5.8%	3.6%	0.590
25	13.6%	14.2%	14.8%	10.7%	3.5%	5.5%	0.622
26	22.6%	23.6%	16.3%	19.4%	5.8%	4.3%	0.921
27	6.8%	11.8%	6.7%	12.7%	9.7%	5.4%	0.531
28	22.6%	7.6%	16.3%	6.3%	9.7%	6.1%	0.686
29	13.6%	14.2%	12.5%	10.7%	5.8%	5.4%	0.621
30	22.6%	14.2%	18.1%	15.5%	9.7%	5.5%	0.856
31	13.6%	14.2%	12.5%	10.7%	5.8%	6.1%	0.627
32	24.7%	10.2%	14.8%	6.9%	2.9%	2.8%	0.624
33	13.6%	14.2%	10.4%	10.7%	3.1%	3.3%	0.553
34	13.6%	14.2%	12.5%	10.7%	3.8%	3.3%	0.580
35	22.6%	23.6%	18.1%	10.7%	8.5%	3.3%	0.868
36	22.6%	23.6%	18.1%	17.3%	3.0%	3.3%	0.879
37	13.6%	18.5%	18.1%	19.4%	9.7%	5.5%	0.849
38	24.7%	11.8%	18.1%	10.7%	9.7%	5.5%	0.806
39	13.6%	14.2%	18.1%	10.7%	5.8%	3.3%	0.656
40	24.7%	7.2%	7.4%	10.7%	2.9%	1.7%	0.546
41	13.6%	14.2%	12.5%	10.7%	5.8%	5.5%	0.622
42	22.6%	20.5%	14.8%	5.7%	3.1%	1.7%	0.685
	0.164	0.162	0.153	0.121	0.068	0.042	71.1%
	avg	avg	avg	avg	avg	avg	avg
	42	42	42	42	42	42	42
	count	count	count	count	count	count	count
	0.059	0.049	0.033	0.036	0.028	0.014	0.128
	sd	sd	sd	sd	sd	sd	sd
	0.068	0.072	0.062	0.053	0.029	0.017	0.531
	min	min	min	min	min	min	min
	0.247	0.236	0.181	0.194	0.106	0.061	0.972
	max	max	max	max	max	max	max

Table 6-7 Summary of Performance Rating Derived	
Estimate	Value
Mean	0.640
Minimum	0.339
Maximum	0.910

Figure 6-2 Collection System Weighted Performance Rating



6.4.1 Annual Reinvestment

It was suspected that performance would be strongly linked to the annual system reinvestment in terms of dollars per mile per year ($/mi**$**yr). The annual investment for each agency was based on the reinvestment reported and the estimated miles of pipeline for the following time periods:

Before 1970
1970-1979
1980-1989
1990-1996

The reinvestment amount considers relief sewers, equalization, rehabilitation, operation and maintenance, equipment, and other reported costs. The reinvestment amount by agency over the life of the system is presented in Table 6-8. The average reinvestment for all years reported at $2,594 per mile per year in 1996 costs would be $5,252 per mile per year based on an average age of 37 years and adjusting costs using the Engineering News Record Construction Cost Index.

The reinvestment data shows that the reinvestment for 1980 to 1996 increased to $9,328 per mile per year.

6.4.2 Regression Analysis for Performance Rating

Multiple linear regression analyses were performed using the derived performance rating as the dependent variable and various sets of independent variables. The purpose of this analysis was to explore the relationship, if any, between performance and key independent variables which may influence system performance. The independent variables considered for analysis, their units, and a code for use in the statistical program, were selected from the list of data requested from the agencies, and are summarized in Table 6-9. Note that the overall maintenance frequency determined in Chapter 5 is a component of this relationship, and is a surrogate for all maintenance activities included in the determination of the overall maintenance frequency. It was hypothesized that the reinvestment amount in terms of $/mi**$**yr and the maintenance frequency influences system performance.

A number of regression analyses were performed to evaluate possible relationships. Of the many analyses performed, the five best relationships are reported here. The coefficient of determinations (R^2) for the five documented analyses are presented in Table 6-10. The analyses show that the best R^2 is obtained when all the independent variables are considered. The R^2 values indicate that the estimated performance rating is highly dependent on maintenance frequency and reinvestment. Only reinvestments during or after 1980 were considered. The regression equation coefficients for the one equation with an R^2 greater than 0.70 is presented in Table 6-11. These regression coefficients were used to estimate the performance rating from those agencies that provided the information required to use the equation. The results, showing the predicted performance rating and the calculated performance ratio using Equation PR1, are presented on Figure 6-3. This figure shows fairly good agreement between measured and predicted performance ratings.

Table 6-8 Agency Reinvestment Data

Utility No.	Total Spent $/mi•yr (All Years Reported)	Total Spent $/ft•yr (All Years Reported)	Total Spent $/mi•/yr (1980 –1996)	Total Spent $/ft•yr (1980 – 1996)
1	$1,484	$0.28	$2,753	$0.52
2				
3	$9,436	$1.79	$20,053	$3.80
4			$31,863	$6.03
5	$3,000	$0.57		
6	$1,145	$0.22		
7	$5,387	$1.02	$10,069	$1.91
8	$3,905	$0.74		
9	$675	$0.13	$1,430	$0.27
10	$484	$0.09		
11	$1,833	$0.35	$10,434	$1.98
12				
13	$3,066	$0.58		
14	$5,902	$1.12	$16,961	$3.21
15	$645	$0.12		
16				
17	$3,267	$0.62		
18	$1,926	$0.36	$3,832	$0.73
19	$1,734	$0.33	$3,776	$0.72
20	$3,657	$0.69		
21	$701	$0.13		
22	$7,381	$1.40	$5,585	$1.06
23				
24	$1,686	$0.32	$8,304	$1.57
25	$1,089	$0.21		
26	$513	$0.10	$1,969	$0.37
27	$258	$0.05		
28				
29				
30	$1,035	$0.20	$1,820	$0.34
31				
32	$8,180	$1.55	$21,641	$4.10
33	$406	$0.08		
34				
35	$579	$0.11		
36	$2,663	$0.50	$3,158	$0.60
37	$1,977	$0.37		
38				
39				
40	$1,828	$0.35		
41				
42	$1,988	$0.38	$5,596	$1.06
	$2,594 avg	$0.49 avg	$9,328 avg	$1.77 avg
	30 count	30 count	16 count	16 count
	$2,377 sd	$0.45 sd	$8,583 sd	$1.63 sd

Table 6-9
Potential Independent Variables Related to Performance Rating

Variable	Unit	Code
Size code	none	Size_cd
Region code	none	Region_cd
Peak month/ADF	ratio	PM_ADF
Peak hour/ADF	ratio	PH_ADF
Maintenance frequency	none	Maintfq
Reinvestment	$/mi**$**yr	$_mi_yr
Pump station density	ps/mi	Ps_mi

Table 6-10

Regression Analysis for Performance Ratios

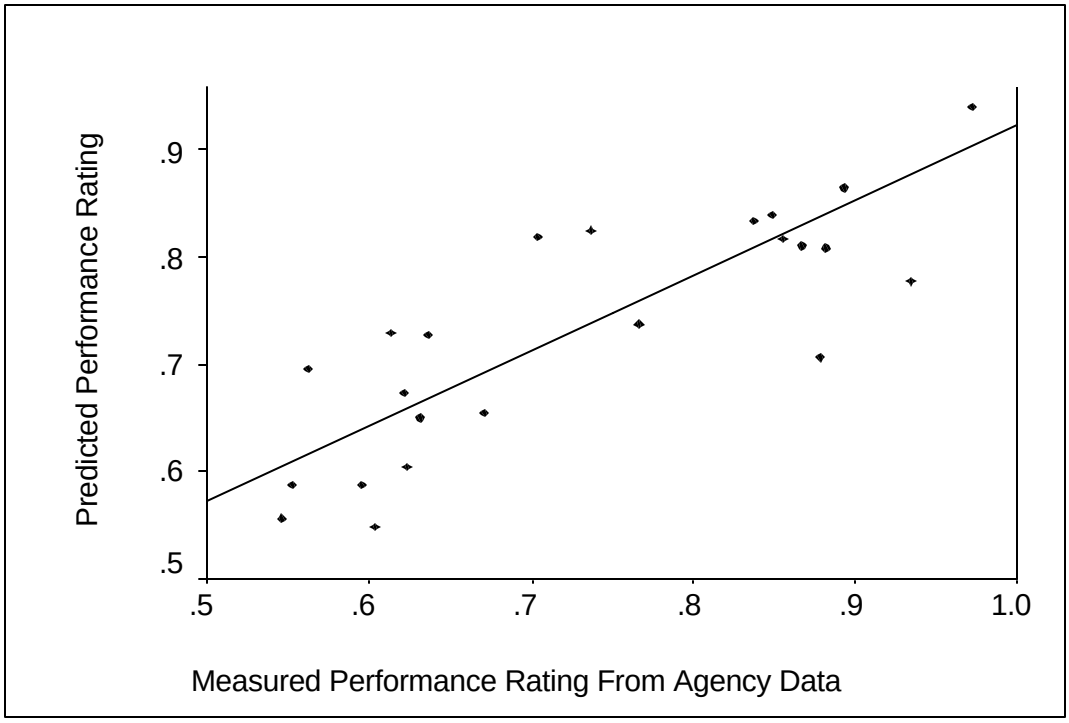
Independent Variables							Coefficient of Determination		Selected Regression Analysis	Equation Name
Reinvestment, $/mi$/yr	Regional Code	Size Code	Peak Month/ADF	Peak Hour/ADF	Pump Stations/Mi	Maintenance Frequency	R^2	Adjusted R^2	$R^2 > 0.70$	
	X	X				X	0.34380	0.11820		
	X	X			X	X	0.35678	0.12730		
	X	X		X	X	X	0.57434	0.32987		
	X	X	X	X	X	X	0.71141	0.50611		
X	X	X	X	X	X	X	0.84710	0.71757	X	PR1

Table 6-11

Regression Coefficients for Performance Rating

Item	Line Regression Equation Coefficients Eq PR1 B_i
Constant	0.751
$/mi$/yr	3.342×10^{-6}
Regional Code	2.179×10^{-2}
Size Code	-1.114×10^{-2}
Peak Month/ADF	-0.117
Peak Hour/ADF	-1.487×10^{-2}
Pump Stations/mi	-0.252
Maintenance Frequency	2.614

Figure 6-3 Predicted Versus Measured Performance Rating



6.5 Estimates of Reinvestment

Because the reinvestment amount is such an important independent factor related to system performance and because it is a very important consideration for agencies, regression analyses were performed to evaluate the system performance rating and reinvestment amount based on reinvestments since 1980. A summary of regression equations is presented in Table 6-12.

The analyses show that reinvestment is related to a number of independent variables but most strongly with regional location, pump stations per mile, maintenance frequency, percent of system greater than 20 years old, and performance rating. Equation RE1 has an R^2 value of 0.473. The relationship between predicted reinvestment, which included performance rating as an independent variable in Equation RE1 and calculated historical reinvestment performance rating is shown in Figure 6-4 which supports the hypothesis of improved performance with increased reinvestment.

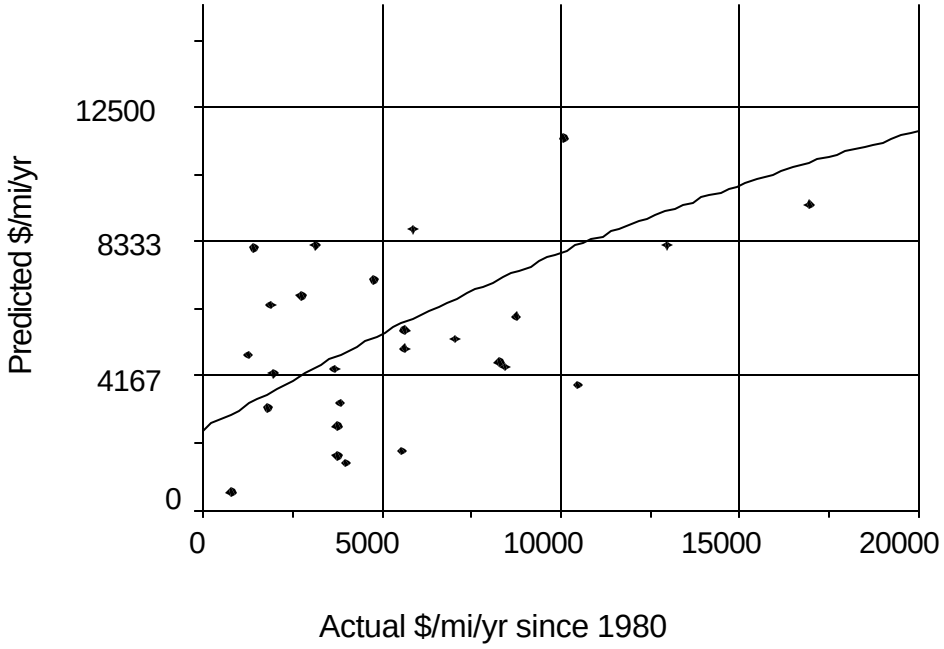
Table 6-12
Regression Analysis for Reinvestment
($/mi yr - Since 1980)

Independent Variables					Coefficient of Determination		Equation Name
Regional Code	Pump Stations/Mile	Maintenance Frequency	% System>20 Yrs Old	Performance Rating	R^2	Adjusted R^2	
X	X	X	X	X	0.473	0.363	RE1
X	X	X		X	0.375	0.275	RE2

Table 6-13
Regression Coefficients for Reinvestment

Item	Linear Regression Equation RE1	Equation Coefficients Equation RE2
Constant	-13,665.9	-3,256.9
Regional Code	-1,151.7	-1,393.2
Pump Station/Mile	24,994.3	18,958.1
Maintenance Frequency	22,968.5	27,770.9
% System > 20 Yrs Old	10,772.1	----
Performance Rating	18,368.9	14,445.8

Figure 6-4 Predicted Versus Actual $/mi$yr



6.6 Conclusion

System performance can be expressed as a single performance rating based on standard performance measures. The performance ratings are strongly related to maintenance frequencies and to reinvestment amounts. The average reinvestment of all agencies surveyed during 1980 to 1996 was $9,328 per mile per year ($1.77 feet per mile per year) which corresponds to an average performance rating of 71%. The average reinvestment of all agencies surveyed during the life of the system was about $5,252 per mile per year ($0.99 per foot per year) when costs are adjusted for inflation.

7.0 Optimizing Collection System Maintenance

7.1 Introduction

This chapter presents maintenance frequencies, performance ratings, and reinvestment rates for optimizing collection system maintenance activities. Optimization should provide a system which performs satisfactorily with a reasonable level of maintenance (reinvestment). It should be remembered that each collection system has its own unique characteristics and requirements and that the information presented in this study is intended to provide guidance for improving system performance through a more balanced maintenance program and appropriate levels of reinvestment. The guidelines presented herein relative to system performance, maintenance levels, and reinvestment will help agencies determine how much maintenance is enough. In order to optimize collection system maintenance, it is necessary to establish the existing system maintenance frequency, performance rating, and reinvestment rate as discussed in the following sections.

7.2 Collection System Maintenance Frequency

The following sections present the methods to determine the maintenance frequency of a given system.

7.2.1 Establish Existing Maintenance Frequency

All maintenance activities should be expressed as rates, such as percentage of system cleaned per year. The procedure presented in Chapter 5 can be used to develop the overall maintenance frequency. The maintenance activities listed in Table 7-1 should be considered when developing the system maintenance frequency.

Table 7-1 Activities for Determination of Maintenance Frequencies	
Maintenance Activity	Suggested Rate Expression
Cleaning of sewer lines	Percentage of system/yr
Root removal	Percentage of system/yr
Pump Station Inspections	number/pump station**$**yr
Flow monitoring	Percentage of system/yr
Manhole inspection	Percentage of system/yr
Smoke/dye testing	Percentage of system/yr
CCTV	Percentage of system/yr
Private sector Inspections	Percentage of system/yr
Manholes rehabilitated	Percentage of manholes requiring rehabilitation actually rehabilitated
Sewer line rehabilitated	Percentage of sewer lines requiring rehabilitation actually rehabilitated
Relief/equalization	Percentage of relief/equalization facilities needed actually constructed
Private sectors rehabilitated	Percentage of private sector needs actually addressed

The following steps describe the determination of system maintenance frequency:

(1) Determine Maintenance Activity Rate

For each maintenance activity, a rate is calculated. For most routine maintenance activities, such as line cleaning, the maintenance activity rate is expressed as the percentage of system cleaned per unit time (%/yr). For example, an agency which has 1,500 miles of sewer and has cleaned 825 miles of sewers over a 5-year period, has a cleaning maintenance rate of 11%/yr determined as follows:

825 miles / (5 years x 1500 miles) = 0.11 = 11% per year

(2) Assign Normalized Frequency to Each Maintenance Activity

Using the data presented in Chapter 5, a normalized frequency rate is assigned to each maintenance activity. This allows the overall maintenance frequency to be determined considering multiple maintenance activities. The normalized frequency for each maintenance activity and the activity rate from Chapter 5 are summarized in Table 7-2. For example, an agency which has a line cleaning frequency of 11%/yr (0.11) will have a normalized maintenance frequency of 5% for this activity.

Table 7-2

Normalized Maintenance Frequency for Given Maintenance Activity Rate

Normalized Frequency	0%	1%	3%	5%	6%	8%	10%	12%	14%	15%	17%	18%	19%	19%	20%	20%
Activity																
Cleaning	-0.20	-0.07	0.05	0.11	0.18	0.24	0.30	0.36	0.42	0.48	0.55	0.61	0.67	0.73	0.79	1.04
Root Removal	-0.11	-0.07	-0.04	-0.02	0.00	0.01	0.03	0.05	0.06	0.08	0.10	0.11	0.13	0.15	0.16	0.23
Pump Station Service	-165.82	-93.42	-21.02	15.18	51.38	87.58	123.78	159.98	196.18	232.38	268.58	304.78	340.98	377.18	413.38	558.18
Flow Monitoring	-0.31	-0.18	-0.05	0.01	0.08	0.14	0.20	0.27	0.33	0.40	0.46	0.53	0.59	0.65	0.72	0.98
Manhole Inspection	-0.23	-0.13	-0.02	0.03	0.09	0.14	0.19	0.25	0.30	0.35	0.41	0.46	0.51	0.57	0.62	0.84
Smoke/Dye Testing	-0.12	-0.07	-0.02	0.00	0.03	0.05	0.07	0.10	0.12	0.15	0.17	0.20	0.22	0.25	0.27	0.37
CCTV	-0.10	-0.06	-0.01	0.01	0.03	0.05	0.07	0.09	0.11	0.13	0.15	0.17	0.19	0.21	0.23	0.31
Private Sector Inspections	-0.06	-0.02	0.03	0.05	0.07	0.09	0.11	0.13	0.15	0.17	0.19	0.21	0.23	0.25	0.28	0.36
Manhole Rehabilitation	-0.30	-0.12	0.07	0.16	0.25	0.34	0.43	0.53	0.62	0.71	0.80	0.89	0.98	1.08	1.17	1.53
Main Line Rehabilitation	-0.28	-0.11	0.05	0.14	0.22	0.30	0.39	0.47	0.55	0.64	0.72	0.80	0.89	0.97	1.05	1.39
Sewer Relief	-0.10	0.07	0.23	0.31	0.39	0.48	0.56	0.64	0.72	0.81	0.89	0.97	1.05	1.14	1.22	1.55
Private I/I Removal	-0.35	-0.14	0.08	0.19	0.30	0.40	0.51	0.62	0.73	0.84	0.95	1.06	1.16	1.27	1.38	1.82

(3) Assign Activity Weighting Factor

The normalized maintenance frequency is then adjusted by the product of itself and the maintenance activity weighting factor presented in Chapter 5. The maintenance activity weighting factors are based on the results of the agency survey in this study and are presented in Table 7-3. The activity weighting factor is an indicator of the importance of the maintenance activity in maintaining collection system performance. For example, in the opinion of the agencies surveyed, sewer cleaning is the most important maintenance activity, representing 16.9% of the total value of all maintenance activities.

Table 7-3
Activity Weighting Factor

Maintenance Activity	Activity Weighting Factor (%)
Cleaning	17.7
Root Removal	8.4
Pump Station Service	14.1
Flow Monitoring	7.0
Manhole Inspection	6.4
Smoke Testing	3.3
CCTV	10.5
Private Sector Inspections	2.0
Manhole Rehabilitation	5.6
Mainline Rehabilitation	12.6
Relief Construction	6.3
Private Sector I/I Removal	6.1

(4) Determine Weighted Normalized Maintenance Activity Frequency

The product of the normalized maintenance activity frequency and the assigned maintenance weight calculates the weighted maintenance activity frequency rate. For example, the weighted normalized maintenance activity frequency for sewer cleaning for an agency with a normalized maintenance activity frequency of 5% for cleaning is:

$$0.05 \times 0.177 = 0.00885 = 0.885\%$$

(5) Determine System Maintenance Frequency

The system maintenance frequency rate is determined by adding the weighted normalized maintenance activity frequencies for all maintenance activities. The system maintenance frequencies for the agencies that responded to the questionnaire ranged from 2.7 to 12.8%, with an average of 8.7%. It is helpful to think of the maintenance frequency in terms of a 100 year period. A 10%

maintenance frequency would mean that, on average, maintenance activities would be performed 10 times in a 100 year period, or every 10 years. A maintenance frequency of 2% would mean that, on average, maintenance activities would be performed twice in a 100 year period, or every 50 years. The system maintenance frequency is an indication of the level of effective maintenance activity. For example, an agency with a system maintenance frequency of 2% could have an inadequate maintenance program, while an agency with a system maintenance frequency of 15% could have an excessive maintenance program. This indicator, however, does not provide any information on whether or not the maintenance program is effective. The effectiveness of the maintenance program may be measured by performance indicators which are discussed in the next section.

7.3 Performance Rating

The second step in optimizing system performance is to establish the existing system performance rating as discussed in the following sections.

7.3.1 Establish Performance Rating

All performance data should be converted to rates. For example, pipe failures can be expressed as pipe failures per mile per year. These performance rates can then be converted to a performance rating using the procedures presented in Chapter 6. The performance indicators listed in Table 7-4 should be considered.

Table 7-4
Performance Measure and Units

Performance Measure	Units
Complaints	complaints/mi**$**yr
Sanitary Sewer Overflows (SSOs)	overflows/mi**$**yr
Pipe Failures	pipe failures/mi**$**yr
Pump Station Failures	failures/ps**$**yr
Peak Hourly Flow/ADF	ratio
Peak Monthly Flow/ADF	ratio

The following steps should be taken to calculate the performance rating:

(1) Determine Performance Measure Rate

For each performance measure, a performance rate is calculated. The performance rate in most cases is defined as the number of occurrences divided by the number of years for which the performance indicator is reported and by the total miles of sewer in the system. For example, the pipe failure performance rate for an agency which has 1,500 miles of sewer and has experienced 370 pipe failures over a 5-year period can be calculated as follows:

370 pipe failures / (5 years x 1500 miles) = 0.049 failures/mi$year

The performance rate for pump station failures is calculated by dividing the number of pump station failures per year by the number of pump stations. The flow performance indicators, peak hour and peak month to average daily flow are expressed as a ratio.

(2) Assign Normalized Performance Rating to Each Performance Measure

Using the data presented in Chapter 6, a normalized performance rating is assigned to each performance measurement. The normalized performance rating for each performance measure is presented in Table 7-5. For example, an agency which has a performance measure of 0.049 failures/mi$yr for pipe failure, will have a normalized performance rating of 50% for this item.

(3) Assign Performance Weighting Factor

The normalized performance rating is then adjusted by multiplying it by the activity weighting factor presented in Chapter 6. The performance activity weighting factors for each performance measure are presented in Table 7-6. The performance weighing factor is a measure of the importance of the performance measure as perceived by the agencies that participated in this survey. For example, the largest weighting factor of 23.6% was assigned to SSOs.

Table 7-5

Normalized Performance Rates for Given Performance Measure Values

Measure/Performance Rates	30%	31%	32%	34%	36%	39%	50%	60%	65%	71%	79%	97%	100%	100%	100%	100%
Pipe Failures	0.219	0.160	0.130	0.115	0.101	0.086	0.056	0.041	0.035	0.029	0.024	0.012	0.006	-0.003	-0.018	-0.077
SSOs	0.189	0.141	0.117	0.105	0.093	0.081	0.057	0.045	0.040	0.035	0.031	0.021	0.016	0.009	-0.003	-0.051
Customer Complaints	41.403	28.939	22.707	19.591	16.475	13.358	7.126	4.010	2.764	1.517	0.271	-2.222	-3.468	-5.338	-8.454	-20.918
Pump Station Failures	0.038	0.028	0.022	0.020	0.017	0.014	0.009	0.006	0.005	0.004	0.003	0.001	0.000	-0.002	-0.004	-0.015
PH/ADF	3.749	3.119	2.939	2.849	2.759	2.669	2.489	2.399	2.363	2.327	2.291	2.219	2.183	2.129	2.039	1.000
PM/ADF	2.382	2.022	1.842	1.752	1.662	1.572	1.392	1.302	1.266	1.230	1.194	1.122	1.086	1.032	0.942	0.583

Table 7-6 Performance Weighting Factor	
Performance Measure	Weighting Factor (%)
Customer Complaints	22.6
Sanitary Sewer Overflows (SSOs)	23.6
Pipe Failures	20.8
Pump Station Failures	17.8
Peak Hourly/ADF Ratio	9.7
Peak Monthly/ADF Ratio	5.5

(4) Calculate Weighted Normalized Performance Rating

The weighted normalized performance rating is calculated by the product of the weighting factor and the normalized performance rate. For example, the weighted normalized performance rating of pipe failure for an agency with a normalized performance rating of 50% is:

$$0.50 \times 0.208 = 0.104 = 10.4\%$$

(5) Determine Overall System Performance Rating

The overall system performance rating is calculated by summing the weighted normalized performance ratings of the six performance measures. The weighted performance rating for the agencies that responded to the questionnaire varied from 33.9 to 91.0%, with an average of 64%. The performance rating is an indication of the level of system performance. For example, an agency with a performance rating of 30% probably is not providing effective service to its customers while an agency with a performance rating of 80% is likely providing safe and effective service.

7.4 Determine Historical Reinvestment Rate

The historical reinvestment rate should be determined based on the information in Table 7-7. If cost data for the life of the system is not available, then the longest period for which data is available should be used. Only costs related to the collection system should be included. The costs of facilities such as wastewater treatment plants should not be included. The reinvestment rate will provide a basis for comparison with other agencies regarding the adequacy of the budget for system maintenance, and can also be compared with predicted reinvestment amounts which may be estimated from system operating characteristics as discussed in this section.

Table 7-7 Determination of Reinvestment	
Reinvestment Item	Unit
Relief construction	$/mi$/yr, over the life of the system

Table 7-7 Determination of Reinvestment	
Equalization basin construction	$/mi$yr, over the life of the system
Rehabilitation costs	$/mi$yr, over the life of the system
Operation and maintenance costs	$/mi$yr, over the life of the system
Equipment costs	Total $, over the life of the system
Other costs	Other costs over the life of the system

The average reinvestment rate for all agencies surveyed was about $5,252/mi$yr ($2,594/mi$yr adjusted for inflation) for the costs considered over the life of each system. Many agencies did not report, or had poor data, for years prior to 1980. For this reason the $5,252/mi$yr reinvestment rate is probably lower than the actual reinvestment amount. The average reinvestment rate for all agencies surveyed for the period 1980 to 1996 was $9,328/mi$yr ($1.77/ft$yr). The rate of reinvestment appears to be increasing, which may be due to agencies trying to Acatch-up@ with system needs and to comply with Environmental Protection Agency requirements. For these reasons, the $9,328/mi$yr may be higher than the average reinvestment rate needed to properly maintain a collection system. Poor correlations were observed between reinvestment (single independent variable) and system performance (dependent variable) using linear regression. This may be due to the complex mix of the drivers for reinvestment. Another factor for this poor correlation may be that much of the reinvestment reported has been relatively recent (in the last 10 years) and that performance data is not yet reflecting any improvement that may have occurred. Accurate performance data for a longer period will be required to properly evaluate this relationship. While exploring other relationships, a high correlation ($R^2 > 0.98$) for both reinvestment time periods (life of system and 1990-1996) was observed between the reinvestment amount ($/mi$yr) 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

The regression coefficients for the reinvestment rates based on survey data are presented in Table 7-8.

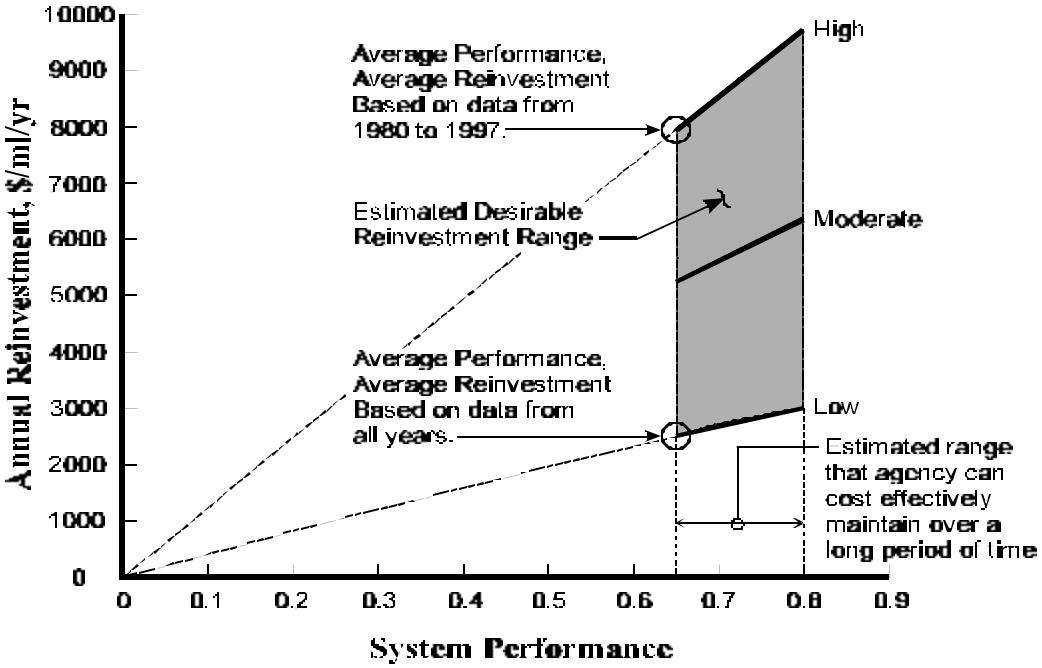
Table 7-8
Reinvestment Regression Coefficients

Dependent Variable: $/mi$yr Reinvestment		
Independent Variable	Equation RE-3 Based on All Reinvestment Data	Equation RE-4 Based on 1980 to 1996 Data
Customer Complaint Rate[(1)]	-2836.49	-6114.06
SSOs[(1)]	-63550.25	-101100.93
Pipe Failure Rate[(1)]	-42308.86	-19817.16
Pump Station Failure Rate[(1)]	-131572.22	-251085.23
Regional Code	-56.04	-942.45
Pump Stations Per Mile	17055.97	46788.79
Peak Hour/ADF Ratio	-3616.08	-6915.00
Average Age	191.08	642.09
Constant	13288.45	17776.14
R^2	0.998	0.984
Adjusted R^2	0.980	0.860

[(1)] Five years of data ending 1996.

It must be remembered that the sample used for this study is relatively small and that some of the agencies likely have very good maintenance programs while the programs of others are deficient. If all agencies had optimized maintenance activities and high quality data, a stronger correlation between reinvestment and performance would be expected. Nevertheless, the reinvestment trends provide some insight into the adequacy of the total reinvestment. In order to develop a better perspective of the relationship between performance and reinvestment, an estimated performance/reinvestment envelope was constructed using the average performance ratios and the reinvestment rates previously presented. For a performance rating of 0.65 to 0.80 cost ranges of $2,500/mi$yr to $8,000/mi$yr and $3,000/mi$yr to $9,700/mi$yr, respectively, appear to form a reasonable envelope of values. The estimated envelope showing reinvestment and desired performance is shown on Figure 7-1. Based on data from the agencies surveyed it was assumed that a desirable range of system performance would be from about 0.65 to 0.80. The data show that a moderate reinvestment level of $5,200/mi$yr to $6,500/mi$yr would be required to achieve this performance. Reinvestment rates higher than the moderate value may indicate that too much money is being spent for the benefit derived, and that some program adjustment is warranted. Reinvestment rates lower than the moderate values indicate a very effective reinvestment program. These values are only guidelines and must be evaluated carefully for each agency.

Figure 7-1
Estimated Desirable System Performance and Reinvestment Envelope



The regression equations presented in Table 7-8 can also be used to estimate the annual reinvestment rate. It is suggested that the results of Equations RE3 and RE4 be used as the limits of the reinvestment rates. Averaging the results of the two equations is a suggested best estimate or starting point for establishing the optimum reinvestment. The actual and predicted reinvestment rates for the agencies surveyed which provided sufficient data to apply Equations RE3 and RE4 are listed in Table 7-9. The data show excellent agreement between predicted and actual values for a wide range of performance ratings and maintenance frequencies.

Table 7-9
Actual and Predicted Reinvestment Rates

Performance Maintenance			Actual Reinvestment [1] $/mi$/yr		Predicted Reinvestment [1] $/mi$/yr		Average [2] $/mi$/yr
Agency No.	Rating	Frequency	All Years	›80-‑96	All Years	›80-‑96	
3	85%	8.5%	$9,436	$20,053	$9,391	$21,956	$15,671
4	91%	7.0%	N/A	$31,863	$12,746	$30,344	$21,545
6	73%	6.8%	$1,145	$7,030	$1,170	$7,006	$4,088
11	58%	3.0%	$1,833	$10,434	$2,224	$10,907	$6,566
17	82%	7.7%	$3,267	$4,737	$3,088	$2,858	$2,973
20	57%	9.4%	$3,657	$12,983	$3,624	$12,260	$7,942
22	89%	10.5%	$7,381	$5,585	$7,400	$6,046	$6,723
25	68%	2.7%	$1,089	$8,445	$1,056	$8,306	$4,681
32	65%	6.4%	$8,180	$21,641	$8,024	$21,965	$14,994
36	80%	6.8%	$2,663	$3,158	$2,629	$4,284	$3,456

[1] AAll years@ indicates that all reinvestment data over the life of the system was used. As noted, many agencies have missing data for the early years of their system. A›80-‑96" indicates that only the reinvestment data from 1980 to 1996 was used.
[2] Average of predicted values.

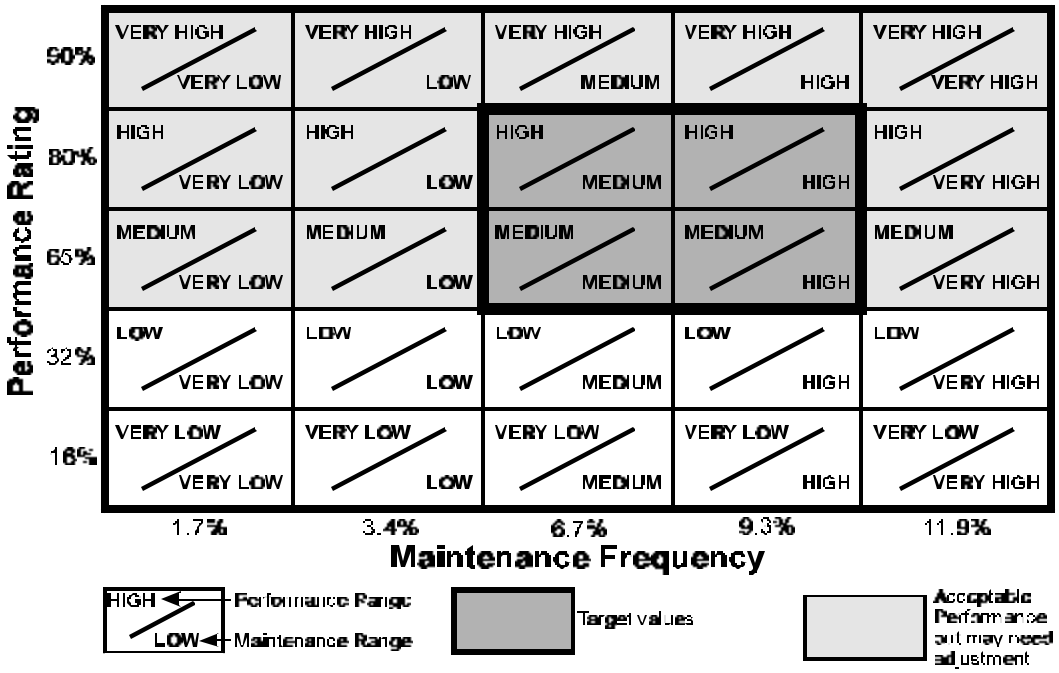
7.5 Optimizing Collection System Maintenance

Once the existing maintenance frequency, performance rating, and reinvestment rate are determined, optimization of maintenance can be evaluated. Optimization is an iterative process requiring judgment and the use of the tools presented in this study. An example of the optimization procedure is presented in the next section using Agency 42 as an example.

7.5.1 Optimization Of Maintenance For an Agency

Optimizing collection system maintenance involves a review and judgment of the system performance, the maintenance frequency, and the reinvestment amount. A target envelope for reinvestment amount and performance, based on results of the survey, is given on Figure 7-1. Reinvestment amounts can also be estimated using the regression equation in Table 7-8. A target envelope for performance rating and maintenance frequency is on Figure 7-2.

Figure 7-2
Estimated Target Envelope for
Performance Rating and Maintenance Frequency



The target values should result in good system performance with a well balanced maintenance program at an acceptable cost. Values to the left and upper left indicate high performance, but the maintenance frequency would be low. Long-term system performance may suffer if maintenance is kept at a low level. Values to the right and upper right may result in high reinvestment amounts. Values with low or very low performance levels represent unacceptable service.

7.5.2 Optimizing Maintenance for Agency No. 42

The maintenance frequency for Agency No. 42 is given in Table 7-10. The maintenance frequency of 7.6% is within the target values of moderate to high range. The performance rating of 62.6% and the reinvestment amount, determined in Table 7-11, would be classified as slightly low. The reinvestment amount of $1,988/mi**$**yr (shown in Table 7-12) based on all years reinvestment also is outside the desirable range on Figure 7-1. The more recent reinvestment of $5,596/mi**$**yr is within the lower portion of the desirable envelope.

Review of the individual performance measures shows that customer complaints, pump station failures, peak hour/ADF ratio, and maximum month/ADF ratio are all below desirable performance levels. A strategy to improve system performance would be to address maintenance items that are most likely to improve the performance deficiencies. The number of pump station failures could be reduced by increasing the number of inspections per year, and customer complaints may be reduced by increasing relief sewer improvements and/or reducing flows. Implementation of these measures will require increased reinvestment in the form of relief, and possible adjustment of priorities and budget.

Table 7-10
Determination of Maintenance Frequency for Agency No. 42

Characteristic Data:	Value		
Miles of Sewer - No.42	525		
Number of Pump Stations	55		
Data			
Activity	Quantity	Years	Rate
Cleaning 1992 -1996, miles	844	5	32.2%
Root Removal 1992 - 1996, miles	20	5	0.8%
Pump Station Inspections 1992 - 1996	1,1876	5	43.2%
Percentage of Flow Monitoring Last 5 Years	2%	5	0.4%
Percentage of Manhole Inspections Last 5 Years	100%	5	20.0%
Percentage of Smoke/Dye Test Last 5 Years	0%	5	0.0%
Percentage of CCTV Last 5 Years	5%	5	1.0%
Percentage of Private Sector Last 5 Years	0%	5	0.0%
Percentage of Manhole Rehabed	95%	n/a	95.0%
Percentage of Main Line Rehabed	60%	n/a	60.0%
Percentage of Relief/ Equal	0%	n/a	0.0%
Percentage of Private Sector	0%	n/a	0.0%
Maintenance Activity Frequency			
Item	Rate		
Cleaning Rate, % system/year	32.2%		
Root Cutting, % System/yr	0.8%		
Pump Station Rate, no/ps**$**yr	43.2		
Flow Monitoring Rate,% System/yr	0.4%		
Manhole Inspect. % System/yr	20.0%		
Smoke/dye Rate, % System/yr	0.0%		
CCTV Rate, % System/yr	1.0%		
Maintenance Activity Frequency			
Item	Rate		
Private Sector Inspection Rate, % System/yr	0.0%		
Manhole Rehab Status	95%		
Main Line Rehab Status	60%		
Sewer Relief Status	0%		
Private I/I Removal Rating	0%		

Table 7-10
Determination of Maintenance Frequency for Agency No. 42

Weighted Normalized Maintenance Activity Frequency			
Rating	Weight	Unadjusted Frequency	Weighted Frequency
Cleaning Rating	17.7%	10%	1.77%
Root Cutting Rating	8.4%	6%	0.50%
Pump Station Rating	14.1%	5%	0.71%
Flow Monitoring Rating	7.0%	3%	0.21%
Manhole Inspect Rating	6.4%	10%	0.64%
Smoke/dye Rating	3.3%	3%	0.10%
CCTV Rating	10.5%	5%	0.53%
Private Sector Inspection Rating	2.0%	1%	0.02%
Manhole Rehab Rating	5.6%	18%	1.01%
Main Line Rehab Rating	12.6%	14%	1.76%
Sewer Relief Rating	6.3%	0%	0.00%
Private I/I Removal Rating	6.1%	1%	0.06%
Total Maintenance Frequency Rating	100.0%	76.0%	7.30%

Table 7-11
Determination of Performance Rating for Agency No. 42

Data	
Performance Measure	Value
Pipe Failure Rate Last 5 Years, no/yr$mi	0.001
SSO Rate Last 5 Years, no/yr$mi	0.029
Customer Complaints Last 5 Years., no/mi$yr	1.552
Pump Station Failures Last 5 Years., no/mi$yr	0.023
Peak Hourly/ADF	3.000
Peak Month/ADF	2.500

Weighted Normalized Performance Activity Rating			
Performance Rating	Weight	Unadjusted Rating	Weighted Rating
Pipe Failure Rating	22.6%	100%	22.6%
SSO Rate Rating	23.6%	87.1%	20.5%
Customer Complaints Rating	20.8%	71.3%	14.8%
Pump Station Failures Rating	17.8%	32.1%	5.7%
Peak Hourly/ADF Rating	9.7%	32.1%	3.1%
Peak Month/ADF Rating	5.5%	30.0%	1.7%
Total	100%		68.5 %

Table 7-12 Determination of Reinvestment		
Reinvestment	All Years	›80-96
Relief $ Total,$/mi$yr	$136	$431
Equal. $ Total, $/mi$yr	$155	$491
Rehab $ Total, $/mi$yr	$490	$1,558
O&M $ Total, $/mi$yr	$1,207	$3,116
Equipment $ Total	$0	$0
Other $ Total	$0	$0
Total Spent, $/mi$yr	$1,988	$5,596
Total Spent, $/ft$yr	$0.38	

Figure 7-1 and the reinvestment regression equations (Table 7-8) can be used to estimate the annual reinvestment needed to achieve a higher performance rating. As indicated on Figure 7-1, a moderate reinvestment amount at a performance rating of 80% would be about $6,500 per mile per year, an increase from the current $5,596 per mile per year. This would result in an increase of about $475,000 per year for the 525 mile system. Using the average result from Equations RE3 and RE4 (Table 7-8) the estimated reinvestment amount is about $8,300 per mile per year, or an increase of about $1.4 million per year. For purposes of discussion, an increase of $1.4 million per year is assumed, which is still within the envelope on Figure 7-1. By focusing cleaning efforts to problem areas, the cleaning rate of 32 percent of the system per year can be reduced to around 20 percent per year. This will help offset some of the cost increase and may not significantly affect performance. This will need to be evaluated only one time. Over a typical planning cycle of 5 to 10 years, the increased reinvestment will result in significant improvements for large capital expenditures such as relief sewers. Agency No. 42 indicated that none of the required relief sewers had been constructed at the time of this survey. In actual practice, cost analyses need to be performed to determine the cost of each activity for the revised maintenance plan to check the plan=s validity. Such an evaluation will not be performed for this example. The costs are unique for each agency and must be evaluated on the basis of local prices, personnel resources, equipment, and production rates. Nevertheless, a brief example of the impact of the reinvestment adjustment is as follows:

(1) Reinvestment increase - $1.4 million.

(2) Reduction due to change in cleaning frequency - ($340,000)
(68 miles x $5,000/mile).

(3) Increase due to more frequent pump station inspections - $424,000
(77 inspections/yr x 55 ps x $100/inspection).

(4) Increased relief reinvestment - $1.3 million.

The resulting plan will be a first step towards achieving a system with a maintenance frequency of about 7.5%, a performance rating of 80%, and a reinvestment of $8,300 per mile per year.

Refining the maintenance and reinvestment will be an iterative process which will require judgment to properly address performance deficiencies. The above example provides an approach to using maintenance frequencies, performance ratings, and system reinvestment amounts in adjusting a maintenance plan and evaluating its adequacy.

7.6 Conclusion

The data collected during this study and the methods used to develop maintenance frequencies, performance ratings, and reinvestment rates can be useful in evaluating the adequacy of existing maintenance programs (including routine maintenance and total reinvestment), and for making modification and adjustments to these programs. By expressing collection system maintenance in terms of overall frequency and performance as an overall rating, it is hoped that the relationship between maintenance (total reinvestment) and system performance will be better understood. This will also help regulators and agencies evaluate acceptable levels of system performance and reinvestment.

7.7 Recommendations

This study is a first effort to evaluate the relationship between collection system performance and maintenance (reinvestment), using an overall rating approach. The data for this study were difficult to collect, were guessed in some cases, and were not readily available from many of the agencies surveyed. It is probable that many agencies across the country also lack good data. It is recommended that agencies compile and keep records of performance and maintenance (total reinvestment) in a standardized format. The information presented in this study includes standard formats for collecting and summarizing data. The definitions and guidelines developed during this study for maintenance, and performance measures should be used by agencies to ensure uniform interpretation and collection of data.

Specific steps to improve the optimization of collection system maintenance are as follows:

1. Review and refine the maintenance, performance, and reinvestment measures used in this report. Develop detailed definitions of each.

2. Develop either an information collection guideline which would request that agencies collect data consistent with results of Step 1 or have a study with a core group of agencies to provide data that can be used to refine these analyses and to generate a AGuideline Report for Collection System Maintenance@.

3. Implement the information collection process and analyze the data to develop cost estimates, maintenance guidelines, and performance measures similar to those presented in this study.

4. Repeat the analysis on a regular basis every 2-5 years as the output will improve with the improved data collection.

Appendix A

Questionnaire

Optimization of Collection System Maintenance Frequencies
American Society of Civil Engineers and Black & Veatch
EPA Cooperative Agreement #CX 826097-01-0

The following questionnaire pertains to *separate collection systems only* and should not include data for combined sewers or wastewater treatment facilities. Please answer as many questions as possible. For data which are not available, simply enter An/a.@ Use judgment, if necessary, since exact figures may not always be available. Finally, please indicate the quality of the data where indicated in each section.

Definitions

1. **Collection System Maintenance:** Any reinvestment in the collection system infrastructure to improve and/or maintain wastewater service. "Maintenance", for purposes of this survey, includes what is traditionally considered maintenance, such as cleaning and lift station service, as well as capital improvements and rehabilitation to "maintain" the system..

2. **Quality of Data.**

a. Very Good. Data based on operational records or recent studies and is fully documented.

b. Good. Mostly based on operational records and recent studies supplemented by personnel knowledgeable of the data requested.

c. Fair. Based mostly on approximations with some supporting documentation but primarily data provided by memory from personnel knowledgeable of the data requested.

d. A Guess. Written records not available to verify but the best guess representing what is reasonably thought to be true by a person somewhat knowledgeable of the data requested.

Please FAX or Mail your completed Questionnaire to:

Richard E. (Rick) Nelson, P.E.
Principal Investigator
Black & Veatch
8400 Ward Parkway
Kansas City, MO 64114
Telephone: 913/458-3510
Fax: 913/458-3730
e-mail: nelsonre@bv.com

Thank You

I. General Information

1. City/Agency: _____
2. Address: _____
3. City/Zip Code: _____
4. Telephone No.: _____
5. Fax No.: _____
6. E-mail: _____
7. Completed By/Title: _____
8. Date: _____

II. Service Area Information

Quality of data for this section: **G** *Very Good (1)* **G** *Good (2)* **G** *Fair (3)* **G** *A Guess (4)*

1. Data is for: City Wide or Total Regional System **G** (1) or Individual Drainage Area **G** (2)
2. Service Area Name: _____
3. Miles of Public Sewer: _____
4. Number of Manholes: _____
5. Number of Connections: _____
6. Area Served (sq mi.): _____
7. Population Served: _____
8. Age of System: _____
   a. Date of original collection system constructed: _____
   b. Date of latest collection system improvement: _____
   c. Age distribution: _____

AGE (YRS)	PERCENT OF SYSTEM
1. 0-10 Years	
2. 11-20 Years	
3. 21-50 Years	
4. 50 – 100 Years	
5. >100 Years	
6. Total	100%

III. Flow Information (all values are MGD unless otherwise indicated)

(Select year within last 3 years of data which best represents your system)

Quality of data for this section: **G** *Very Good (1)* **G** *Good (2)* **G** *Fair (3)* **G** *A Guess* (4)

1. Data is for: City Wide or Total Regional System **G** (1) or Individual Drainage Area **G** (2)
2. Year of data: _____
3. Average annual daily flow: _____
4. Maximum daily flow observed:* _____
5. Peak hourly flow observed:* _____
6. Indicate basis for peak hourly flow reported in item #III.4 (ie. Measured annual, estimated, weather and other related condition upon which estimate was made.

_____

_____

7. Maximum month average daily flow:
8. Minimum month average daily flow:
9. Percent of system below the average groundwater table:

*Indicates basis for flows reported (i.e., measured annual, estimated, weather and other related condition upon which estimate was made):

IV. System Characteristic Information

Quality of data for this section: **G** *Very Good (1)* **G** *Good (2)* **G** *Fair (3)* **G** *A Guess* (4)

1. Percent of system greater than 24 inches in diameter: _____
2. Number of pumping (lift) stations: _____
3. Total installed horsepower of lift stations: _____
4. Total energy consumed by all lift stations, kwh/yr: _____
5. Total length of force mains, miles: _____
6. Number of equalization basins upstream of WWTP: _____
7. Total volume of equalization basins, mg: _____
8. Percent of system which is industrial/commercial: _____
9. Typical velocity of flow, ft/s (min/max/typical): _____

V. System Performance Rates

Estimate numbers of storm events that exceeded the capacity of your system and caused SSOs.
Quality of data for this section: **G** *Very Good (1)* **G** *Good (2)* **G** *Fair (3)* **G** *A Guess (4)*

CUMULATIVE NUMBER OF EVENTS IN LAS ...				
ITEM	**1 Yr**	**5 Yr**	**10 Yr**	**20 Yr**
1. Pipe Failures (1)				
2. Manhole Overflows				
3. Treatment Overflows				
4. Basement Backups				
5. Other				
6. Customer Complaints (2)				
7. Pump Station Failures (3)				

(1) Pipe failure is defined as a pipe which has lost its structural integrity as evidenced by total or partial collapse (lost of 50% of pipe area or 25% of pipe wall along any circumference).

(2) Number of customer complaints related to the performance of the collection system. Based on customer complaint records.

(3) Number o pump station failures that result in station overflows. Based on operational records

VI. Routine Maintenance Frequencies

Quality of data for this section: **G** *Very Good (1)* **G** *Good (2)* **G** *Fair (3)* **G** *A Guess (4)*

TOTAL COMPLETED EACH YEAR					
ITEM	**1996**	**1995**	**1994**	**1993**	**1992**
1. Cleaning, miles of sewer					
2. Root Removal/Treatment, miles of sewer					
3. Main Line Stoppages Cleared, number					
4. House Service Stoppages Cleared, number					
5. Inspections and Services of Lift Stations, number					

VII. Inspection Methods Used and Status

Quality of data for this section: ***G*** *Very Good (1)* ***G*** *Good (2)* ***G*** *Fair (3)* ***G*** *A Guess (4)*

INSPECTIONS METHOD AND STATUS (1)				
	CUMULATIVE PERCENT OF SYSTEM QUANTITY INSPECTED IN LAST ...			
INSPECTION TASK	**1 YR**	**5 YR**	**10 YR**	**20 YR**
1. Flow Monitoring/Capacity Evaluation (2)				
2. Manhole (3)				
3. Smoke/Dye Test				
5. Private Sector Building Inspection (4)				

(1) Inspection % may exceed 100% of actives have been performed more than once. Percentage should be base on total quantity of task completed divided by total system. For example, in a system with 100 manholes, if 50 manholes were inspected twice each in the last year, the 100% of the system quantity would have been inspected in the last 1 year; not 50%. This data will help establish the frequency of inspection activities.

(2) Percent of subsystem (basins) monitored and evaluated.

(3) Surface or internal inspections.

(4) Inspections for area drains, downspouts, cleanouts, sump discharges and other private sector inflow sources into the sewer system.

VIII. Approximate Rehabilitation Status Percent Complete:

Quality of data for this section: ***G*** *Very Good (1)* ***G*** *Good (2)* ***G*** *Fair (3)* ***G*** *A Guess (4)*

REHABILITATION TASK	**PERCENT COMPLETE** (1)
1. Manhole	
2. Main line/public service connection repairs	
3. Relief/equalization	
4. Private Sector (lateral and illegal disconnect program)	

(1) Indicate the completion status of total estimated rehabilitation required to bring each item to a new or like new condition. For example: (a) if a system requires not rehabilitation (a like new system) then all rehabilitation tasks would be 100% complete; (b) in a 100 manhole system, if a total of 50 manholes require rehabilitation and 25 manholes have already been rehabilitated, then the rehabilitation status would be 50% complete; not 25% (i.e. 25/50 – 0.50).

XI. Estimated System Maintenance Costs:

Quality of data for this section: **G** *Very Good (1)* **G** *Good (2)* **G** *Fair (3)* **G** *A Guess (4)*

TOTAL DOLLARS SPENT (1)				
ITEM	**1990-1996 (7 yrs)**	**1980-1989 (10 yrs)**	**1970-1970 (10 yrs)**	**PRE-1970 (variable – list # of yrs.) (____ yrs.)**
1. Relief (Increased capacity) (2)				
2. Equalization (2)				
3. Rehabilitation/replacement				
4. O&M Budget (collection system only)				
5. Equipment Replacement (if not included in O&M above)				
6. Other Costs (4)				

(1) Includes engineering, construction and legal costs. Cost values should not be adjusted for infiltration.

(2) Does not include sewer extensions to serve growth. Only costs required to upgrade the existing collection system should be included.

(3) Differentiate whether it is in-system storage or if it is storage at the WWTP which is used to equalize wet weather flows.

(4) Description of "other costs"

X. Estimated Importance of Performance and Maintenance Activities

Based on your opinion, enter the relative importance of the various system **performance** indicators. The total should be up to 100%

1. System Performance Importance (Weight)	
Performance Indicator	**(Importance %)**
1. Pipe Failures	
2. Sanitary Sewer Overflows (SSOs)	
3. Customer Complaints	
4. Pump Station Failures	
5. Peak Hourly/ADF Ratio	
6. Peak Month/ADF Ratio	
Total	**100%**

X. Estimated Importance of Performance and Maintenance Activities

Based on your opinion, enter the relative importance of the various system performance indicators. The total should be up to 100%

2. Maintenance Activity Importance (Weight)	
Maintenance Activity	**(Importance %)**
1. % System Cleaned/Yr	
2. % System Root Removal/Yr	
3. Lift Station Service	
4. Flow Monitoring/Capacity Evaluation	
5. Manhole Inspection	
6. Smoke/Dye Testing	
7. CCTV Inspections	
8. Private Sector Inspections	
9. Manhole Rehabilitation	
10. Main Line Rehabilitation	
11. Relief Sewer Construction	
12. Private Sector I/I Source Removal	
Total	**100%**

XI. Effectiveness of Program:

1. Are you satisfied with your system maintenance (total reinvestment) program:

   a. Strongly Agree _____ (system performance is as required, cost effective budget)

   b. Agree _____ (system performance is generally as required, budget adequate)

   c. Not Sure _____ (system performance not defined, budget may be adequate)

   d. Disagree _____ (system performance generally not as required, budget not adequate)

   e. Strongly Disagree _____ (system performance and budget unacceptable)

2. What would you do different, if anything?

_____
_____
_____
_____
_____
_____
_____
_____

Thank You

Appendix B

Data Provided by Respondents

	Size	Region	Date	Quality of Data II	Data For	Miles of Sewer	Number of Manholes	Number of Connection	Area Served	Population Served	Date of Original System	Date of Most Recent	Age 0 - 10 Yrs.	Age 11 - 20 Yrs.	Age 21 - 50 Yrs.	Age 51 - 100 Yrs.	Age > 100 Yrs.
Item	2	3	11	12	13	15	16	17	18	19	20	21	22	23	24	25	26
Form No.			1.8	II	II.1	II.3	II.4	II.5	II.6	II.7	II.8.a	II.8.b	II.8.c.1	II.8.c.2	II.8.c.3	II.8.c.4	II.8.c.5
No.	size	region	date	Qual_II	datafor	milessew	nummh	numconn	area	pop	dateorg	datelast	age10	age20	age50	age100	ageold
1	Large	NE	07/03/97			4891	128,691	388,238	1000	1,400,000	**1880**		19.6%	21.2%	51.3%	7.9%	0.0%
2	Small	CENTRAL	07/11/97	1	1	418	8,129	29,144	44	75,561	1900	1997	17.0%	19.0%	34.0%	30.0%	0.0%
3	Small	CENTRAL	04/11/97	2	1	190	3,855	18,000	50	56,000	1880	1997	5.0%	10.0%	70.0%	10.0%	5.0%
4	Large	CENTRAL	05/02/97	2	1	511	6,535		1650	2,500,000	1886	1996	1.0%	13.0%	67.0%	10.0%	9.0%
5	Large	CENTRAL	06/10/97	2		1520	32,108	300,000	280	900,000	1900	1997	6.0%	19.0%	73.0%	1.0%	1.0%
6	Medium	CENTRAL	04/07/97	2	1	900	27,000	60,000	26	180,000	1885	1997	10.0%	17.0%	49.0%	22.0%	2.0%
7	Medium	CENTRAL	05/27/97	2	1	119	1,200		161	280,000	1890	1997	2.0%	7.0%	76.0%	15.0%	0.0%
8	Medium	CENTRAL	06/11/97	3	1	2000	35,000	160,000	300	465,000	1910	1997	10.0%	10.0%	50.0%	30.0%	0.0%
9	Small	CENTRAL	04/17/97	1	1	300	7,243	24,000	39	78,000	1890	1996	19.0%	23.0%	42.0%	16.0%	0.0%
10	Large	CENTRAL	05/19/97	1	1	2953	82,900	220,000	244	850,000	1830	1997	5.0%	5.0%	20.0%	65.0%	5.0%
11	Large	CENTRAL	05/09/97			2017	60,000	176,004	201	632,958	1850	1997	20.0%	19.0%	37.0%	24.0%	0.0%
12	Large	CENTRAL	06/10/97	1		2500	44,000	212,000	390	875,000	1854	1997	4.0%	12.0%	40.0%	40.0%	4.0%
13	Large	NW	07/14/97	2	2	3250	43,500	182,386	183	700,000	1950	1983	35.0%	30.0%	35.0%	0.0%	0.0%
14	Large	SW	06/20/97	1	1	1250	20,400	1,143,980	770	4,770,000	1927	1997	3.0%	3.0%	58.0%	36.0%	0.0%
15	Large	NW	02/27/97	2	1	1550	36,000	136,814	110	525,000	1876	1997	1.0%	7.0%	44.0%	34.0%	14.0%
16	Large	CENTRAL	07/28/97	2	1	2255	35,000	138,975	250	619,320	1917	1997	30.0%	35.0%	30.0%	5.0%	0.0%
17	Large	CENTRAL	04/05/97	1		4010	30,493	285,000	290	1,070,168	1881	1997	25.0%	35.0%	30.0%	10.0%	0.0%
18	Medium	SE	04/16/97	3	1	1100	18,000	66,000	115	200,000	1910	1997	10.0%	10.0%	50.0%	30.0%	0.0%
19	Medium	CENTRAL		2	1	800	18,000	57,000	85	150,000	1945	1997	20.0%	30.0%	30.0%	20.0%	0.0%
20	Large	SE	02/27/97	1	1	2543	59,150	258,152	266	950,000	1919	1997	30.0%	40.0%	27.0%	3.0%	0.0%
21	Medium	SE	07/21/97	1	1	32	160	390	38	136,500	1969	1997	50.0%	15.0%	35.0%	0.0%	0.0%
22	Medium	SW		1		1435	19,346	127,578	187	456,445	1954	1997	60.0%	28.0%	12.0%	0.0%	0.0%
23	Large	SW	06/20/97	1	1	3986	63,837	348,973	460	1,000,000	1890	1997	20.0%	35.0%	35.0%	10.0%	0.0%
24	Medium	CENTRAL	08/29/97	1	1	1750	51,042	121,880	180	373,644	1909	1997	10.0%	30.0%	50.0%	10.0%	0.0%
25	Medium	CENTRAL	09/04/97	2		1600	40,000	125,000	125	310,000	1890	1997	10.0%	20.0%	30.0%	30.0%	10.0%
26	Medium	SW	08/25/97	3	1	875	13,000	60,000	185	183,000	1955	1997	25.0%	25.0%	50.0%	0.0%	0.0%
27	Medium	CENTRAL		1	1	1766	29,026	93,060	200	335,000	1850	1997	12.0%	20.0%	40.0%	21.0%	7.0%
28	Medium	SW	08/27/97	1	1	1141	23,281	114,857	108	405,517	1950	1997	51.0%	9.0%	34.0%	6.0%	0.0%
29	Medium	NE	08/26/97	3	1	820	17,300	60,000	296	200,000	1900	1997	**20.0%**	**25.0%**	**40.0%**	**15.0%**	**0.0%**
30	Medium	SW	05/02/97	1		2729	45,626	187,000	425	475,000	1901	1997	16.9%	26.8%	53.6%	2.7%	0.0%
31	Large	SE	08/26/97	2		2600	55,000	140,000	240	560,000	1800	1997	20.0%	44.0%	25.0%	10.0%	1.0%
32	Small	NE	05/05/97	2	1	72	1,500	2,500	25	86,900	1978	1997	25.0%	75.0%	0.0%	0.0%	0.0%
33	Large	CENTRAL	05/30/97	2		4332	91,365	301,545	440	906,885	1930	1997	11.6%	8.0%	34.6%	45.8%	0.0%
34	Large	CENTRAL		2		5700	100,000	368,000	600	1,720,000	**1900**		30.0%	40.0%	20.0%	10.0%	0.0%
35	Medium	SW	09/25/97	2	1	548	10,863	41,650	54	191,000	1917	1997	25.0%	50.0%	24.0%	1.0%	0.0%
36	Medium	CENTRAL	10/06/97	1	1	949	21,100	67,693	70	150,000	1894	1997	21.0%	21.0%	47.0%	10.0%	1.0%
37	Medium	SW	11/05/97	2		1600	29,000	141,000	162	450,000	**1900**	1997	8.0%	20.0%	71.0%	1.0%	0.0%
38	Small	SW	11/14/97	1	1	40	836	4,022	7	14,000	1931	1997	3.0%	17.0%	50.0%	30.0%	0.0%
39	Medium	NW	10/28/97	2	1	747	6,333	62,000	120	200,000	1911		15.0%	23.0%	60.0%	2.0%	0.0%
40	Small	NW	12/09/97	1	1	120	1,590	11,150	10	23,485	1900	1997	27.0%	16.0%	42.0%	15.0%	0.0%
41	Medium	SW	12/15/97	1		1274	18,190	104,000	102	396,011	1800	1997	24.0%	29.0%	28.0%	9.0%	10.0%
42	Medium	SW	12/30/97	2	1	525	10,000	52,000	50	180,000	1880	1997	5.0%	15.0%	30.0%	50.0%	0.0%

	Size	Region	Total %	Average Age	Quality of Data III	Data For	Year of Flow Data	Avg Annual Daily	Max. Daily Flow	Peak Hourly Flow	Peak Hourly Basis	Max. Month Daily	Min. Month Daily	% System in Groundwater	Quality of Data IV.	% System > 24"	Number of Pumping Sta.
Item ->	2	3	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
Form No. ->			II.8.c.6	Calc	III	III.1	III.2	III.3	III.4	III.5	III.6	III.7	III.8	III.9	IV	IV.1	IV.2
No.	size	region	agetot	avgage	qual_III	dif_III	yrdta	adf	mdf	phf	flwbas	mxmadf	mnmadf	grdwtr	qual_IV	per24	nops
1	Large	NE	100.0%	28.0			1996	192.0	350.0	400.0	Metered	216.0	177.0	30.0%		5.5%	43
2	Small	CENTRAL	100.0%	38.1	1		1996	14.6	26.9	30.0	Flow Meters	18.2	13.6	10.0%	1	6.0%	11
3	Small	CENTRAL	100.0%	40.0	2	1	1988	7.7	15.0	14.0	Est -peak wet	8.4	6.6	30.0%	3	12.9%	16
4	Large	CENTRAL	100.0%	44.2	3	2	1996	213.3	288.0	599.0	Measured	237.6	197.0		2	68.0%	61
5	Large	CENTRAL	100.0%	30.7	2	1	1996	88.6	179.6	200.0	Est -Pump	140.4	33.9	75.0%	2	8.0%	214
6	Medium	CENTRAL	100.0%	39.2		1	1993	34.6	116.4	116.4	Max Capacity	44.5	20.1			8.0%	23
7	Medium	CENTRAL	100.0%	39.0	1	1	1996	39.6	97.7	132.9	Measured	49.2	36.5	50.0%		70.0%	17
8	Medium	CENTRAL	100.0%	42.0	1		1996	70.5	150.0	180.0	Measured	125.0	63.0	15.0%	2	20.0%	60
9	Small	CENTRAL	100.0%	31.1	1	1	1995	12.1	20.0	28.0	Est	13.1	11.1		1	7.0%	4
10	Large	CENTRAL	100.0%	63.0	1	1	1996	216.0	475.0	583.0	Metered Flow	395.0	140.0		1		131
11	Large	CENTRAL	100.0%	34.8	1	1	1995	160.6	252.8	289.0	Metered	186.9	132.6			12.0%	11
12	Large	CENTRAL	100.0%	51.0			1997	113.0	250.0	250.0	Metered	135.0	90.0		3		202
13	Large	NW	100.0%	18.5	2	1	1996	160.5	316.4		Metered	198.3	148.7	10.0%	2	3.0%	71
14	Large	SW	100.0%	47.9	1	1	1996	520.0	684.0	942.0	Measured	532.0	507.0		1	38.0%	48
15	Large	NW	100.0%	59.5	2	1	1996	50.0	74.6			66.1		5.0%	2	4.0%	4
16	Large	CENTRAL	100.0%	21.0	2		1996	76.9	110.5			76.8			2	8.7%	82
17	Large	CENTRAL	100.0%	24.5	1	1	1996	177.0	343.7	380.4	Measured	221.0	164.0	25.0%	2	21.5%	16
18	Medium	SE	100.0%	42.0	1		1997	28.0	90.0	90.0	Measured	60.0	25.0	50.0%	3	20.0%	90
19	Medium	CENTRAL	100.0%	31.0	2	1	1996	31.0	67.0	71.0	Measured	41.0	23.0	25.0%	2	12.0%	35
20	Large	SE	100.0%	19.2		1	1996	307.0	500.0	600.0	Measured	408.0	290.0	75.0%	2	1.2%	930
21	Medium	SE	100.0%	17.0	1	1	1996	9.6	11.8	16.2	Measured	10.6	8.2	90.0%	1	26.0%	27
22	Medium	SW	100.0%	11.4	1	2	1996	68.3	74.8	95.0	Measured	72.0	64.0	10.0%	1	4.0%	32
23	Large	SW	100.0%	26.0	2	2	1996	59.2	63.4	78.0	Measured	61.1	56.7		2	5.6%	19
24	Medium	CENTRAL	100.0%	30.0	1	1	1996	55.0			Estimated	70.6	42.8		1	5.0%	57
25	Medium	CENTRAL	100.0%	49.0	2	1	1996	42.0	57.0	117.6	Weather	43.2	35.7	20.0%	3		40
26	Medium	SW	100.0%	22.5	1	1	1997	15.1	19.3	30.0	Estimated	18.4	13.4	0.0%	3	5.0%	27
27	Medium	CENTRAL	100.0%	42.1	4		1996	98.0	115.0	125.0	Estimated	110.0	93.3	70.0%	3	15.0%	35
28	Medium	SW	100.0%	20.3	1		1997	49.3	55.9	90.0	Measured	54.1	45.9	0.0%		6.3%	2
29	Medium	NE	100.0%	30.0	2		1996	18.2				20.9	16.0				
30	Medium	SW	100.0%	25.7	2	2	1996	60.0	79.0	123.0	Measured	62.0	56.0	0.0%	1	3.5%	36
31	Large	SE	100.0%	25.1	3		1996	64.5	72.0		Measured	72.0	57.9	20.0%	2	20.0%	50
32	Small	NE	100.0%	12.5		1	1996	19.2	73.7	80.0	Measured	27.2	11.8		3	20.0%	55
33	Large	CENTRAL	100.0%	48.2	2	2	1996	55.9	112.4	164.9	Metered Flow	77.2	45.5		2		220
34	Large	CENTRAL	100.0%	22.0	2			236.0	536.0	650.0				30.0%	3	5.0%	377
35	Medium	SW	100.0%	17.9	3		1997	15.0		34.0	Estimated				2	2.7%	5
36	Medium	CENTRAL	100.0%	29.4	1	1	1997	40.7	115.0	140.0	Measured	55.0	31.0	25.0%	2	11.0%	32
37	Medium	SW	100.0%	29.0	1		1997	57.1	69.5	72.5	Estimated	58.5	46.5	5.0%	3	6.0%	14
38	Small	SW	100.0%	42.7	1	1	1996	1.6	3.2	3.1	Estimated	1.7	1.3	70.0%	1	0.0%	5
39	Medium	NW	100.0%	26.7				63.6	244.1	240.0	Measured	83.6	57.9	60.0%		12.0%	36
40	Small	NW	100.0%	29.7	1	1	1996	6.0	25.0	25.5	Measured	14.5	2.9	90.0%	2	4.0%	10
41	Medium	SW	100.0%	34.6			1995	63.0	94.0		Measured	64.4	60.9		2	19.0%	16
42	Medium	SW	100.0%	50.5	3	1	1996	24.0	60.0	72.0	Measured	60.0	21.0	0.0%	3	14.0%	55

	Size	Region	Manhole Overflows Last 5 Yr.	Manhole Overflows Last 10 Yr.	Manhole Overflows Last 20 Yr.	Treatment Overflows Last 1 Yr.	Treatment Overflows Last 5 Yr.	Treatment Overflows Last 10 Yr.	Treatment Overflows Last 20 Yr.	Basement Backups Last 1 Yr.	Basement Backups Last 5 Yr.	Basement Backups Last 10 Yr.	Basement Backups Last 20 Yr.	Other Last 1 Yr.	Other Last 5 Yr.	Other Last 10 Yr.	Other Last 20 Yr.
Item ->	2	3	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
Form No. ->			V.2.2	V.2.3	V.2.4	V.3.1	V.3.2	V.3.3	V.3.4	V.4.1	V.4.2	V.4.3	V.4.4	V.5.1	V.5.2	V.5.3	V.5.4
No.	size	region	mho5	mho10	mho20	tro1	tro5	tro10	tro20	bmb1	bmb5	bmb10	bmb20	otr1	otr5	otr10	otr20
1	Large	NE	1,102	2,051	3,398					430	2,860	5,460	8,000				
2	Small	CENTRAL	120	293	765					9	44	108	283				
3	Small	CENTRAL	2	20	50	0	0	0	0	12	75	250	1,000				
4	Large	CENTRAL	20	30	60	0	0	0	0	4	20	30	50				
5	Large	CENTRAL								25				200			
6	Medium	CENTRAL				1				1							
7	Medium	CENTRAL	7	9		2	6	10		11	22	30					
8	Medium	CENTRAL				0	0	0	0	200							
9	Small	CENTRAL	5	7		0	0	0	0	15	55	91					
10	Large	CENTRAL								2,642							
11	Large	CENTRAL								759							
12	Large	CENTRAL				147	345			2,376	2,714						
13	Large	NW	924	1,848		0	0	0	0	53	275	505					
14	Large	SW	27	57	70	0	0	6	19					1	105	135	316
15	Large	NW								17	150						
16	Large	CENTRAL	646			3	5	10	20								
17	Large	CENTRAL	70			0	2			118	783			0	0		
18	Medium	SE	250	500	1,000	0	0	0	0								
19	Medium	CENTRAL				0	0	0	0								
20	Large	SE	250			0	1			0	0	0	0				
21	Medium	SE	5			0	0	0	0	0	1						
22	Medium	SW	179	406	1,326	1	5	10	20	0	3	5	10	4	15	25	40
23	Large	SW	1,000	2,500						0	0	0	0				
24	Medium	CENTRAL	1,486							37	227			17	27		
25	Medium	CENTRAL				2				100							
26	Medium	SW	15			0	5	10	15	0	0	0	0	0	0	0	0
27	Medium		400	750	1,200	30	160	300	500	283	1,650	4,230	10,790				
28	Medium	SW	640	1,280	2,560					1	5	10	20	235	1,175	2,350	4,700
29	Medium	NE															
30	Medium	SW							1	30	215	500	900				
31	Large	SE	1,656	3,280						70	298			410	3,265	6,118	
32	Small	NE	15	35	50	2	10	20	30	3	10	30	50				
33	Large	CENTRAL				9				3,039				28			
34	Large	CENTRAL															
35	Medium	SW	8			0	1			2	4						
36	Medium	CENTRAL	9							3	10	400					
37	Medium	SW	275			0	0	0	0	22	161						
38	Small	SW	13			0	0	1		0	1						
39	Medium	NW								20				5			
40	Small	NW	0			20	100			15	60			10	35		
41	Medium	SW	761											64	100		
42	Medium	SW	70			1	6			2	5						

	Size	Region	Customer Complaints Last 1 Yr.	Customer Complaints Last 5 Yrs.	Customer Complaints Last 10 Yrs.	Customer Complaints Last 20 Yrs.	Pump Station Failures Last 1 Yr.	Pump Station Failures Last 5 Yrs.	Pump Station Failures Last 10 Yrs.	Pump Station Failures Last 20 Yrs.	Quality of Data VI.	Cleaning in 1992, miles	Cleaning in 1993, miles	Cleaning in 1994, miles	Cleaning in 1995, miles	Cleaning in 1996, miles	Cleaning 1992 -1996, miles
Item ->	2	3	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Form No. ->			V.6.1	V.6.2	V.6.3	V.6.4	V.7.1	V.7.2	V.7.3	V.7.4	VI	VI.1.1	VI.1.2	VI.1.3	VI.1.4	VI.1.5	VI.1.6
No.	size	region	cust1	cust5	cust10	cust20	psfail1	psfail5	psfail10	psfail20	qual_VI	micln92	micln93	micln94	micln95	micln96	miclntot
1	Large	NE	6,241				10	123	223		1	216	238	268	262	298	1,282
2	Small	CENTRAL	216	1,032	2,151	4,501	1	2	2		1	177	135	168	162	138	780
3	Small	CENTRAL	284	1,600	4,000	10,000	0	3	5	10	3	30	35	40	46	53	204
4	Large	CENTRAL	20	40	80	120	1	1	2	4	2	10	10	10	10	10	50
5	Large	CENTRAL	150								3			359	359	359	1,077
6	Medium	CENTRAL	251				3				1	511	452	437	478	402	2,280
7	Medium	CENTRAL					3	4	7		2	7	8	9	7	11	42
8	Medium	CENTRAL					0	0	0	0	3					200	200
9	Small	CENTRAL	15	55	91		0	0	0		1	180	151	152	168	177	828
10	Large	CENTRAL	7,823				65	346			1					95	95
11	Large	CENTRAL	3,555				14				1	422	341	407	318	381	1,869
12	Large	CENTRAL	5,457	18,991			281	623	747	840	1	39	41	42	46	101	269
13	Large	NW	6,616	30,009	51,484		0	0	0		1	760	844	854	813	852	4,123
14	Large	SW					0	1	15	32	1				400	449	849
15	Large	NW	800	4,000							2	2,000	2,000	2,000	2,045	1,939	9,984
16	Large	CENTRAL	5,668	34,901	86,924			36			1	245	174	225	172	137	953
17	Large	CENTRAL	11,975	44,172			3	28			1	912	887	678	781	1,000	4,258
18	Medium	SE					1	3	8	10	3					204	204
19	Medium		25	100	250	500	2	25	100	500	2	10	10	10	15	100	145
20	Large	SE	4,600	23,000			14	70			1			600	600	600	1,800
21	Medium	SE					0	0	0	0	3	10	10	10	10	10	50
22	Medium	SW	640	2,981	4,998	8,625	1	5	10	15	2	206	228	218	227	232	1,111
23	Large	SW					0	0	5	10	2	821	1,016	1,141	1,239	1,200	5,417
24	Medium	CENTRAL	2,593	13,402	21,095		0	20			2	974	651	752	623	851	3,851
25	Medium	CENTRAL	1,200				100				2					400	400
26	Medium	SW	250	1,500	3,000	6,000	0	2			1	183	190	197	202	219	991
27	Medium		900	6,320	16,000	45,000	4	35	75	120	2	200	180	170	190	195	935
28	Medium	SW	439	2,195	4,390	8,780	20	100	200	400	1	481	634	783	863	804	3,565
29	Medium	NE									2	92	108	99	101	86	486
30	Medium	SW	300	2,000	5,000		4	30	80	160	2	1,000	1,100	1,200	1,300	1,400	6,000
31	Large	SE	4,700	18,700			2	5	7		1	843	1,090	619	579	629	3,760
32	Small	NE	4	10	40	60	2	5	7	14							0
33	Large	CENTRAL					26				2					637	637
34	Large										2		3,420	2,280	1,710	1,140	8,550
35	Medium	SW	55				0	0	0		2	141	157	132	128	182	739
36	Medium	CENTRAL	1,100	6,500	10,200		0	5	10		3	200	200	225	225	225	1,075
37	Medium	SW						1	2		2	481	494	544	717	578	2,814
38	Small	SW	24				0	0	0	0	3	34	20	20	30	20	124
39	Medium	NW	150				1								451	429	880
40	Small	NW	8	25			2	5			2		20	15	20	20	75
41	Medium	SW	749	1,347							2	590	751	668	737	793	3,539
42	Medium	SW	800	3,800			10	60			2	150	165	150	184	195	844

	Size	Region	Root Removal 1992, miles	Root Removal 1993, miles	Root Removal 1994, miles	Root Removal 1995, miles	Root Removal 1996, miles	Root Removal 1992 - 1996, miles	ML Stoppages Fixed 1992	ML Stoppages Fixed 1993	ML Stoppages Fixed 1994	ML Stoppages Fixed1995	ML Stoppages Fixed 1996	ML Stoppages Fixed 1992 - 1996	Service Stoppages Fixed 1992	Service Stoppages Fixed 1993	Service Stoppages Fixed 1994
Item ->	2	3	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101
Form No. ->			VI.2.1	VI.2.2	VI.2.3	VI.2.4	VI.2.5	VI.2.6	VI.3.1	VI.3.2	VI.3.3	VI.3.4	VI.3.5	VI.3.6	VI.4.1	VI.4.2	VI.4.3
No.	size	region	mirt92	mirt93	mirt94	mirt95	mirt96	mirttot	nostop92	nostop93	nostop94	nostop95	nostop96	nostopto	nohou92	nohou93	nohou94
1	Large	NE	45.9	59.7	47.5	66.7	59.7	279.6	872	852	828	1,381	853	4,786	854	862	630
2	Small	CENTRAL	1.0	27.0	18.0	31.0	26.0	103.0	36	40	22	32	34	164	0	0	0
3	Small	CENTRAL	0.0	0.0	0.0	0.0	0.0	0.0	100	90	80	70	59	399	215	205	195
4	Large	CENTRAL	2.0	2.0	2.0	2.0	0.5	8.5	1	1	1	0	2	5	0	0	0
5	Large	CENTRAL			70.0	70.0	70.0	210.0			260	260	260	780			
6	Medium	CENTRAL	0.0	0.0	0.0	0.0	0.0	0.0	304	311	282	260	251	1,408			
7	Medium	CENTRAL	0.0	0.0	0.0	0.0	0.0	0.0	1	0	0	0	1	2			
8	Medium	CENTRAL					200.0	200.0					400	400			
9	Small	CENTRAL			1.0	1.1	2.0	4.1			46	40	15	101			
10	Large	CENTRAL					17.0	17.0						0			
11	Large	CENTRAL			16.0	14.5	16.4	46.8						0	0	0	0
12	Large	CENTRAL	75.1	7.1	6.8	12.7	6.4	108.1	54	31	46	48	54	233	923	711	584
13	Large	NW					4.3	4.3	618	764	598	557	512	3,049	1,418	1,663	1,634
14	Large	SW						0.0						0			
15	Large	NW	0.0	0.0	0.0	0.0	0.0	0.0				12	15	27	0	0	0
16	Large	CENTRAL		0.4	1.1	0.8	0.2	2.5	401	330	274	268	255	1,528	580	694	886
17	Large	CENTRAL	108.0	89.0	48.0	27.0	12.0	284.0	1,827	1,916	1,997	2,017	2,040	9,797	3,393	3,473	3,969
18	Medium	SE					100.0	100.0					744	744			
19	Medium	CENTRAL		3.0	5.0	5.0	5.0	21.0	1,500	1,500	1,500	1,350	1,600	7,450	1,500	1,500	1,500
20	Large	SE			25.0	25.0	25.0	75.0				2,400	3,827	6,227			
21	Medium	SE	0.0	0.0	0.0	0.0	0.0	0.0				2	4	6			
22	Medium	SW						0.0	63	48	47	53	47	258			
23	Large	SW	0.0	0.0	0.0	1.0	1.0	2.0	315	305	252	264	250	1,386	0	0	0
24	Medium	CENTRAL	12.0	10.5	4.0	1.0	1.0	28.5	365	495	536	488	531	2,415			
25	Medium	CENTRAL					200.0	200.0					490	490			
26	Medium	SW	17.0	20.0	24.0	27.0	30.0	118.0	42	45	49	55	53	244	0	0	0
27	Medium	CENTRAL		100.0	75.0	85.0	110.0	480.0	260	280	210	230	175	1,155	310	350	305
28	Medium	SW	1.0	1.0	1.0	1.0	1.0	5.0	134	132	135	130	128	659	2	2	2
29	Medium	NE						0.0	319	279	338	368	418	1,722	343	336	322
30	Medium	SW						0.0	590	540	480	410	372	2,392	0	0	0
31	Large	SE	581.0	615.0	506.0	551.0	311.0	2,564.0	664	723	676	410	519	2,992	685	851	899
32	Small	NE	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	1	1	0	0	0
33	Large	CENTRAL						0.0				746	470	1,216			
34	Large	CENTRAL						0.0				2,120	2,000	4,120			981
35	Medium	SW					0.0	0.0	28	25	30	22	24	129			
36	Medium	CENTRAL	0.0	0.0	30.0	0.0	0.0	30.0	100	120	100	90	80	490			
37	Medium	SW	11.0	9.0	4.0	7.0	8.0	39.0	2	6	4	4	8	24			
38	Small	SW	0.0	0.0	0.0	0.0	0.1	0.1	7	7	6	5	4	29	15	12	12
39	Medium	NW				5.0	6.0	11.0				40	40	80			
40	Small	NW			2.0	3.0	5.0	10.0		3	4	4	6	17			
41	Medium	SW	360.0	336.0	313.0	394.0	380.0	1,783.0						0			
42	Medium	SW	0.0	5.0	5.0	5.0	5.0	20.0			400	380	414	1,194	0	0	0

	Size	Region	Service Stoppages Fixed 1995	Service Stoppages Fixed 1996	Service Stoppages Fixed 1992 -1996	Lift Station Inspections 1992	Lift Station Inspections 1993	Lift Station Inspections 1994	Lift Station Inspections 1995	Lift Station Inspections 1996	Lift Station Inspections 1992 - 1996	Quality of Data VII.	% Flow Monitoring Last 1 Yr	% Flow Monitoring Last 5 Yr	% Flow Monitoring Last 10 Yr	% Flow Monitoring Last 20 Yr	% Manhole Inspections Last 1 Yr.
Item ->	2	3	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116
Form No. ->			VI.4.4	VI.4.5	VI.4.6	VI.5.1	VI.5.2	VI.5.3	VI.5.4	VI.5.5	VI.5.6	VII	VII.1.1	VII.1.2	VII.1.3	VII.1.4	VII.2.1
No.	size	region	nohou95	nohou96	nohouto	nolsin92	nolsin93	nolsin94	nolsin95	nolsin96	nolsinto	qual_VII	fm1	fm5	fm10	fm20	mh1
1	Large	NE	619	740	3,705	16,400	14,600	14,600	14,600	15,700	75,900		100.0%	100.0%	100.0%	100.0%	4.0%
2	Small	CENTRAL	0	0	0	0	0	380	380	388	1,148	2	0.0%	0.0%	0.0%	0.0%	30.0%
3	Small	CENTRAL	185	173	973	9,100	9,100	9,100	9,100	9,100	45,500	3	1.0%	10.0%	95.0%	95.0%	3.0%
4	Large	CENTRAL	0	0	0	15,000	15,000	15,000	15,000	15,000	75,000	2	100.0%	200.0%	300.0%	400.0%	20.0%
5	Large	CENTRAL			0			5,590	5,590	5,590	16,770	3					50.0%
6	Medium	CENTRAL			0						0	3	8.0%	17.0%	25.0%	25.0%	4.0%
7	Medium	CENTRAL			0	1,800	1,800	1,800	1,800	1,800	9,000	1	12.0%	100.0%	100.0%	100.0%	12.0%
8	Medium	CENTRAL		0	0					365	365		1.0%	30.0%	70.0%	80.0%	5.0%
9	Small	CENTRAL			0	200	200	200	200	200	1,000	2	0.0%	5.0%	5.0%	5.0%	2.1%
10	Large	CENTRAL		179	179	5,000	5,000	6,300	6,800	6,812	29,912	1					
11	Large	CENTRAL	0	0	0						0	3	100.0%	200.0%			
12	Large	CENTRAL	589	514	3,321						0	2					0.0%
13	Large	NW	1,301	1,317	7,333	828	828	828	840	852	4,176	3	100.0%	500.0%	900.0%	1400.0%	0.1%
14	Large	SW			0	48	48	48	48	48	240	1	50.0%	250.0%	500.0%	1000.0%	100.0%
15	Large	NW	0	0	0	100	100	100	100	100	500	2					60.0%
16	Large	CENTRAL	933	1,021	4,114						0	3	10.0%	20.0%	25.0%	35.0%	10.0%
17	Large	CENTRAL	3,952	5,270	20,057	416	416	832	832	832	3,328	3	7.0%	20.0%	30.0%	35.0%	7.0%
18	Medium	SE			0	86	88	89	90	94	447	4	0.0%	0.0%	0.0%	0.0%	17.0%
19	Medium	CENTRAL		1,500	7,500	25	38	38	1,850	1,900	3,851	2	5.0%	25.0%	26.0%	26.0%	7.0%
20	Large	SE	2,400	2,346	4,746	0	0	45,000	45,000	45,220	135,220	1	20.0%	100.0%	100.0%		30.0%
21	Medium	SE			0	50	53	55	55	57	270	2	0.0%	30.0%			0.0%
22	Medium	SW			0	2,750	2,800	2,800	2,850	2,904	14,104	3	100.0%	100.0%	100.0%		60.0%
23	Large	SW	0	0	0	1,872	1,872	1,872	1,872	1,872	9,360	2	0.0%	0.0%	0.0%	0.0%	30.0%
24	Medium	CENTRAL			0	6,055	7,733	7,886	8,316	9,192	39,182	2	45.0%	45.0%	100.0%		59.0%
25	Medium	CENTRAL		0	0					365	365	4	5.0%	0.0%	0.0%	0.0%	5.0%
26	Medium	SW	0	0	0	145	150	200	225	250	970	3	100.0%	100.0%	100.0%	100.0%	50.0%
27	Medium	CENTRAL		300	1,585	9,200	13,960	11,100	9,250	9,100	52,610	2	70.0%	75.0%	76.0%	77.0%	35.0%
28	Medium	SW	2	2	10	156	156	156	104	104	676						
29	Medium	NE	368	472	1,841						0	2	80.0%	80.0%	80.0%		2.0%
30	Medium	SW	0	0	0				2,533	2,946	5,479		1.0%	5.0%	10.0%	20.0%	
31	Large	SE	829	1,132	4,396			5,720	6,188	3,000	14,908	3	40.0%				29.0%
32	Small	NE	0	0	0						0	3	10.0%	20.0%			100.0%
33	Large	CENTRAL			0												7.3%
34	Large	CENTRAL		850	2,831						0	3					
35	Medium	SW			0	52	52	52	52	52	260	2	0.0%	0.0%	10.0%		45.6%
36	Medium	CENTRAL			0	4,160	4,160	4,160	4,160	4,160	20,800	2	30.0%	55.0%	60.0%	65.0%	40.0%
37	Medium	SW			0						0	2					
38	Small	SW	5	10	54	3,500	1,300	1,300	1,300	1,300	8,700	2	0.0%	75.0%	125.0%	125.0%	5.0%
39	Medium	NW	5	5	10				432	432	864		100.0%	500.0%			70.0%
40	Small	NW			0				75	50	125	2	0.0%	100.0%	200.0%	300.0%	5.0%
41	Medium	SW			0						0						
42	Medium	SW	0	0	0		2,800	3,023	3,105	2,948	11,876	4	1.0%	2.0%			20.0%

	Size	Region	% Manhole Inspections Last 5 Yr.	% Manhole Inspections Last 10 Yr.	% Manhole Inspections Last 20 Yr.	% Smoke/Dye Test Last 1 Yr.	% Smoke/Dye Test Last 5 Yr.	% Smoke/Dye Test Last 10 Yr.	% Smoke/Dye Test Last 20 Yr.	% CCTV Last 1 Yr.	% CCTV Last 5 Yr.	% CCTV Last 10 Yr.	% CCTV Last 20 Yr.	% Private Sector Last 1 YR.	% Private Sector Last 5 YR.	% Private Sector Last 10 YR.	% Private Sector Last 20 YR.
Item ->	2	3	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131
Form No. ->			VII.2.2	VII.2.3	VII.2.4	VII.3.1	VII.3.2	VII.3.3	VII.3.4	VII.4.1	VII.4.2	VII.4.3	VII.4.4	VII.5.1	VII.5.2	VII.5.3	VII.5.4
No.	size	region	mh5	mh10	mh20	smk1	smk5	smk10	smk20	tv1	tv5	tv10	tv20	psi1	psi5	psi10	psi20
1	Large	NE	10.0%	20.0%	35.0%	2.0%	5.0%	8.0%	15.0%	4.0%	15.0%	20.0%	40.0%	0.0%	0.5%	1.0%	1.0%
2	Small	CENTRAL	80.0%	80.0%	80.0%	0.0%	0.0%	0.0%	80.0%	2.0%	10.0%	25.0%	30.0%	0.0%	0.0%	0.0%	0.0%
3	Small	CENTRAL	10.0%	95.0%	100.0%			95.0%	100.0%	5.0%	15.0%	30.0%	35.0%	0.0%	0.0%	100.0%	100.0%
4	Large	CENTRAL	40.0%	60.0%	80.0%	1.0%	2.0%	2.0%	2.0%	10.0%	20.0%	30.0%	40.0%	0.0%	0.0%	0.0%	0.0%
5	Large	CENTRAL	50.0%			50.0%				5.0%	5.0%			0.0%			
6	Medium	CENTRAL	50.0%	60.0%	60.0%	8.0%	17.0%	25.0%	25.0%	12.0%	23.0%	40.0%	40.0%				
7	Medium	CENTRAL	47.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	12.0%	47.0%	53.0%	53.0%	0.0%	0.0%	0.0%	0.0%
8	Medium	CENTRAL	20.0%	50.0%	60.0%	5.0%	20.0%	40.0%	50.0%	2.0%	10.0%	30.0%	50.0%				
9	Small	CENTRAL	4.1%	6.2%		0.0%	5.0%	5.0%	5.0%	3.0%	48.0%	100.0%					
10	Large	CENTRAL								1.0%							
11	Large	CENTRAL				1.0%	3.0%	4.2%		0.7%	6.0%	13.6%					
12	Large	CENTRAL	50.0%	100.0%		1.0%	3.0%			4.0%	7.2%			0.0%	0.0%	0.0%	0.0%
13	Large	NW	0.7%	2.1%	7.0%	0.1%	0.5%	2.0%	4.0%	3.0%	15.0%	23.0%	38.0%	0.0%	0.0%	0.0%	0.0%
14	Large	SW	500.0%	1000.0%	2000.0%	0.0%	0.0%	0.0%	0.0%	15.0%	37.0%	40.0%	50.0%				
15	Large	NW	100.0%	100.0%	100.0%	1.0%	1.0%	1.0%	1.0%	13.0%	45.0%						
16	Large	CENTRAL	50.0%	70.0%	70.0%	25.0%	50.0%	70.0%	85.0%	10.0%	50.0%	70.0%	70.0%				
17	Large	CENTRAL	20.0%	30.0%	35.0%	7.0%	20.0%	30.0%	35.0%	3.0%	18.0%	30.0%	40.0%	7.0%	20.0%	30.0%	35.0%
18	Medium	SE	18.0%	19.0%	22.0%	5.0%	50.0%	50.0%	50.0%	1.7%	8.3%	16.7%	33.3%				
19	Medium	CENTRAL		32.0%	32.0%	25.0%	26.0%	26.0%	26.0%	2.0%	25.0%	26.0%	26.0%	0.0%	0.0%	0.0%	0.0%
20	Large	SE	100.0%	100.0%		30.0%	100.0%	100.0%		30.0%	100.0%	100.0%		30.0%	100.0%	100.0%	
21	Medium	SE	90.0%			0.0%				0.0%	90.0%			5.0%			
22	Medium	SW	250.0%	450.0%	800.0%	10.0%	50.0%	100.0%	200.0%	2.3%	7.9%	14.7%	26.0%	0.0%	0.0%	0.0%	0.0%
23	Large	SW	200.0%	400.0%	800.0%	1.0%	1.0%	1.0%	1.0%	7.8%	65.0%	90.0%	130.0%	0.0%	0.0%	0.0%	0.0%
24	Medium	CENTRAL	211.0%	336.0%		31.0%	84.0%	126.0%		7.0%	27.0%	40.0%		30.0%	70.0%		
25	Medium	CENTRAL				5.0%				15.0%				5.0%	0.0%	0.0%	0.0%
26	Medium	SW	50.0%	50.0%	50.0%	0.0%	0.0%	0.0%	0.0%	20.0%	75.0%	75.0%	75.0%	0.0%	0.0%	0.0%	0.0%
27	Medium	CENTRAL		60.0%	70.0%	10.0%	15.0%	17.0%	18.0%	5.0%	8.0%	11.0%	15.0%	2.0%	3.0%	4.0%	5.0%
28	Medium	SW															
29	Medium	NE	54.0%			0.0%	0.0%	0.0%	0.0%	1.0%	11.0%						
30	Medium	SW				0.0%	0.0%	0.0%	0.0%	2.0%	6.0%			0.0%	0.0%	0.0%	0.0%
31	Large	SE	368.0%			17.0%	218.0%			2.5%	222.0%			0.0%	0.0%	0.0%	0.0%
32	Small	NE	200.0%	300.0%	400.0%			1.0%		20.0%							
33	Large	CENTRAL				2.0%				2.4%							
34	Large	CENTRAL															
35	Medium	SW	100.0%			0.0%	0.0%	1.0%		3.0%	7.0%	8.0%					
36	Medium	CENTRAL	95.0%	100.0%	100.0%	30.0%	60.0%	60.0%	60.0%	10.0%	17.0%	24.0%	32.0%	40.0%	85.0%	85.0%	85.0%
37	Medium	SW				0.6%	3.3%			3.0%	7.0%						
38	Small	SW	105.0%	135.0%	135.0%	1.0%	101.0%	101.0%	101.0%	33.0%	33.0%	63.0%	63.0%	1.0%	101.0%	101.0%	101.0%
39	Medium	NW	100.0%			5.0%				12.0%	60.0%						
40	Small	NW	20.0%	40.0%	60.0%	0.0%	25.0%	50.0%	75.0%	0.0%	25.0%	50.0%	75.0%	0.0%	0.0%	0.0%	0.0%
41	Medium	SW															
42	Medium	SW	100.0%	200.0%	300.0%	0.0%	0.0%	0.0%	0.0%	2.0%	5.0%	10.0%	20.0%				

	Size	Region	Data Quality VIII	% Manhole Rehabed	% Main Line Rehabed	% Relief/ Equal	% Private Sector	Data Quality IX	Relief $ < 1970	Relief $ '70 - '79	Relief $ "80 - '89	Relief $ '90 - 96	Relief $ Total	Equal. $ < 1970	Equal. $ '70 - '79
Item ->	2	3	132	133	134	135	136	137	138	139	140	141	142	143	144
Form No. ->			VIII	VIII.1	VIII.2	VIII.3	VIII.4	IX	IX.1.1	IX.1.2	IX.1.3	IX.1.4	IX.1.5	IX.2.1	IX.2.2
No.	size	region	qual_VIII	mhrehab	lnrehab	rerehab	prireh	qual_IX	rel70	rel79	rel89	rel96	reltot	eq70	eq79
1	Large	NE		75.0%	50.0%	80.0%	0.0%		$0	$0	$0	$48,800,000	$48,800,000		
2	Small	CENTRAL	4	20.0%	50.0%		10.0%	1				$0	$0		
3	Small	CENTRAL	3	33.0%	29.0%	62.0%	69.0%	4		$1,000,000	$2,000,000	$5,000,000	$8,000,000	$0	$0
4	Large	CENTRAL	2	90.0%	0.0%	0.0%	0.0%	2		$140,000,000	$72,000,000	$60,000,000	$272,000,000	$0	$0
5	Large	CENTRAL	4	75.0%	75.0%		0.0%	4	$0				$0		
6	Medium	CENTRAL	4	20.0%	20.0%	5.0%	0.0%	2				$10,000,000	$10,000,000		
7	Medium	CENTRAL		100.0%	100.0%	100.0%	100.0%	2	$1,303,000	$126,000	$1,216,000	$586,000	$3,231,000	$0	$0
8	Medium	CENTRAL	2	30.0%	40.0%	50.0%		2				$7,000,000	$7,000,000		
9	Small	CENTRAL	3	25.0%	50.0%			1					$0		
10	Large	CENTRAL											$0		
11	Large	CENTRAL	4	10.0%	2.0%		1.0%						$0		
12	Large	CENTRAL											$0		
13	Large	NW	3	0.1%	1.0%	0.0%		1					$0		
14	Large	SW	1	56.0%	56.0%	67.0%		1			$1,400,000	$43,000,000	$44,400,000		
15	Large	NW	2	100.0%	100.0%	100.0%	100.0%	3				$2,500,000	$2,500,000		
16	Large	CENTRAL	4	5.0%	10.0%		5.0%	1					$0		
17	Large	CENTRAL	1	40.0%	50.0%	80.0%	90.0%					$54,320,000	$54,320,000		$1,025,000
18	Medium	SE	3	2.0%	2.0%	20.0%	0.0%	4		$20,000,000	$25,000,000	$0	$45,000,000	$0	$0
19	Medium	CENTRAL		40.0%	30.0%	60.0%	0.0%	3			$1,000,000	$2,000,000	$3,000,000	$0	$0
20	Large	SE	1	96.0%	70.0%	25.0%	95.0%		$0	$0	$0	$0	$0	$0	$0
21	Medium	SE	2	100.0%	90.0%			2				$0	$0		
22	Medium	SW	1	99.9%	100.0%	100.0%	100.0%	2		$18,157,229	$24,570,187	$42,391,582	$85,118,998		$5,000,000
23	Large	SW	2	1.0%	1.0%	0.0%	0.0%	2	$0	$0	$0	$0	$0	$0	$0
24	Medium	CENTRAL	2	30.0%	30.0%	60.0%	30.0%	2				$9,500,000	$9,500,000		
25	Medium	CENTRAL	4	5.0%	1.0%		1.0%	4				$14,000,000	$14,000,000		
26	Medium	SW	3	0.0%	25.0%	10.0%	0.0%	3			$1,000,000	$5,450,000	$6,450,000	$0	$0
27	Medium	CENTRAL		20.0%	20.0%	10.0%	5.0%	2	$1,100,000	$800,000	$1,200,000	$1,800,000	$4,900,000	$0	$0
28	Medium	SW											$0		
29	Medium	NE											$0		
30	Medium	SW	4	5.0%	5.0%	10.0%	0.0%	2			$8,900,000	$4,000,000	$12,900,000	$0	$0
31	Large	SE	2	5.0%	3.0%	50.0%	0.0%	3				$4,000,000	$4,000,000		
32	Small	NE		90.0%	95.0%			3				$900,000	$900,000		
33	Large	CENTRAL					0.0%	3			$25,425,145	$44,638,800	$70,063,945		
34	Large	CENTRAL		40.0%	44.0%	35.0%	17.0%						$0		
35	Medium	SW	4	25.0%	25.0%	50.0%		3			$2,800,000	$600,000	$3,400,000	$0	$0
36	Medium	CENTRAL	2	20.0%	15.0%	0.0%	0.0%	3			$0	$0	$0	$0	$5,000,000
37	Medium	SW	3		31.0%								$0		
38	Small	SW	1	20.0%	2.0%	100.0%	95.0%						$0		
39	Medium	NW			5.0%		3.0%						$0		
40	Small	NW	2	5.0%	5.0%		0.0%	3	$0	$0	$0	$2,000,000	$2,000,000	$0	$0
41	Medium	SW	3	99.0%	99.9%	100.0%	100.0%						$0		
42	Medium	SW	4	95.0%	60.0%			3			$1,500,000	$2,100,000	$3,600,000		

	Size	Region	Equal. $ '80 - '89	Equal. $ '90 - '96	Equal. $ Total	Rebab $ < 1970	Rehab $ '70 - '79	Rehab $ '80 - '89	Rehab $ '90 - '96	Rehab $ Total	O&M $ <1970	O&M $ "70 - '79	O&M $ "80 - '89	O&M $ "90 - '96
Item ->	2	3	145	146	147	148	149	150	151	152	153	154	155	156
Form No. ->			IX.2.3	IX.2.4	IX.2.5	IX.3.1	IX.3.2	IX.3.3	IX.3.4	IX.3.5	IX.4.1	IX.4.2	IX.4.3	IX.4.4
No.	size	region	eq89	eq96	eqtot	rehab70	rehab79	rehab89	rehab96	rehabto	om70	om79	om89	om96
1	Large	NE			$0	$0	$5,000,000	$72,900,000	$41,700,000	$119,600,000	$0	$0	$20,700,000	$14,500,000
2	Small	CENTRAL			$0				$900,000	$900,000				$3,908,000
3	Small	CENTRAL	$0	$0	$0		$7,500,000	$10,000,000	$35,000,000	$52,500,000		$1,600,000	$2,500,000	$3,500,000
4	Large	CENTRAL	$0	$0	$0		$13,000,000	$18,000,000	$31,900,000	$62,900,000		$16,000,000	$39,200,000	$43,000,000
5	Large	CENTRAL			$0					$0			$75,000,000	$65,000,000
6	Medium	CENTRAL			$0				$13,600,000	$13,600,000				$14,000,000
7	Medium	CENTRAL	$0	$0	$0	$201,000	$0	$1,152,000	$5,719,000	$7,072,000		$3,600,000	$5,500,000	$5,600,000
8	Medium	CENTRAL		$0	$0		$50,000,000	$75,000,000	$105,000,000	$230,000,000				$84,000,000
9	Small	CENTRAL	$32,000	$28,000	$60,000			$245,000	$300,000	$545,000			$2,444,000	$2,895,000
10	Large	CENTRAL		$0	$0					$0				$90,000,000
11	Large	CENTRAL			$0				$10,800,000	$10,800,000			$48,883,527	$68,959,300
12	Large	CENTRAL			$0					$0				
13	Large	NW			$0					$0		$9,000,000	$75,981,000	$99,353,000
14	Large	SW			$0			$27,000,000	$109,000,000	$136,000,000			$43,000,000	$130,000,000
15	Large	NW			$0				$14,000,000	$14,000,000				$25,000,000
16	Large	CENTRAL			$0					$0				$4,377,371
17	Large	CENTRAL	$5,270,000	$63,000	$6,358,000				$56,490,000	$56,490,000		$60,000,000	$77,400,000	$66,400,000
18	Medium	SE	$0	$20,000,000	$20,000,000		$2,000,000	$2,000,000	$10,000,000	$14,000,000	$0	$0	$0	$10,000,000
19	Medium	CENTRAL		$0	$0			$1,000,000	$15,000,000	$16,000,000			$2,000,000	$3,044,000
20	Large	SE	$0	$0	$0	$0	$0	$0	$32,609,198	$32,609,198	$0	$0	$0	$145,803,513
21	Medium	SE		$0	$0				$0	$0				$381,200
22	Medium	SW			$5,000,000		$0	$6,500,000	$0	$6,500,000			$8,498,154	$12,071,921
23	Large	SW	$0	$0	$0		$1,000,000	$2,500,000	$2,100,000	$5,600,000			$35,000,000	$55,000,000
24	Medium	CENTRAL		$30,000,000	$30,000,000				$15,000,000	$15,000,000				$34,000,000
25	Medium	CENTRAL			$0				$14,000,000	$14,000,000				$22,400,000
26	Medium	SW	$0	$0	$0	$0	$0	$0	$500,000	$500,000				$3,000,000
27	Medium	CENTRAL		$0	$0	$600,000	$300,000	$300,000	$1,200,000	$2,400,000	$1,600,000	$2,500,000	$3,600,000	$4,200,000
28	Medium	SW			$0					$0				
29	Medium	NE			$0					$0				
30	Medium	SW	$0	$0	$0			$6,400,000	$11,400,000	$17,800,000			$16,400,000	$22,979,496
31	Large	SE		$12,000,000	$12,000,000					$0			$35,301,161	$34,956,049
32	Small	NE			$0					$0				$6,500,000
33	Large	CENTRAL			$0			$9,700,285	$5,144,520	$14,844,805				
34	Large	CENTRAL			$0					$0				
35	Medium	SW	$0	$0	$0			$500,000	$1,200,000	$1,700,000				$575,296
36	Medium	CENTRAL	$1,000,000	$0	$6,000,000	$100,000	$200,000	$800,000	$1,200,000	$2,300,000	$1,000,000	$15,000,000	$18,000,000	$23,000,000
37	Medium	SW			$0			$12,500,000	$41,845,000	$54,345,000			$17,500,000	$19,870,000
38	Small	SW			$0					$0				
39	Medium	NW			$0					$0				
40	Small	NW	$0	$0	$0	$0	$0	$0	$3,000,000	$3,000,000				$1,515,000
41	Medium	SW			$0					$0				$4,000,000
42	Medium	SW	$2,000,000	$2,100,000	$4,100,000			$5,000,000	$8,000,000	$13,000,000		$6,000,000	$12,000,000	$14,000,000

	Size	Region	O&M $ Total	Equipment $ < 1970	Equipment $ '70 - '79	Equipment $ '80 - '89	Equipment $ '90 - '96	Equipment $ Total	Other $ <1970	Other $ '70 - '79	Other $ '80 - '89	Other $ '90 - '96	Other $ Total	Total $ (all years)
Item ->	2	3	157	158	159	160	161	162	163	164	165	166	167	
Form No. ->			IX.4.5	IX.5.1	IX.5.2	IX.5.3	IX.5.4	IX.5.5	IX.6.1	IX.6.2	IX.6.3	IX.6.4	IX.6.5	
No.	size	region	omtot	omeq70	omeq79	omeq89	omeq96	omeqto	oth70	oth79	oth89	oth96	othtot	
1	Large	NE	$35,200,000	$0	$0	$0	$0	$0					$0	$203,600,000
2	Small	CENTRAL	$3,908,000					$0					$0	$4,808,000
3	Small	CENTRAL	$7,600,000	$0	$0	$0	$1,400,000	$1,400,000			$2,214,000		$2,214,000	$71,714,000
4	Large	CENTRAL	$98,200,000					$0					$0	$433,100,000
5	Large	CENTRAL	$140,000,000					$0					$0	$140,000,000
6	Medium	CENTRAL	$14,000,000				$2,800,000	$2,800,000					$0	$40,400,000
7	Medium	CENTRAL	$14,700,000	$0	$0	$0	$0	$0					$0	$25,003,000
8	Medium	CENTRAL	$84,000,000				$7,000,000	$7,000,000					$0	$328,000,000
9	Small	CENTRAL	$5,339,000				$351,650	$351,650					$0	$6,295,650
10	Large	CENTRAL	$90,000,000					$0					$0	$90,000,000
11	Large	CENTRAL	$117,842,827					$0					$0	$128,642,827
12	Large	CENTRAL	$0					$0					$0	$0
13	Large	NW	$184,334,000					$0					$0	$184,334,000
14	Large	SW	$173,000,000					$0					$0	$353,400,000
15	Large	NW	$25,000,000					$0				$18,000,000	$18,000,000	$59,500,000
16	Large	CENTRAL	$4,377,371					$0					$0	$4,377,371
17	Large	CENTRAL	$203,800,000					$0					$0	$320,968,000
18	Medium	SE	$10,000,000	$0	$0	$0	$0	$0					$0	$89,000,000
19	Medium	CENTRAL				$607,000	$1,155,000	$1,762,000			$8,939,900	$8,264,800	$17,204,700	$43,010,700
20	Large	SE	$145,803,513	$0	$0	$0	$0	$0	$0	$0	$0	$126,000	$126,000	$178,538,711
21	Medium	SE	$381,200				$0	$0					$0	$381,200
22	Medium	SW	$20,570,075		$300,000	$1,100,000	$2,150,000	$3,550,000					$0	$120,739,073
23	Large	SW	$90,000,000					$0					$0	$95,600,000
24	Medium	CENTRAL	$34,000,000					$0					$0	$88,500,000
25	Medium	CENTRAL	$22,400,000				$35,000,000	$35,000,000					$0	$85,400,000
26	Medium	SW	$3,000,000				$150,000	$150,000					$0	$10,100,000
27	Medium	CENTRAL						$0					$0	$19,200,000
28	Medium	SW	$0					$0					$0	$0
29	Medium	NE	$0					$0					$0	$0
30	Medium	SW	$39,379,496			$1,700,000	$645,135	$2,345,135					$0	$72,424,631
31	Large	SE	$70,257,210				$1,651,887	$1,651,887					$0	$87,909,097
32	Small	NE	$6,500,000					$0					$0	$7,400,000
33	Large	CENTRAL	$0					$0					$0	$84,908,750
34	Large	CENTRAL						$0					$0	$0
35	Medium	SW	$575,296					$0			$0	$0	$0	$5,675,296
36	Medium	CENTRAL	$66,000,000					$0					$0	$74,300,000
37	Medium	SW	$37,370,000					$0					$0	$91,715,000
38	Small	SW	$0					$0					$0	$0
39	Medium	NW	$0					$0					$0	$0
40	Small	NW	$1,515,000					$0	$0	$0	$0	$0	$0	$6,515,000
41	Medium	SW	$4,000,000					$0					$0	$4,000,000
42	Medium	SW	$32,000,000					$0					$0	$52,700,000

	Size	Region	Perf. Weight - Pipe Failure	Perf. Weight - SSOs	Perf. Weight - Complaints	Perf. Weight - PS Failures	Perf. Weight - Pk Hr/ ADF	Perf. Weight - Pk Mo/ ADF	Perf. Weight - Total	Maint. Weight - % Cleaned	Maint. Weight - % Root Cleaned	Maint. Weight - Lift Station Service	Maint. Weight - Flow/Capacity	Maint. Weight - Manhole	Maint. Weight - Smoke	Maint. Weight - CCTV	Maint. Weight - Private
Item ->	2	3	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182
Form No. ->			X.1.1	X.1.2	X.1.3	X.1.4	X.1.5	X.1.6	X.1.7	X.2.1	X.2.2	X.2.3	X.2.4	X.2.5	X.2.6	X.2.7	X.2.8
No.	size	region	perpf	perfsso	perfcomp	perfps	perfpkhr	perfpkmo	perktot	maintcl	maintrt	maintls	maintfm	maintmh	maintsmk	mainttv	maintpri
1	Large	NE															
2	Small	CENTRAL	27.0%	32.0%	32.0%	9.0%	0.0%	0.0%	100%	25.0%	10.0%	5.0%	1.0%	1.0%	1.0%	10.0%	5.0%
3	Small	CENTRAL	35.0%	35.0%	20.0%	0.0%	5.0%	5.0%	100%	15.0%	0.0%	5.0%	5.0%	2.0%		3.0%	0.0%
4	Large	CENTRAL	25.0%	25.0%	25.0%	25.0%			100%	6.0%	0.0%	35.0%	18.0%	12.0%	0.0%	13.0%	0.0%
5	Large	CENTRAL	18.0%	18.0%	14.0%	27.0%	14.0%	9.0%	100%	15.0%	15.0%	15.0%	8.0%	5.0%	5.0%	10.0%	3.0%
6	Medium	CENTRAL	25.0%	25.0%	40.0%	10.0%	0.0%	0.0%	100%	10.0%	10.0%	10.0%					
7	Medium	CENTRAL	16.7%	25.0%	25.0%	16.7%	16.6%	0.0%	100%	10.0%	0.0%	10.0%	20.0%	10.0%	0.0%	10.0%	0.0%
8	Medium	CENTRAL	80.0%	5.0%	10.0%	5.0%			100%								
9	Small	CENTRAL	35.0%	15.0%	20.0%	20.0%	7.0%	3.0%	100%	40.0%	5.0%	20.0%		15.0%			
10	Large	CENTRAL	20.0%	20.0%	40.0%	10.0%	5.0%	5.0%	100%	20.0%	10.0%	0.0%	5.0%	4.0%	10.0%	20.0%	10.0%
11	Large	CENTRAL	15.0%	30.0%	30.0%	15.0%	5.0%	5.0%	100%	12.0%	10.0%	10.0%	4.0%	8.0%	6.0%	12.0%	4.0%
12	Large	CENTRAL								22.0%	10.0%	22.0%	2.0%	3.0%	2.0%	10.0%	1.0%
13	Large	NW	5.0%	30.0%	30.0%	35.0%	0.0%	0.0%	100%	25.0%	5.0%	35.0%	10.0%	5.0%	0.0%	10.0%	0.0%
14	Large	SW	25.0%	25.0%	15.0%	25.0%	8.0%	2.0%	100%	15.0%	15.0%	15.0%	5.0%	5.0%		10.0%	
15	Large	NW	80.0%	5.0%	10.0%	2.0%	2.0%	1.0%	100%	60.0%	5.0%	5.0%	5.0%	1.0%	1.0%	12.0%	3.0%
16	Large	CENTRAL	20.0%	20.0%	20.0%	20.0%	10.0%	10.0%	100%	13.6%	9.1%	31.9%		0.9%		2.7%	0.9%
17	Large	CENTRAL	25.0%	39.0%	25.0%	3.0%	5.0%	3.0%	100%	15.0%	12.0%	2.0%	10.0%	10.0%	2.0%	10.0%	2.0%
18	Medium	SE	20.0%	20.0%	20.0%	20.0%	5.0%	15.0%	100%	4.8%	19.0%	9.5%	9.5%	4.8%	9.5%	4.8%	4.8%
19	Medium	CENTRAL		20.0%	10.0%	20.0%	15.0%	15.0%	100%	8.0%	5.0%	20.0%	15.0%	5.0%	5.0%	5.0%	1.0%
20	Large	SE	20.0%	20.0%	10.0%	10.0%	20.0%	20.0%	100%	5.0%	5.0%	5.0%	10.0%	10.0%	10.0%	10.0%	10.0%
21	Medium	SE	30.0%	25.0%	10.0%	25.0%	0.0%	10.0%	100%	20.0%	0.0%	50.0%	0.0%	5.0%	0.0%	15.0%	0.0%
22	Medium	SW	12.0%	40.0%	20.0%	25.0%	2.0%	1.0%	100%	34.0%	1.0%	20.0%	10.0%	9.0%	1.0%	15.0%	0.0%
23	Large	SW	50.0%	10.0%	20.0%	20.0%	0.0%	0.0%	100%	35.0%	0.0%	15.0%	0.0%	20.0%	3.0%	15.0%	0.0%
24	Medium	CENTRAL	15.0%	10.0%	20.0%	50.0%	2.0%	3.0%	100%	0.0%	30.0%	10.0%	2.0%	2.0%	2.0%	7.0%	1.0%
25	Medium	CENTRAL	30.0%	30.0%	20.0%	10.0%	5.0%	5.0%	100%								
26	Medium	SW	10.0%	25.0%	25.0%	20.0%	10.0%	10.0%	100%	10.0%	10.0%	10.0%	20.0%	10.0%	0.0%	10.0%	0.0%
27	Medium	CENTRAL		30.0%	20.0%	10.0%	10.0%	10.0%	100%	10.0%	10.0%	10.0%	6.0%	15.0%	6.0%	6.0%	3.0%
28	Medium	SW															
29	Medium	NE															
30	Medium	SW	10.0%	20.0%	60.0%	10.0%	0.0%	0.0%	100%	20.0%	15.0%	5.0%	10.0%	5.0%	0.0%	8.0%	1.0%
31	Large	SE	15.0%	25.0%	25.0%	25.0%	5.0%	5.0%	100%	20.0%	20.0%	30.0%	1.0%	1.0%	2.0%	4.0%	0.0%
32	Small	NE	5.0%	20.0%	5.0%	70.0%	0.0%	0.0%	100%	15.0%	0.0%	30.0%	5.0%	20.0%	0.0%	25.0%	
33	Large	CENTRAL	22.0%	27.0%	20.0%	20.0%	8.0%	3.0%	100%	13.0%	8.0%	11.0%	7.0%	7.0%	5.0%	5.0%	2.0%
34	Large	CENTRAL		25.0%	35.0%	15.0%	3.0%	2.0%	100%								
35	Medium	SW	20.0%	20.0%	10.0%	25.0%	13.0%	12.0%	100%	12.0%	5.0%	14.0%	10.0%	7.0%	5.0%	14.0%	5.0%
36	Medium	CENTRAL	15.0%	20.0%	30.0%	5.0%	20.0%	10.0%	100%	5.0%	5.0%	5.0%	5.0%	10.0%	10.0%	10.0%	5.0%
37	Medium	SW	30.0%	40.0%	10.0%	20.0%			100%	27.0%	17.0%	3.0%	4.0%	2.0%	7.0%	14.0%	0.0%
38	Small	SW	12.0%	48.0%	20.0%	15.0%	1.0%	4.0%	100%	18.0%	10.0%	17.0%	6.0%	4.0%	5.0%	10.0%	3.0%
39	Medium	NW	10.0%	20.0%	30.0%	5.0%	25.0%	10.0%	100%	30.0%	2.0%	12.0%	2.0%	2.0%	1.0%	12.0%	1.0%
40	Small	NW	20.0%	25.0%	20.0%	15.0%	10.0%	10.0%	100%	20.0%	10.0%	15.0%	5.0%	10.0%	5.0%	10.0%	0.0%
41	Medium	SW	25.0%	15.0%	15.0%	25.0%	10.0%	10.0%	100%	50.0%	20.0%	13.0%	1.0%	1.0%	4.0%	5.0%	1.0%
42	Medium	SW	10.0%	50.0%	10.0%	20.0%	5.0%	5.0%	100%	10.0%	10.0%	10.0%	20.0%	5.0%	0.0%	40.0%	0.0%

	Size	Region	Maint. Weight - Manhole Rehab	Maint. Weight - Main Rehab	Maint. Weight - Relief	Maint. Weight - Private I/I	Maint. Weight - Total	Satisfaction	What Different
Item ->	2	3	183	184	185	186	187	188	189
Form No. ->			X.2.9	X.2.10	X.2.11	X.2.12		X.1	X.2
No.	size	region	maintmhr	maintmn	maintre	maintpr	maintot	satis	diff
1	Large	NE							
2	Small	CENTRAL	1.0%	35.0%	5.0%	1.0%	100.0%	b	
3	Small	CENTRAL	5.0%	35.0%	15.0%	15.0%	100.0%	b	
4	Large	CENTRAL	8.0%	8.0%	0.0%	0.0%	100.0%	a	
5	Large	CENTRAL	5.0%	5.0%	4.0%	10.0%	100.0%	c	
6	Medium	CENTRAL	10.0%	10.0%	10.0%	40.0%	100.0%	c	
7	Medium	CENTRAL	0.0%	20.0%	10.0%	10.0%	100.0%	b	
8	Medium	CENTRAL	10.0%	70.0%	20.0%	0.0%	100.0%	b	
9	Small	CENTRAL	10.0%	10.0%			100.0%	c	
10	Large	CENTRAL	1.0%	5.0%	5.0%	10.0%	100.0%	b	
11	Large	CENTRAL	10.0%	12.0%	6.0%	6.0%	100.0%	c	
12	Large	CENTRAL	8.0%	10.0%	5.0%	5.0%	100.0%		
13	Large	NW	5.0%	5.0%	0.0%	0.0%	100.0%	b	
14	Large	SW	5.0%	15.0%	15.0%		100.0%	a	
15	Large	NW	1.0%	4.0%	2.0%	1.0%	100.0%	b	
16	Large	CENTRAL	4.5%	27.3%		9.1%	100.0%	d	
17	Large	CENTRAL	10.0%	10.0%	10.0%	7.0%	100.0%	b	
18	Medium	SE	9.5%	14.2%	4.8%	4.8%	100.0%	c	
19	Medium	CENTRAL		20.0%	2.0%	4.0%	100.0%	c	
20	Large	SE	5.0%	10.0%	10.0%	10.0%	100.0%	a	
21	Medium	SE	5.0%	5.0%	0.0%	0.0%	100.0%	c	
22	Medium	SW	2.0%	2.0%	5.0%	1.0%	100.0%	a	
23	Large	SW	2.0%	10.0%	0.0%	0.0%	100.0%	b	
24	Medium	CENTRAL	4.0%	10.0%	2.0%	30.0%	100.0%	b	
25	Medium	CENTRAL						c&d	
26	Medium	SW	10.0%	10.0%	10.0%	0.0%	100.0%	b	
27	Medium	CENTRAL		11.0%	6.0%	2.0%	100.0%	d	
28	Medium	SW						b	
29	Medium	NE							
30	Medium	SW	5.0%	10.0%	20.0%	1.0%	100.0%	b	
31	Large	SE	1.0%	5.0%	15.0%	1.0%	100.0%	d	
32	Small	NE	5.0%		0.0%		100.0%	b	
33	Large	CENTRAL	6.0%	13.0%	18.0%	5.0%	100.0%	d	
34	Large	CENTRAL							
35	Medium	SW	8.0%	8.0%	7.0%	5.0%	100.0%	d	
36	Medium	CENTRAL	15.0%	10.0%	5.0%	15.0%	100.0%	c	
37	Medium	SW	1.0%	20.0%	5.0%	0.0%	100.0%	d	
38	Small	SW	5.0%	10.0%	2.0%	10.0%	100.0%	b	
39	Medium	NW	4.0%	12.0%	12.0%	10.0%	100.0%	b	
40	Small	NW	10.0%	10.0%	0.0%	5.0%	100.0%	c	
41	Medium	SW	1.0%	2.0%	1.0%	1.0%	100.0%	b	
42	Medium	SW	0.0%	5.0%	0.0%	0.0%	100.0%	c	

Appendix C

Maintenance Activities Weighting

Collection System Maintenance Weighting

Maintenance Weighting - % System Cleaned

Crosstab Table For Average maintcl by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	13.0%	5.4%	26.7%	15.0%	
NE	0.0%	0.0%	15.0%	5.0%	
NW	42.5%	30.0%	20.0%	30.8%	
SE	12.5%	12.4%		12.5%	
SW	25.0%	20.4%	18.0%	21.1%	
	18.6%	13.6%	19.9%	16.9%	17.7%
				Count->	36

Maintenance Weighting - % System Root Cleaned

Crosstab Table For Average maintrt by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	8.2%	7.5%	5.0%	6.9%	
NE	0.0%	0.0%	0.0%	0.0%	
NW	5.0%	2.0%	10.0%	5.7%	
SE	12.5%	9.5%		11.0%	
SW	7.5%	9.8%	10.0%	9.1%	
	6.6%	5.8%	6.3%	6.5%	8.4%
				Count->	36

Maintenance Weighting - Lift Station Service

Crosstab Table For Average maintls by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	14.1%	8.1%	10.0%	10.7%	
NE	0.0%	0.0%	30.0%	10.0%	
NW	20.0%	12.0%	15.0%	15.7%	
SE	17.5%	29.8%		23.6%	
SW	15.0%	9.4%	17.0%	13.8%	
	13.3%	11.9%	18.0%	14.8%	14.2%
				Count->	36

Maintenance Weighting - Flow Monitoring

Crosstab Table For Average maintfm by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	6.0%	6.0%	2.0%	4.7%	
NE	0.0%	0.0%	5.0%	1.7%	
NW	7.5%	2.0%	5.0%	4.8%	
SE	5.5%	4.8%		5.1%	
SW	2.5%	9.4%	6.0%	6.0%	
	4.3%	4.4%	4.5%	4.5%	6.9%
				Count->	33

Maintenance Weighing - Manhole Inspection

Crosstab Table For Average maintmh by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	5.5%	5.3%	6.0%	5.6%	
NE	0.0%	0.0%	20.0%	6.7%	
NW	3.0%	2.0%	10.0%	5.0%	
SE	5.5%	4.9%		5.2%	
SW	12.5%	4.9%	4.0%	7.1%	
	5.3%	3.4%	10.0%	5.9%	6.5%
				Count->	35

Maintenance Weighing - Smoke Testing

Crosstab Table For Average maintsmk by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	3.3%	2.9%	0.3%	2.2%	
NE	0.0%	0.0%	0.0%	0.0%	
NW	0.5%	1.0%	5.0%	2.2%	
SE	6.0%	4.8%		5.4%	
SW	1.5%	2.1%	5.0%	2.9%	
	2.3%	2.2%	2.6%	2.5%	3.3%
				Count->	31

Maintenance Weighting - CCTV

Crosstab Table For Average mainttv by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	9.2%	4.8%	4.3%	6.1%	
NE	0.0%	0.0%	25.0%	8.3%	
NW	11.0%	12.0%	10.0%	11.0%	
SE	7.0%	9.9%		8.5%	
SW	12.5%	13.3%	10.0%	11.9%	
	7.9%	8.0%	12.3%	9.2%	10.5%
				Count->	34

Maintenance Weighting - Private Sector Inspections

Crosstab Table For Average maintpri by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	2.5%	1.3%	1.7%	1.8%	
NE	0.0%	0.0%	0.0%	0.0%	
NW	1.5%	1.0%	0.0%	0.8%	
SE	5.0%	2.4%		3.7%	
SW	0.0%	0.9%	3.0%	1.3%	
	1.8%	1.1%	1.2%	1.5%	2.0%
				Count->	32

Maintenance Weighting - Manhole Rehab

Crosstab Table For Average maintmhr by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	5.8%	8.0%	5.3%	6.4%	
NE	0.0%	0.0%	5.0%	1.7%	
NW	3.0%	4.0%	10.0%	5.7%	
SE	3.0%	7.3%		5.1%	
SW	3.5%	3.4%	5.0%	4.0%	
	3.1%	4.5%	6.3%	4.6%	5.6%
				Count->	37

Maintenance Weighing - Main Rehabilitation

Crosstab Table For Average maintmn by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	10.0%	18.9%	26.7%	18.5%	
NE	0.0%	0.0%	0.0%	0.0%	
NW	4.5%	12.0%	10.0%	8.8%	
SE	7.5%	9.6%		8.6%	
SW	12.5%	7.1%	10.0%	9.9%	
	6.9%	9.5%	11.7%	9.2%	12.6%
				Count->	36

Maintenance Weighting - Relief

Crosstab Table For Average maintre by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	5.3%	6.9%	6.7%	6.3%	
NE	0.0%	0.0%	0.0%	0.0%	
NW	1.0%	12.0%	0.0%	4.3%	
SE	12.5%	2.4%		7.5%	
SW	7.5%	6.0%	2.0%	5.2%	
	5.3%	5.5%	2.2%	4.6%	6.3%
				Count->	35

Maintenance Weighting - Private Sector I/I Removal

Crosstab Table For Average maintpr by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	5.8%	12.6%	5.3%	7.9%	
NE	0.0%	0.0%	0.0%	0.0%	
NW	0.5%	10.0%	5.0%	5.2%	
SE	5.5%	2.4%		4.0%	
SW	0.0%	1.0%	10.0%	3.7%	
	2.4%	5.2%	5.1%	4.1%	6.1%
				Count->	34

Appendix D

Collection System Performance Weighting

Collection System Performance Weighting

Performance Weighting - Pipe Failure

Crosstab Table For Average perpf by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	18.3%	27.7%	32.3%	26.1%	
NE	0.0%	0.0%	5.0%	1.7%	
NW	42.5%	10.0%	20.0%	24.2%	
SE	17.5%	25.0%		21.3%	
SW	37.5%	14.6%	12.0%	21.4%	
	23.2%	15.5%	17.3%	18.9%	23.3%
				count->	38

Performance Weighting - SSO

Crosstab Table For Average perfsso by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	22.7%	20.6%	27.3%	23.5%	
NE	0.0%	0.0%	20.0%	6.7%	
NW	17.5%	20.0%	25.0%	20.8%	
SE	22.5%	22.5%		22.5%	
SW	17.5%	26.3%	48.0%	30.6%	
	16.0%	17.9%	30.1%	20.8%	24.4%
				count->	38

Performance Weighting - Complaints

Crosstab Table For Average perfcomp by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	23.2%	21.9%	24.0%	23.0%	
NE	0.0%	0.0%	5.0%	1.7%	
NW	20.0%	30.0%	20.0%	23.3%	
SE	17.5%	15.0%		16.3%	
SW	17.5%	18.8%	20.0%	18.8%	
	15.6%	17.1%	17.3%	16.6%	21.4%
				count->	38

Performance Weighting - Pump Station Failure

Crosstab Table For Average perfps by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	15.0%	15.8%	9.7%	13.5%	
NE	0.0%	0.0%	70.0%	23.3%	
NW	18.5%	5.0%	15.0%	12.8%	
SE	17.5%	22.5%		20.0%	
SW	22.5%	18.1%	15.0%	18.5%	
	14.7%	12.3%	27.4%	17.6%	18.3%
				count->	38

Performance Weighting - Peak Hour Flow/ADF

Crosstab Table For Average perfpkhr by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	5.6%	8.6%	4.0%	6.0%	
NE	0.0%	0.0%	0.0%	0.0%	
NW	1.0%	25.0%	10.0%	12.0%	
SE	12.5%	2.5%		7.5%	
SW	4.0%	5.0%	1.0%	3.3%	
	4.6%	8.2%	3.8%	5.8%	6.9%

count-> 35

Performance Weighting Peak Month Flows/ADF

Crosstab Table For Average perfpkmo by region and size

	Large	Medium	Small	Avg- Reg.	Avg - All
CENTRAL	4.1%	5.4%	2.7%	4.1%	
NE	0.0%	0.0%	0.0%	0.0%	
NW	0.5%	10.0%	10.0%	6.8%	
SE	12.5%	12.5%		12.5%	
SW	1.0%	4.8%	4.0%	3.3%	
	3.6%	6.5%	4.2%	5.3%	5.7%

count-> 35

Appendix E

Literature Review

Appendix E Literature Review

Review of the Literature

The authors of this project conducted an extensive literature search to obtain nationwide information on current trends in maintenance of wastewater collection systems.

The literature review included a search of the 1990-1997 publications listed below:

- Beton werk und Fertigtel - Technik
- Civil Engineering
- Engineering News Record
- Journal of Infrastructure System
- Journal of Professional Issues in Engineering
- Journal of Urban Planning and Development
- Optimizing the Resources for Water Management - Proceedings of the ASCE 17th Annual National Conference (1990)
- Proceedings of the International Conference on Pipeline Infrastructure II (1993)
- Proceedings of the 1995 Construction Congress
- Proceedings of the 1991 Specialty Conference on Environmental Engineering
- Public Works
- Urban Drainage Rehabilitation Programs and Techniques (1994)
- Water Engineering and Management
- Water Resources Infrastructure: Needs, Economic, and Financing (1990)
- Water Resources Planning and Management and Urban Water Resources (1991) - Proceedings of the 18th Annual Conference and Symposium
- Water Resources Planning and Management and Urban Water Resources (1993) - Proceedings of the 20th Anniversary Conference on Water Management in the 90s
- Water Resources Planning and Management: Saving a Threatened Resource - In Search of Solutions, Proceedings of the Water Resources Sessions at Water Forum (1992)
- 1992 Nation Conference on Water Resources Planning and Management (Water Forum 92)

Summary of Findings

Information from the following papers was used, in part, in the development of the survey form used for this study.

Anonymous (1994) Districts expand sewer rehabilitation program. *Public Works*, v125, n 9, 34-35.

The article describes system reinvestment through installation of a pipe liner in 40,000 linear feet of large diameter sewer (48 inches and larger) in 1993. The systems oldest sewers were constructed in 1926.

Burgess, Edward H. (1990) Planning model for sewer system rehabilitation. Proceedings of ASCE's Conference on Water Resources Infrastructure: Needs, Economics, and Financing, Fort Worth, TX, April 18-20, 1990.

A probabilistic model is developed to simulate long-term variation in the structural condition of wastewater collection systems. The effect of both deterioration and rehabilitation strategies as an extension of current sewer system planning and management practices was discussed.

Bergman, William (1991) 1991 Update on sanitary sewer rehabilitation metropolitan Chicago. *Water Resources Planning and Management and Urban Water Resources*, 825-829.

The following data for the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) was reported:

- Provided collection for 875 square miles, 5,100,000 people plus commercial/industrial population equivalent to 4,500,000 people.
- 520 miles of interceptor sewer, seven water reclamation plants.
- 125 communities own and operate separate sanitary sewers with a total discharge population equivalent of 2,000,000 people.
- MWRDGC required each community to do comprehensive sewer rehabilitation in 1973.
- 1973-1985 - $100,000,000 was spent by tributary communities, but was not successful in reducing I/I.
- 1986 - I/I Corrective Action Program (ICAP).
- 1987-1991 - estimated that an additional $140,000,000 (to the previous $100,000,000) would be needed to complete cost-effective rehabilitation.

The reinvestment needs for the I/I corrective program were identified at $240,000,000.

Dillard, Wayne C. (1993) Management of sewer system rehabilitation for the overflow abatement program in Nashville, Tennessee. Proceedings of the International Conference on Pipeline Infrastructure II, San Antonio, TX, August 16-17, 1993.

To comply with state order to abate overflows of wastewater from sanitary sewers:

- **$** Metropolitan Department of Water and Sewer Services (MWS) owns and operates:
  - 472,700 acre service area.
  - three treatment facilities permitted to treat dry flow of 148.5 mgd plus a wet flow of 100 mgd.
- **$** Phase I project to provide replacement or rehab of deteriorated sewers and overloaded pumping stations. Limited flow monitoring and TV inspection data for these early projects. Because of inadequate data and data interpretation on a system-wide basis, a defect classification system was developed which would consistently categorize common defects and provide criteria for assigning degrees of severity and rehabilitation techniques.
- **$** A two- and five-year recurrent interval design was used based on how environmentally "sensitive" an area is.

Erdos, Lawrence I. (1991) Rehabilitation of urban pipelines. Proceedings of the 18th Annual Conference and Symposium, New Orleans, LA, May 20-22, 1991.

An article for the City of Los Angeles which projected a year 2000 budget of $4.9 billion for rehabilitation of the 6,000 miles of mainline sanitary sewers (8 inches to 14 feet in diameter). This is in addition to the $1 billion spent over the past 10 years.

Galeziewski, Thomas M. (1996) Plumbing the quality of a sewer system. *Civil Engineering* (New York) 66, 1 January 1996.

Phoenix, AZ

- **$** Sewers in this study were installed in mid-1960s.
- **$** Corrosion problems in unlined sewers.

Condition Assessment Program - $570,000. The assessment was to locate defective pipes and prioritize them for rehabilitation. Also, recommended a method of rehabilitation or replacement.
Estimated cost of rehab/replacement was $8.47 million.

Phoenix wastewater collection system size:

- $ 3,700 miles (8 to 90-inch in diameter).
- $ 7,200 manholes.

Unlined pipe: 116,347 ft (24 to 60-inch diameter) 258 manholes.

Gray, William R. (1990) Sanitary sewer bypass reduction program. ***Water/Engineering and Management,*** **v 137, n 5, May 1990.**

Elmhurst, Illinois, has a population of 44,000. The area is served by approximately 77,000 linear feet of gravity sewer and 10 lift stations.

Elmhurst implemented a program to reduce the incidence of sanitary sewer backups into basements and bypassing of wastewater into receiving streams following moderate to intense storm events.

Upgrading of system included 59,000 linear feet of sanitary relief sewers and force mains along with upgrading of lift stations.

Gregory, Henry N. Jr. (1990) New technologies help Houston inspect its sewers. ***Public Works, v 121, n 2, February 1990.***

The City of Houston, Texas, conducted a physical inspection program on its 4,500 mile sewer system using laptop computers and image storage software and hardware. Cost of the program was estimated at $100 million.

Harman, Duane G. (1990) Evaluation plus history equals sewer renovation. Proceedings of ASCE's Conference on Water Resources Infrastructure: Needs, Economics, and Financing, Fort Worth, TX, April 18-20, 1990.

Fort Worth Zoo
477 manholes, 194,000 feet of sewer
3,952 residential units and 18 acres of commercial.

Intensive survey activities including flow monitoring, computer modeling, and analysis for cost-effective I/I removal. Key data are as follows:

- $ 2060 I/I sources identified (849 infiltration sources, 1,211 inflow sources).
- $ The I/I costs are for treatment and transport of the I/I flow rate. Treatment cost is for increasing treatment capacity, plus the present worth of increased cost of plant

operation for 20 years at 8.78 percent interest. Treatment cost for Fort Worth is $10.115/gpd of I/I. Transport cost is for constructing relief sewers to carry the I/I. The "present worth" of the renovation work is the construction cost for eliminating specific I/I sources, to accomplish a level of I/I reduction, plus the treatment and transport cost for the remaining I/I.

Cost-effective levels	Repair Cost
23% infiltration removal	<$1.05/gpd
68.5% inflow removal	<$1.70/gpd

Summary of Recommend Plan		
	Capital Cost (Million $)	Estimated Maintenance & Savings ($/20 Years)
I/I Removal	0.802	$0
New Sewers	0.775	$84,620
Maintenance	0.758	$770,620
Total	2.335	$855,240

- $ Maintenance includes TV lines and review of historical records. Historical records for all pipes were reviewed. Those with maintenance cost projected over 20 years that exceeded replacement costs were included for replacement.
- $ Reduced I/I by 60%.
- $ Effective cost of recommended plan: $2.335 million - $0.855 million = $1.480 million.

Kerri, Ken; Arbour, Rick (1998) Collection systems. ***Methods for Evaluating and Improving Performance.***

Nationwide public awareness of collection system performance has increased in recent years because of the frequency and severity of sanitary sewer overflows (SSOs). The occurrence of SSOs indicates that a growing number of wastewater collection system agencies are failing to meet their primary responsibility, which is to convey the community=s wastewater in a manner that protects the public=s safety and health, and the environment.

The ability to effectively operate and maintain a collection system so it performs as intended depends greatly on proper design, construction and inspection, acceptance, and system start-up. The benefits of an effectively operated and maintained collection system include management and protection of the community=s assets (investment in the system), service to customers, regulatory compliance, protection of the safety and health of the public, environmental protection, and cost-effective use of agency resources.

This manual includes:

- Information on how to establish an effective collection system O&M program that will maintain the functional and structural integrity of the collection system,
- Information regarding how to evaluate the adequacy and effectiveness of existing O&M programs through the use of performance indicators, and
- Information on how to improve the performance of collection systems.

Steps in the evaluation process include:

- Verifying and validating what is being done right,
- Identifying areas of the O&M program that affect system performance,
- Identifying areas of opportunity for more cost-effective O&M of the system,
- Identifying areas of potential liability, and
- Adapting successful ideas and solutions from other agencies nationwide to improve performance.

This manual provides a detailed analysis of the data provided by 13 agencies whose systems consist of sanitary sewers only. The benchmark data are organized by both population served and miles of gravity sewer. Agencies can compare their system characteristics with other systems and also their level of production, performance, and budget with other similar agencies. Subjects for comparison include operation and maintenance data, finance, training and certification, safety, level of service, regulatory compliance, O&M policies and procedures, and information management. Critical performance indicators include stoppages per 100 miles of gravity sewer, complaints per 100,000 population served, and response time for service requests

.

Macaitis, William (1993) Collection system inspection and rehabilitation program. *Water Resources Planning and Management and Urban Water Resources*.

Metropolitan Water Reclamation District of Greater Chicago:

- Serves area of 875 square miles.
- 535 mile collection system.
- The first sewer was constructed in 1906. Present worth of sewers is $3.8 billion. Sewers 50 years or older have a total length of 170 miles and a present worth of $1.5 billion.
- Spent approximately $3 million in last 10 years on emergency repairs.

Macaitis, William; Kuhl, Robert (1994) Local Sewer Rehabilitation - Metro Chicago. ***Urban Drainage Rehabilitation Programs and Techniques*****, 111-122**

The Metropolitan Water Reclamation District of Greater Chicago is a regional wastewater agency encompassing an area of 875 sq. miles in Cook County, Illinois. The city of Chicago and 124 neighboring municipalities are served by the Water Reclamation District. The purpose of the study was to reduce overloading of the conveyance system and to alleviate the widespread occurrence of home and basement flooding.

The Water Reclamation District formulated and adopted a rehabilitation program in the 1970s and revised the program in 1985, which was patterned after the US EPA cost-effective methodology. The agencies were given two options: Either reduce the average wet-weather flow to 150 gpcpd under the old (1970s) program or implement a sewer rehabilitation program based upon the US EPA Corrective Action Program

(ICAP). Details of the ICAP option were defined in the "Sewer Summit Agreement," developed jointly by the IEPA, the Water Reclamation District, and local agencies.

The main features of the ICAP program included a Sewer System Evaluation Study (SSES) which consisted of a data collection and flow monitoring program, sewer system investigations, plans for corrective action in both public and private sectors, and construction of projects.

Based on the submitted SSES reports, the Water Reclamation District estimated that the total cost for local sanitary sewer systems rehabilitation would be $240 million (1985 dollars). Of this total, $100 million of work was completed prior to the 1985 Sewer Summit Agreement. The ICAP program represents a savings of $1.16 billion to the local agencies compared to the estimated $1.4 billion needed to complete the Sewer Rehabilitation, 150 option program. As a result of a 1993 Water Reclamation District survey, with 90 percent of the public sector and 80 percent of the private sector work completed, a revised estimate of $195 million (from the original $240 million estimate) was projected to be spent by the local agencies on sanitary sewer system rehabilitation as a result of the Sewer Summit Agreement.

Of the corrective work performed in the public sector, all identified I/I sources associated with manholes were found to be cost-effective to repair. In general, sewer grouting was determined to be a cost-effective repair. Sewer lining, sewer replacement, and interconnection repairs were usually found not to be cost-effective. In the private sector,

down spouts and foundation sumps were found to be cost-effective repair items. Gravity foundation drain disconnections were generally found not to be cost-effective.

All agencies are required by the Sewer Summit Agreement to establish a long-term Operation & Maintenance (O&M) program. The three core elements of an acceptable O&M program are:

1. A five-year inspection cycle of all sewers and appurtenances.
2. TV inspection of any problem areas.
3. A program funded by annual budget appropriations or user fees.

The Water Reclamation District's treatment plants and interceptor system were designed and sized nominally for 150 gpcpd. The ICAP program reduced flows from 764 to 370 gpcpd, but the residual flow would have to be accommodated to prevent backups and overflows. It was determined that storing peak flows at remote sites for treatment at off-peak hours and providing additional regional treatment plant capacity as required would be the most cost-effective plan. The flow equalization was estimated to cost $0.6 billion.

Macaitis, William; Paintal, Amreek (1994) Interceptor inspection and rehabilitation program. ***Urban Drainage Rehabilitation Programs and Techniques,*** **123-142**.

Description of methods conducted in inspection and rehabilitation for program: physical inspection, CCTV inspection, void defect inspection, flow monitoring, computerized mapping, documentation, and underground advisory committee.

Metropolitan Water Reclamation District of Greater Chicago: One third of the system is more than 50 years old; with cave-ins being a common occurrence.

- **$** Based on costs experienced during last 10 years, average annual cost of unscheduled emergency repair has been $300,000.
- **$** A program cost $1.4 million per year not including cost of rehabilitating sewers

Nelson, Richard E., ***ASSES Experience in Kansas,*** **presented at the Kansas Water Pollution Control Association, Lawrence, KS, April 1993, 20 pages.**

Sewer System Evaluation Survey (SSES) are being performed or being considered throughout Kansas in an effort to meet regulator requirements and to improve sewerage service to customers. Following completion of the SSES, rehabilitation work is performed to correct identified deficiencies. A survey was conducted encompassing 10 cities and agencies, which include 12 service areas. The cities/agencies surveyed ranged in area from 9 to 150 square miles, with 55 to 1,500 miles of sewer line and an average daily flow

(ADF) from 1.2 MGD to 60 MGD, with populations ranging from 10,500 to 285,000 persons. The average age of the cities/agencies ranged from 20 to 63 years. Conclusions based on collected information include: (1) routine inspection activities include manhole inspections, line inspections and testing, and private sector work, (2) sewer systems degrade continuously and a plan is required to effectively manage this degradation, (3) rehabilitation is effective in improving system performance, (4) rehabilitation costs are typically about $25 per foot of sewer, but vary widely and are system-dependent, and (5) annual inspection frequency of about 6 to 10 percent of the system per year can be a cost-effective way to manage system performance.

Malik, Omesh; Pumphery, Jr., Norman D.; Roberts, Freddy L., ASanitary Sewers: State-of-the-Practice@. *ASCE Infrastructure condition Assessment,* 297-306.

Researchers are developing the framework of a sanitary sewer management system (SSMS). Too often and predominantly, a Aworst first@ or Acrisis management@ system exists, causing inefficient use of the meager resources available for maintaining and upgrading the sanitary sewer system. Of those who have a systematic management procedure in place, little compatibility exists so that the municipalities have difficulty in sharing information. As a first step in development of the SSMS, a state-of-practice survey was mailed to over 450 cities and sanitation districts across the United States. A survey was conducted through 121 cities and agencies, with population ranging from 40,000 to 832,750 persons. Cities with populations less than 20,000 or with less than 50 miles of sewer have been excluded from this study. The average age of the cities/agencies ranged from 29 to 42 years. An average city or sanitation district has 1,075 kilometers (667 miles) of sewer, a population of 221,199, and an annual budget of almost $3 million. On the average each city spent an average of about $14 per person and $2,790 per kilometer ($4,497 per mile) of sewer in the 1995. Each kilometer of sewer serves 228 people. According the survey, only 48% of the cities have some established procedures set down for planned maintenance, consisting mostly of the cleaning the lines, and only 45% of the respondents use some kind of subjective criteria for repairing sewers which are in poor conditions. Only 21% of the cities have any kind of historical data upon which to base decisions for the future, with only 26% of the cities making an attempt to predict the future condition of the different sections of the system. Several steps are involved to establish the state-of-practice for sanitary sewer management and for condition assessment.

Wright, Andrew G. (1996) Miami looks for alternatives to blue-chip sewer overhaul. *Engineering News Record*, McGraw-Hill, Inc., 22-25.

Program started - 1988
Target end date - 2002
Estimated expense - $1.1 billion

- **$** System Characteristics
  - 400 sq. miles.
  - 2,400 miles of gravity sewers.
  - 640 miles of force mains.
  - 874 pump stations.
  - average flow = 320 mgd.
  - peak flow = >700 mgd.
  - three treatment plants.
- **$** US EPA brought a federal lawsuit against Miami and to settle, Miami agreed to the $1.1 billion program.
- **$** They believe the program should be much less than $1.1 billion when completed.
- **$** Between 1985 and 1994 system-wide overflows were between 2,200 and 2,600.

Zimmerman, Robert A; Martin, Robert D., AFrom Prevention to Prediction,@ *Water Environment & Technology*, August, 1993.

- **$** A model to predict sewer system rehabilitation needs has enabled the city of Moorhead, Minnesota, to preserve its gravity sewer system and minimize costly repairs. The city used information from an existing preventive maintenance program and expanded it into a predictive maintenance program. Information from a routine preventive maintenance program, including sewer cleaning reports, sewer service connection records, sewer inspections, and video inspection reports, was used to develop the predictive model. Data collected included:
  - **$** pipe location
  - **$** pipe diameter
  - **$** pipe length
  - **$** pipe age
  - **$** video inspection status
  - **$** pipe condition
  - **$** type of rehabilitation required
  - **$** length of pipe in need of rehabilitation

The statistical relationship between the percent of sewer lengths needing rehabilitation and sewer pipe age can be expressed as:

$$Y = 0.00183^{0.070x}$$

where Y = the percent of the total length of sewer lines requiring rehabilitation, and x = the age of sewer pipe in years.

Bibliography

(1) Anonymous (1994) Districts expand sewer rehabilitation program. *Public Works*, v 125 n 9, 34-35.

(2) Arbour, Rick; Kerri, Ken (1998) Collection Systems. *Methods for Evaluating and Improving Performance*, California State University, Sacramento Foundation.

(3) Bergman, William (1991) 1991 Update on sanitary sewer rehabilitation metropolitan Chicago. *Water Resources Planning and Management and Urban Water Resources*, 825-829.

(4) Browne, Roger; Knott, Graham (1993) Television and scanning sonar in Seattle metro's siphons and brick sewers. Proceedings of the International Conference on Pipeline Infrastructure II, San Antonio, TX.

(5) Burgess, Edward H. (1990) Planning model for sewer system rehabilitation. Proceedings of ASCE's Conference on Water Resources Infrastructure: Needs, Economics, and Financing, Fort Worth, TX April 18-20, 1990.

(6) Day, Michael D. (1990) Balancing needs. Growth & infrastructure rehabilitation. Proceedings of ASCE's Conference on Water Resources Infrastructure: Needs, Economics, and Financing, Fort Worth, TX April 18-20, 1990.

(7) Dillard, Wayne C. (1993) Management of sewer system rehabilitation for the overflow abatement program in Nashville, Tennessee. Proceedings of the International Conference on Pipeline Infrastructure II, San Antonio, TX August 16-17, 1993.

(8) Edwards, Curtis L. (1991) Mission Bay Park, San Diego sewage interceptor system. Proceedings of ASCE's 18th Annual Conference and Symposium, New Orleans, LA May 20-22, 1991.

(9) Erdos, Lawrence I. (1991) Rehabilitation of urban pipelines. Proceedings of the 18th Annual Conference and Symposium, New Orleans, LA May 20-22, 1991.

(10) Galeziewski, Thomas M. (1996) Plumbing the quality of a sewer system. *Civil Engineering* (New York) 66, 1 January 1996.

(11) Gray, William R. (1990) Sanitary sewer bypass reduction program. *Water/Engineering and Management*, v 137, n 5 May 1990.

(12) Gregory, Henry N. Jr. (1990) New technologies help Houston inspect its sewers. *Public Works*, v 121, n 2 February 1990.

(13) Gwaltney, Tim (1995) Total system solution**T**M. Proceedings of the 1995 Construction Congress, San Diego, CA October 22-26, 1995.

(14) Haas, C. (1995) Evaluation of new underground infrastructure maintenance technologies. *Journal of Infrastructure Systems*, 1, 4.

(15) Hannan, Philip (1994) Collection system material improvements for precast concrete manholes in the Americal wastewater technique. Beton werk und Fertigteil-Technik, v 60, n 4, April 1994.

(16) Harman, Duane G. (1990) Evaluation plus history equals sewer renovation. Proceedings of ASCE's Conference on Water Resources Infrastructure: Needs, Economics, and Financing, Fort Worth, TX April 18-20, 1990.

(17) Huckabee, Adrian J. (1990) Developing a wastewater plan for an urbanizing area - The case of Johnson County, Texas. Proceedings of ASCE's 17th Annual National Conference, Fort Worth, TX April 17-21, 1990.

(18) Karaa, Fad (1989) Infrastructure maintenance management system development. *Journal of Professional Issues in Engineering*, v 115, n 4 October 1989.

(19) Lund, Jay R. (1990) Cost-effective maintenance and replacement scheduling. Proceedings of ASCE's Conference on Water Resources Infrastructure: Needs, Economics, and Financing, Fort Worth, TX April 18-20, 1990.

(20) Macaitis, William (1993) Collection system inspection and rehabilitation program. *Water Resources Planning and Management and Urban Water Resources.*

(21) Macaitis, William; Paintal, Amreek (1994) Interceptor inspection and rehabilitation program. *Urban Drainage Rehabilitation Programs and Techniques*, 123-142.

(22) Macaitis, William; Kuhl, Robert (1994) Local Sewer Rehabilitation - Metro Chicago. *Urban Drainage Rehabilitation Programs and Techniques*, 111-122.

(23) Malik, Omesh; Pumphery, Jr., Norman D.; Roberts, Freddy L., ASanitary Sewers: State-of-the-Practice@. *ASCE Infrastructure condition Assessment,* 297-306.

(24) Morin, Kenneth (1991) Navy targets effective infiltration/ inflow elimination. Proceedings of ASCE's 1991 Specialty Conference on Environmental Engineering, Reno, NV.

(25) Nelson, Arthur C. (1991) Wastewater planning and administration concerns along southeastern U.S. coast. *Journal of Urban Planning and Development*, v 117, n 1 March 1991.

(26) Nelson, Richard E., A*SSES Experience in Kansas*,@ presented at the Kansas Water Pollution Control Association, Lawrence, KS, April 1993, 20 pages.

(27) Pickell, Mark B., ed. (1993) Proceedings of the International Conference on Pipeline Infrastructure II, San Antonio, TX August 16-17, 1993.

(28) Rowlett, Thomas (1992) When sewer rehab doesn't stop basement flooding. Water Resources Planning and Management: Saving a Threatened Resource - In Search of Solutions. Proceedings of the Water Resources Sessions at Water Forum.

(29) Schindewolf, Jimmie (1995) Texas-sized SSO solution. *Civil Engineering*, 65, 12, December 1995.

(30) Serpente, Robert F. (1994) Understanding the modes of failure for sewers. *Urban Drainage Rehabilitation Programs and Techniques*, 86-100.

(31) Wright, Andrew G. (1996) Miami looks for alternatives to blue-chip sewer overhaul. *Engineering News Record*, McGraw-Hill, Inc., 22-25.

(32) Zimmerman, Robert A; Martin, Robert D., AFrom Prevention to Prediction,@ *Water Environment & Technology,* August, 1993.

Appendix F

Optimization of Collection System Maintenance Frequencies and System Performance (with sample diskette)

11/23/98

Title: Optimization of Collection System Maintenance Frequencies and System Performance

By:American Society of Civil Engineers
For: EPA, Cooperative Agreement # CX 824902-01-0
Author: Black & Veatch
Contact: Rick Nelson, Principal Investigator
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Characteristic Data

No.	Characteristic Data	Qty	
1	Miles of Sewer	525	
2	Number of Pump Stations	55	
3	Size Code	2	
4	Regional Code	5	
5	System Reinvestment, $/mi/yr	$1,988	life of system
6	System Reinvestment, $/mi/yr	$5,596	1980-1996
7	Pump Stations/ mile	0.105	
8	Average System Age	50.0	

Size Code		
1	Small	<100,000
2	Medium	100,000-500,000
3	Large	> 500,000

Regional Code	
1	Central
2	Northeast
3	Northwest
4	Southeast
5	Southwest

Determination of Maintenance Frequency

No.	Maintenance Activity	Qty	Unit	Years	Rate	Unit	Relative Importance	Standardized Frequency	Weighted Frequency
1	Cleaning of Sewer Lines	844	miles	5	32.2%	% system/yr	17.7%	10.0%	1.77%
2	Root Removal	20	miles	5	0.8%	% system/yr	8.4%	6.0%	0.50%
3	Pumping Station Inspection	11876	number	5	43.2	no/ps/yr	14.1%	5.0%	0.71%
4	Flow Monitoring	2%	% system	5	0.4%	% system/yr	7.0%	3.0%	0.21%
5	Manhole Inspection	100%	% system	5	20.0%	% system/yr	6.4%	10.0%	0.64%
6	Smoke/Dye Testing	0%	% system	5	0.0%	% system/yr	3.3%	3.0%	0.10%
7	CCTV	5%	% system	5	1.0%	% system/yr	10.5%	5.0%	0.53%
8	Private Sector Inspections	0%	% system	5	0.0%	% system/yr	2.0%	1.0%	0.02%
9	Manhole Rehabilitated	95%	% complete	n/a	95%	% complete	5.6%	18.0%	1.01%
10	Sewer Line Rehabilitated	60%	% complete	n/a	60%	% complete	12.6%	14.0%	1.76%
11	Relief/Equalization	0%	% complete	n/a	0%	% complete	6.3%	0.0%	0.00%
12	Private Sectors Rehabilitated	0%	% complete	n/a	0%	% complete	6.1%	1.0%	0.06%
							100.0%		**7.3%**
							sum		***Maintenance Frequency***

Determination of Performance Rating

No.	Performance Measure	Qty	Unit	Years	Rate	Unit	Relative Importance	Standardized Frequency	Weighted Frequency
1	Pipe Failures	3	number	5	0.001	no/mi/yr	22.6%	100.0%	22.6%
2	SSOs	76	number	5	0.029	no/mi/yr	23.6%	87.1%	20.5%
3	Customer Complaints(1)	4074	number	5	1.552	no/mi/yr	20.8%	71.3%	14.8%
4	Pump Station Failures	60	number	5	0.023	no/mi/yr	17.8%	32.1%	5.7%
5	Peak Hourly/ ADF Ratio	3	ratio	n/a	3	ratio	9.7%	32.1%	3.1%
6	Peak Month/ ADF Ratio	2.5	ratio	n/a	2.5	ratio	5.5%	30.0%	1.7%

(1) Includes complaints, basement backups and "other".

100.0%		**68.5%**
sum		***Performance Rating***

Equation Results:

Equation Name	Result
PR1	47.0%
RE1	($10,247)
RE2	$2,502
RE3	$4,203
RE4	$11,087