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Handbook

Sewer System Infrastructure Analysis and Rehabilitation

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Center for Environmental Research Information

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CHAPTER 1

Introduction

Many of our nation's sewer systems date back over 100 years to the 19th century, when brick sewers where common.[1] These and other more recent sewer systems can be expected to ultimately fail in time, but because they are placed underground, signs of accelerated deterioration and capacity limitations are not readily apparent until there is a major failure. Sewer pipe failures start with cracking, lateral deflection, crown sag and offset joints, as well as by deteriorated mortar and exposed reinforcing caused by hydrogen sulfide (H_2S) corrosion. Most of what the community sees is the inevitable result of prolonged neglect, such as cracked pavement, collapsed streets, backed-up sewers, streams and groundwater contamination or local flooding.[1] Proper sewer evaluation and maintenance schedules would help communities identify the condition of their sewer system's infrastructure, and timely rehabilitation could save the community large expenditures required to replace the deteriorated sewers, and extend the sewer use life. Tables 1-1 and 1-2 indicate the amount of money spent for sewer system major rehabilitation projects by U.S. EPA under the construction grants program.[2] In addition to the construction grants program, municipalities and utilities have utilized State Revolving Funds, Community Development Block Grant and other funding options to fund Infrastructure needs. Adequate sewer system Infrastructure evaluation and rehabilitation is of prime importance as the first step in this effort.

1.1 Purpose and Intended Audience

This Handbook provides guidance on the evaluation and rehabilitation of existing sewers. It presents information on typical problems, procedures and methods for rehabilitation, case study information, budgetary costs, advantages and disadvantages of rehabilitation techniques, and application of these techniques and materials/equipment used in rehabilitation. It also guides the reader in understanding the importance of, and ways for, conducting the sewer system evaluation and identifying the rehabilitation procedure that best suits a particular problem. By necessity, information contained in this Handbook for conducting a sewer system evaluation is general and not site-specific. The intent is to present sufficient information to enable engineers and public decision makers to plan and conduct sewer system evaluation and rehabilitation under circumstances which might be encountered when dealing with a specific sewer system. Because a variety of circumstances are encountered in sewer systems, all of the methodology presented in this Handbook will not apply to each project. It is emphasized that the reader should apply only those portions of the methodology that are relevant to the specific project under study.

1.1.1 Definition of Sewer System Infrastructure

Sewer system infrastructure conveys wastewater used by individuals and by commercial and industrial establishments to wastewater treatment facilities, ultimately to be returned to the natural environment. These systems protect public health and the environment and encourage economic development.[3]

1.1.2 Importance of Maintaining Infrastructure System Integrity

The primary importance of sewer system evaluation and rehabilitation is to maintain the structural integrity of the sewer system for dependable transfer of wastewater from the source to the treatment facility.[4] Since the passage of Public Law 92-500 in 1972, more emphasis has been placed on sewer rehabilitation to reduce the hydraulic loads placed on the treatment plants from excessive infiltration/inflow (I/I). When the integrity of a sewer system is allowed to deteriorate, extraneous water from I/I sources enter the sewers. These flows reduce the capability of sewer systems and treatment facilities to transport and treat domestic and industrial wastewaters. As a result, wastewater treatment processes are upset and poorly treated wastewater is discharged to the environment.

Infiltration occurs when existing sewer lines undergo material and joint degradation and deterioration, as well as when new sewer lines are poorly designed and constructed. Inflow normally occurs when rainfall enters the sewer system through direct connections such as roof leaders, catch basins, manholes, and other direct cross connections. The elimination of I/I by sewer system

TABLE 1-1 CONSTRUCTION GRANTS FUNDING SPENDING FOR CATEGORY IIIA, MILLION $ (2)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Summary
EPA REGION	IIIA	IIIA	IIIA	IIIA	IIIA	IIIA	IIIA	IIIA	IIIA	IIIA	IIIA	IIIA	IIIA
I	10.08	65.28	10.17	0.65	19.26	7.63	20.28	17.68	12.29	13.76	0.69	---	177.07
II	---	0.13	6.71	4.39	5.97	18.44	49.37	9.58	22.86	3.32	---	---	120.76
III	0.34	34.25	0.36	22.39	11.77	51.21	47.87	2.26	20.80	4.88	7.26	3.66	207.04
IV	14.05	24.31	11.09	9.32	12.45	13.80	23.51	4.18	9.71	2.97	16.44	7.63	149.43
V	40.94	35.67	74.21	13.77	23.47	98.21	144.57	104.81	40.29	65.41	33.38	19.70	694.44
VI	2.86	15.35	41.52	87.03	9.20	44.34	29.24	38.23	17.89	7.83	30.40	6.65	330.54
VII	8.84	16.82	14.88	14.44	16.76	19.26	3.30	2.55	2.55	2.67	13.31	6.66	122.03
VIII	1.59	2.00	0.57	---	---	---	2.00	---	0.47	---	2.00	0.32	8.95
IX	19.13	2.10	2.55	10.91	0.72	1.40	6.03	---	2.68	27.81	31.65	25.00	129.95
X	2.42	4.83	6.56	7.49	6.71	0.65	4.30	2.66	0.18	6.43	8.49	6.17	56.88
SUMMARY	100.25	200.73	168.62	170.37	106.31	254.93	330.48	181.95	129.69	135.06	143.62	75.78	1997.10

NOTES:

IIIA: That portion of the eligible cost of a wastewater treatment construction project (including an appropriate portion of all eligible administrative, legal, architect and engineering, contingency and like costs) that is required for the identification of sewer infiltration/inflow problems. This can also include costs for a preliminary infiltration/inflow analysis or a detailed sewer system evaluation survey

TABLE 1-2 CONSTRUCTION GRANTS FUNDING SPENDING FOR CATEGORY IIIB, MILLION $ (2)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Summary
EPA REGION	IIIB	IIIB	IIIB	IIIB	IIIB	IIIB	IIIB	IIIB	IIIB	IIIB	IIIB	IIIB	IIIB
I	2.06	107.17	5.57	8.50	30.26	20.63	50.97	23.48	3.88	---	---	---	252.50
II	---	9.44	22.61	22.35	0.20	24.60	3.50	10.67	---	8.55	30.62	---	132.53
III	9.14	56.81	43.45	17.10	25.90	51.77	41.45	5.85	---	2.01	63.83	3.97	321.29
IV	13.18	58.09	14.68	29.64	26.66	27.72	11.01	8.83	1.28	19.34	9.65	---	220.09
V	30.36	50.89	20.85	38.96	54.30	59.84	102.46	9.34	5.97	6.58	2.31	32.45	414.31
VI	0.89	31.30	23.73	30.31	10.34	33.99	10.77	0.13	2.81	---	0.65	---	144.92
VII	28.40	26.41	37.35	12.46	5.44	15.37	---	0.21	---	0.57	2.30	0.91	128.50
VIII	0.99	1.80	0.77	1.87	---	4.18	14.18	---	3.41	1.51	7.14	6.01	41.87
IX	4.24	21.83	16.37	23.48	0.37	5.33	4.39	1.89	---	10.58	---	---	88.48
X	31.93	25.91	18.96	1.60	0.94	0.32	5.01	2.16	---	1.88	---	1.41	90.13
TOTAL	121.19	389.65	204.34	186.26	154.40	243.77	243.73	62.57	17.35	51.02	116.49	44.75	1834.62

NOTES:

IIIB: That portion of the eligible cost of a wastewater treatment construction project (including administrative, legal, architect and engineering and like costs) that is required for replacement and/or major rehabilitation of existing sewer systems. Costs are applicable if the corrective actions are necessary for the total integrity of the system. Major rehabilitation is considered to be extensive repair of existing sewers beyond the scope of normal maintenance programs where sewers are collapsing or are structurally unsound.

rehabilitation can often substantially reduce the cost of wastewater collection and treatment. However, a logical and systematic evaluation of the sewer system is necessary to determine the cost-effectiveness of any sewer system rehabilitation program designed to eliminate exfiltration, infiltration and inflow.

The reduction of I/I can result in a significant reduction in hydraulic loading at collection and treatment facilities during periods of wet weather, thus lowering capital and O&M costs and prolonging the lifetime-capacity of the treatment facility.[3] Pipeline rehabilitation techniques can restore capacity and structural reliability for 30-70 percent of the sewer replacement costs.

1.1.3 Existing Source Documents

There have been a number of reports published that provide information on sewer system infrastructure evaluation and rehabilitation. A description of these materials is provided in order, starting from the oldest dated publication:

- *Handbook for Sewer System Evaluation and Rehabilitation.*[4] This document was prepared to provide the general guidance and technical information on the methodology necessary for an effective investigation and correction of I/I conditions in a sewer system. The handbook describes the methods for conducting I/I analysis, sewer system evaluation surveys, sewer system rehabilitation and budgetary cost estimating techniques for the rehabilitation methodologies mentioned. The handbook does not contain regulatory requirements to indicate the applicable U.S. EPA regulations on existing, new or upgraded systems.
- *Sewer System Evaluation, Rehabilitation and New Construction: A Manual of Practice.*[5] This document was prepared to assist the reader in the detailed investigation of Sewer System Evaluation and Sewer Analysis. It emphasized sewer system evaluation, sewer rehabilitation and the design of new systems to minimize I/I. Sewer cleaning equipment and methods of sewer inspection are discussed in detail. Factors which govern the cost of conducting rehabilitation work and an analysis of factors to be considered for each rehabilitation method are described. The MOP does not provide detailed information on the regulatory requirements.
- *Existing Sewer Evaluation and Rehabilitation.*[3] This manual provides guidelines for the evaluation and rehabilitation of sanitary sewers. It describes the purpose and scope of sanitary sewer rehabilitation and also provides detailed information to the user implementing a sewer rehabilitation program. Major emphasis of the manual is on the reduction of I/I, while less emphasis is placed on maintaining the structural integrity of the sanitary sewer. The manual describes the various methods and materials used for sewer system rehabilitation.
- *Recommended Specifications for Sewer Collection System Rehabilitation.* Fifth Edition. August 1987. The National Association of Sewer Service Companies (NASSCO) has published recommended specifications for sewer collection system rehabilitation. The book is intended to assist engineers and municipal officials in properly specifying materials, methods, equipment and procedures for sewer rehabilitation projects. Specifications are provided for the following rehabilitation procedures: sewer line cleaning, sewer flow control, TV inspection, sewer pipe joint testing, sewer pipe joint sealing, sewer manhole sealing, sewer manhole rehabilitation, sewer manhole lining, sliplining of sewers, and cured-in-place pipe installations. The document also contains sections on measurement of payments, contract responsibilities and definitions.

These reports summarize and provide information and procedures that were applicable at the time of publication on various elements of a comprehensive sewer system analysis. There was not, however until now, a single source document that can be referred to by a reader to obtain comprehensive information on state-of-the-art sewer system rehabilitation techniques and methodologies.

1.2 The Need for a Sewer System Infrastructure Handbook

1.2.1 Changing Requirements

This handbook has been prepared to address the need for consolidating, updating and expanding the information presently available from various sources and to refine some of the previous data analysis methodologies.

The *Handbook for Sewer System Evaluation and Rehabilitation*[4] took into account the regulations in effect at that time and also the available technological procedures to reduce I/I. Federal regulations pertaining to I/I were subsequently revised and simplified in 1981 and 1982.

Studies conducted by U.S. EPA in 1980 concluded that I/I removal rates were substantially less than expected for those rehabilitation methods due to migration of infiltration from rehabilitated areas to non-rehabilitated areas.

Currently, new materials of construction and new techniques and approaches for sewer rehabilitation have been developed and shown to be cost-effective in sewer system rehabilitation. These new techniques are described in Chapter 6 of this handbook.

1.2.2 Comprehensive Analytical Procedures

Unique investigative and analytical techniques have been developed that should be utilized to obtain reliable flow reduction estimates of rehabilitation effectiveness, and selection of rehabilitation methods. Measurements and separate identification of rainfall induced infiltration (RII) is carried out by new methods of evaluating and analyzing flow and rainfall data. New techniques such as the analysis and understanding of infiltration migration phenomenon and improved cost-effectiveness analysis procedures have been implemented by many consulting engineers to more realistically project I/I reduction. These new techniques are described in later sections of this handbook. Studies conducted by the U.S. EPA found that infiltration sources removed by rehabilitation will migrate under certain conditions to unrehabilitated locations.[6,7] As a result, the cost-effectiveness analyses were made applicable for an entire subarea rather than the more conventional individual source approach.

With the availability of new materials of construction such as polyethylene, PVC and other plastic and durable materials described in Chapter 6, coupled with new techniques for trenchless pipe installation, sewer system rehabilitation has become more cost-effective and easy to implement. Consulting engineers, municipalities and utilities have started to understand and take into account the total water balance of a sewer system, based on infiltration, inflow, RII, exfiltration and migration. New data and procedures have led to a more realistic understanding of the limitations and accuracy of methods now employed.

1.3 User's Guide

This document contains six chapters that provide the reader with a condensed summary of pertinent I/I and SSES evaluation and rehabilitation methodologies. It differs from previous documents in that more emphasis is placed on state-of-the art technology rather than on prescribed regulatory requirements.

Table 1-3 presents a brief description of each of the six chapters of this handbook along with a user profile for each chapter.

1.4 References

When an NTIS number is cited in a reference, that reference is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

1. Brown and Caldwell. *Utility Infrastructure Rehabilitation.* NTIS No. PB86-N14642, Department of Housing and Urban Development, Washington, DC, 1984.

2. Grants Information and Control System, Sewer System Major Rehabilitation Projects, U.S. EPA, Construction Grants Federal Budget Spending.

3. *Existing Sewer System Evaluation and Rehabilitation.* ASCE Manuals and Reports on Engineering Practice No. 62, WPCF Manual of Practice FD-6. American Society of Civil Engineers, Water Pollution Control Federation, 1983.

4. *Handbook for Sewer System Evaluation and Rehabilitation.* EPA/430/9-75/021, Municipal Construction Division, Office of Water Program Operations, Environmental Protection Agency, Washington, DC, 1975.

5. American Public Works Association. *Sewer System Evaluation Rehabilitation and New Construction: A Manual of Practice.* EPA/600/2-77/017d, NTIS No. PB-279248. U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Office of Research and Development, Cincinnati, Ohio, December 1977.

6. RJN Environmental Associates, Inc. *National Alternative Methodology for Sewer System Evaluation, Wellington Suburban Sanitary Commission,* 1988.

7. National Water Well Association, RJN Environmental Associates, Inc., and Washington Suburban Sanitary Commission. *Impact of Groundwater Migration on Rehabilitation of Sanitary Sewers.* 1984.

Table 1-3. Summary of Handbook Contents

Chapter	Description	User Profile
1. Introduction	Describes purpose, intended audience, definition of infrastructure, describes source documents, and importance of sewer system infrastructure evaluation.	• All readers
2. Regulatory Requirements Requirements	Provides summary of past U.S. EPA regulations relative to roles of state and federal agencies; provides matrix of state regulations and approval requirements for sewer system improvements	• Regulatory personnel • City officials • Consulting engineers • Public works directors • City planners
3. Preliminary Analysis of Sewer Systems	Describes historical and financial reasons for evaluation of sewer infrastructure needs, outlines a simplified preliminary sewer system and I/I analysis evaluation methodology including sources of information and required resources, presents flow diagram of a sewer system evaluation plan, summarizes the basic elements of infiltration inflow analysis, including the impact of exfiltration and migration	• City planners • City officials • Public works directors • Sewer system study planners • Consulting engineers • Supervisors and staff conducting a sewer evaluation • City sewer
4. Sewer System Evaluation	Describes new techniques and sub-system approach to the traditional sewer system evaluation, includes planning the survey, the physical survey, cleaning, inspection and presentation of separate infiltration and inflow data, cost effective analysis, references other source documents for specific details and proven technological approaches	• Public works directors • Public works officials • Consulting engineers • City managers • Supervisors and staff planning and conducting sewer evaluations • City sewer maintenance staff
5. Corrosion Analysis and Control	Describes the types and mechanisms of sewer corrosion, the importance of corrosion to the integrity of the sewer system, describes how to plan and conduct a sewer system corrosion survey, corrosion inspections techniques, analytical data required, provides methods of rehabilitating corroded sewers; methods for predicting corrosion and methods of conducting corrosion surveys	• City planners • City Officials • Consulting engineers • City engineers • City sewer maintenance staff • Supervisors and staff conducting a sewer system evaluation • Public works directors
6. Sewer System Rehabilitation	Provides the latest information on state-of-the-art sewer rehabilitation techniques including a) excavation and replacement, b) chemical grouting, c) insertion lining, d) inversion lining, e) specialty lining, f) liners, g) coatings and h) building sewers; includes detailed cost estimates for each technique along with case histories of successful projects.	• City managers • Public works officials • Consulting engineers • City engineering staff • Supervisors and staff planning and conducting rehabilitation projects • Contractors • Sub-contractors • Inspectors

CHAPTER 2

Regulatory Requirements

2.1 Historical Background

The Water Pollution Control Act Amendments (Public Law 92-500, October 18, 1972), require that the U.S. EPA construction grant applicants investigate the condition of their sewer systems. The grant cannot be approved unless it is documented that each sewer system discharging into such treatment works is not subject to "excessive infiltration and inflow." This requirement was implemented in the Rules and Regulations for Sewer Evaluation and Rehabilitation (40CFR35.927). In addition, I/I analysis and Sewer System Evaluation Surveys (SSES) were required to be conducted on a routine basis to document I/I, and also to indicate the most cost effective method of rehabilitation required to correct the sewer pipe and manhole structure damage.[1]

The I/I analysis should document the non-existence or possible existence of excessive I/I in each sewer system tributary to the treatment works. The analysis should identify the presence and type of I/I that exists in the sewer system including estimated flow rates. The following information should be evaluated and included:

- Estimated flow data at the treatment facility, all significant overflows and bypasses, and, if necessary, flows at key points within the sewer system
- Relationship of existing population and industrial contribution to flows in the sewer system
- Geographical and geological conditions which may affect the present and future flow rates or correction costs for the I/I
- A discussion of age, length, type, materials of construction and known physical conditions of the sewer system

The SSES should include a systematic examination of the sewer system to determine the specific locations, estimated flow rates, method of rehabilitation and cost of rehabilitation versus the cost of transportation and treatment for each defined source of infiltration and each defined source of inflow.[1] The results of the SSES should be summarized in a report that should include:[2]

- A justification for each sewer section cleaned and internally inspected
- A proposed rehabilitation program for the sewer system to eliminate all defined excessive I/I

2.2 Summary of Applicable U.S. EPA and State Regulations

The following is a Summary of Federal and State Regulations and Guidelines for I/I analysis and SSES applicable under the U.S. EPA construction grant program.[1,3]

The grant applicant must determine the I/I conditions in the sewer system by analyzing the preceding year's flow records from existing treatment plant and pump stations. For smaller systems where flow records may not be available, the grant applicant shall obtain flow data by conducting flow monitoring at a single point at the treatment plant during high groundwater periods and also during rainstorms. If there is a likelihood of excessive I/I in a portion of the collection system, it is desirable to monitor that portion separately. <u>No further I/I analysis will be necessary if domestic wastewater plus non-excessive infiltration does not exceed 120 gallons per capita per day (gpcd) during periods of high groundwater. The total daily flow during a storm should not exceed 275 gpcd, and there should be no operational problems, such as surcharges, bypasses or poor treatment performance resulting from hydraulic overloading of the treatment works during storm events.</u> The flow rate of 120 gpcd for infiltration analysis contains two flow components: 80 gpcd of domestic base flow and 40 gpcd of non-excessive infiltration. This is a national average based on the results of a needs survey of 270 Standard Metropolitan Statistical Area Cities. Where the flow rate (domestic base flow and infiltration based on the highest 7 to 14 day average) does not significantly exceed 120 gpcd (in the range of 130 gpcd) the city may proceed with the treatment works design without further analysis. When infiltration significantly exceeds 120 gpcd, further evaluation of the sewer system must be performed to determine the possibility of excessive I/I through a cost effectiveness analysis. Following the I/I study, a SSES must be performed. The result of the SSES will allow the city to formulate sewer rehabilitation program to eliminate the portion of the I/I that is excessive and size the treatment plant accordingly.

With the elimination of the U.S. EPA construction grants program in October of 1990, all Federal regulations for I/I analysis and SSES under this program will no longer be applicable. Individual states now have their own guidelines and regulations to follow. A survey of state regulatory officials indicates that many states however still follow Ten States Standards[2] and past U.S. EPA standards such as CG85[3] I/I and SSES guidance documents (See Table 2-1). State agencies evaluate general plans and feasibility studies submitted by an applicant for any treatment plant modification application. If the general plan and feasibility study submitted by the applicant show flow variations during wet weather conditions, the State Agency investigates the cause and may request the applicant to conduct a SSES and I/I analysis. They may further request information on the cost effectiveness of rehabilitation versus building a new plant.

2.3 Description of the Relative Roles of the U.S. EPA, State Agencies, and Local Agencies

The U.S. EPA has been very involved in sewer system evaluation and rehabilitation projects since 1973 as a result of the construction grant program. Under this program, the U.S. EPA provided grants to municipalities for I/I analyses, for SSES if excessive flow was found, and for rehabilitation if excessive I/I was found. With the completion of the construction grants program in 1990, the U.S. EPA will play a smaller role in this effort, while the roles of the state and local agencies will become larger.

Table 2-1 outlines the regulations which currently (April 1991) apply to sewer expansion and rehabilitation in each state.[4] As the table shows, requirements vary from state to state. Within the states, requirements depend upon the source of funding for the project.

2.4 Certification Requirements

2.4.1 Historical Perspective

Section 204 of the 1981 Amendments to the Clean Water Act requires that U.S. EPA grant applicants must, after one year's of operation, certify to the U.S. EPA that the project meets design specifications and effluent limitations, including I/I reduction projections. The purpose of the certification requirements is to ensure that effective sewer rehabilitation projects were carried out through the grant assistance programs. On May 12, 1982, U.S. EPA promulgated regulations which clarified and implemented the 1981 requirements. These regulations can be found in 40CFR35. The definition of municipal treatment works was expanded to include interceptor and collector sewers. Furthermore, I/I analysis and SSES work were included in the treatment works performance certification requirements. The grantee is required to certify performance after one year, as stated in the 1981 regulations. In addition, the grantee must prepare a corrective action report for projects not meeting performance requirements, establish a schedule for corrections, and determine a new certification date. These certification requirements apply to all Step 3 grants awarded on or after May 12, 1982.[5]

As a basis for the grantee's certification that SSES performance specifications are being met, a six to twelve month post-rehabilitation monitoring program is recommended. This program will generally include one or more flow monitoring stations, groundwater and rainfall measurements, and other measurements as required to quantify I/I reduction in the rehabilitated areas.[5]

It is the grantee's responsibility to certify that the SSES design and performance standards for I/I reduction have or have not been met. If it is found that these standards have not been met, the grantee must identify specific causes and must rectify the situation at other than federal expense.[5]

2.4.2 Current Situation

With the completion of the construction grants program, it is uncertain whether the states will require a certification program similar to the one required for the federal grants. However, it is a good practice for cities to continue this policy to ensure program effectiveness.

Table 2-1 State Agency Regulations for Sewer System Improvements

	Regulations to be followed for SSES and I/I analysis (CG 85, 10 States) or for expansion or rehabilitation of existing sanitary sewers or lift stations:							Required before applying to expand or upgrade a treatment plant:	
STATE	CG85	10 States Standards	State Review	State Approval	Permit to Install	Other		SSES	I/I Analysis
AK	(a)	yes	yes	yes	yes	no	:	no	no
AL	(a)	(a)	(a)	(a)	no	no	:	(a)	no
AR	(a)	(b,c)	yes	yes	no	(e)	:	(f)	yes
AZ	no	no	yes	yes	no	(g)	:	no	no
CA	(a)	no	(a)	(a)	no	no	:	(a)	(a)
CO	(a)	no	no	(b)	(b)	no	:	no	no
CT	(d)	no	yes	yes	no	(e)	:	yes	yes
DE	(a)	yes	(a)	yes	yes	(h)	:	(a)	(a)
FL	(a)	yes	yes	yes	yes	no	:	yes	yes
GA	(l)	(b,l)	yes	yes	no	no	:	no	no
HI	yes	(c)	yes	yes	no	(g)	:	yes	yes
IA	(a)	(l)	yes	yes	yes	(g)	:	(a)	(a)
ID	yes	yes	yes	(c)	no	no	:	(i)	(i)
IL	(a)	no	yes	yes	yes	(g)	:	no	no
IN	yes	yes	yes	yes	yes	(g)	:	yes	yes
KS	(d)	(d)	yes	yes	yes	(g)	:	no	yes
KY	(a)	yes	yes	yes	yes	no	:	(a)	(a)
LA	no	no	yes	yes	yes	no	:	no	(a)
MA	no	no	yes	yes	(i)	(e,g)	:	yes	yes
MD	(a)	no	yes	yes	yes	no	:	(a)	(a)
ME	(d)	no	yes	yes	no	(e)	:	(i)	(i)
MI	(a)	yes	yes	yes	yes	(e)	:	(f)	yes
MN	(d)	yes	yes	yes	yes	no	:	(j)	(j)
MO	(a)	no	yes	yes	yes	(g)	:	(i)	(i)
MS	no	yes	yes	yes	no	(g)	:	(f)	(j)
MT	(a,d)	yes	yes	yes	no	no	:	(a)	(a)
NC	no	no	yes	yes	yes	(e)	:	yes	yes
ND	(d)	yes	yes	yes	no	no	:	(f)	(a,j)
NE	yes	yes	yes	yes	(b)	no	:	(a)	(a)
NH	(d)	no	yes	yes	no	(k)	:	no	no
NJ	(d)	no	yes	yes	yes	(g)	:	(i)	(i)
NM	(a)	no	yes	(j)	no	no	:	(a)	(a)
NV	no	yes	yes	yes	no	(e)	:	(a)	(a)
NY	yes	yes	yes	yes	(c)	(g)	:	(a)	(a)
OH	(a)	(l)	yes	yes	yes	(g)	:	(a,i)	(a,i)
OK	(a)	no	yes	yes	yes	(g)	:	no	yes
OR	no	no	yes	yes	no	(g)	:	yes	(f)
PA	(c,d)	no	yes	yes	yes	(g)	:	yes	yes

Table 2-1, continued.

STATE		Which regulations must be followed for SSES and I/I analysis (CG 85, 10 States) or for expansion or rehabilitation of existing sanitary sewers or lift stations? CG85	10 States Standards	State Review	State Approval	Permit to Install	Other		What is required before applying to expand or upgrade a treatment plant? SSES	I/I Analysis
RI	:	yes	no	yes	yes	no	(e)	:	yes	yes
SC	:	(c,d)	yes	yes	yes	yes	(g)	:	no	yes
SD	:	no	(d)	yes	yes	no	no	:	(a)	(a)
TN	:	no	(l)	yes	yes	no	(g)	:	(f)	(a)
TX	:	yes	no	yes	yes	no	no	:	(i)	yes
UT	:	(a)	(a)	no	no	no	no	:	no	no
VA	:	no	no	yes	yes	yes	(g)	:	no	yes
VT	:	yes	yes	yes	yes	yes	(e,g)	:	yes	yes
WA	:	(d)	no	yes	yes	no	(g)	:	no	yes
WI	:	no	no	yes	yes	no	(g)	:	(g)	(g)
WV	:	(c,d)	yes	yes	yes	yes	no	:	(f)	yes
WY	:	(a)	no	yes	yes	yes	(g)	:	no	yes

(a) for projects funded by EPA grants, the State Revolving Fund, or similar programs
(b) for expansion or rehabilitation of lift stations.
(c) for expansion or rehabilitation of sewers.
(d) for SSES and I/I analysis.
(e) other published texts, manuals or guidelines.
(f) decision to perform SSES is based on results of I/I analysis.
(g) state regulations or standards.
(h) for expansion.
(i) sometimes.
(j) for state funded projects.
(k) permit to discharge required for expansion of sewers.
(l) as a guideline.

2.5 References

When an NTIS number is cited in a reference, that reference is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

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CHAPTER 3

Preliminary Analysis of Sewer Systems

3.1 Introduction

This chapter presents information on how to conduct a preliminary sewer system analysis to determine quickly and easily if there are serious infiltration/inflow (I/I) problems, evaluate the extent of these problems, and select the approach for further analysis and investigation.

Before implementing a thorough I/I analysis and Sewer System Evaluation Survey (SSES), a preliminary analysis of the sewer system should be conducted to quickly establish the degree of I/I in the system. For systems that have not been evaluated, the following occurrences indicate the need for a preliminary sewer system analysis:

- Greater than anticipated flows measured at the wastewater treatment plant
- Flooded basements during periods of intensive rainfall
- Lift station overflows
- Sewer system overflows or by-passes
- Excessive power costs for pumping stations
- Overtaxing of lift station facilities, often resulting in frequent electric motor replacements
- Hydraulic overloading of treatment plant facilities
- Excessive costs of wastewater treatment including meter charges levied by sanitary districts or other jurisdictional authorities
- Aesthetic and water quality problems associated with by-passing of raw wastewater
- Surcharging of manholes resulting in a loss of pipe overburden through defective pipe joints and eventual settlement or collapse
- Odor complaints
- Structural failure
- Corrosion

3.2 Historical Reasons for Sewer System Analysis and Evaluation

Historically, the evaluation of sewer systems has occurred because of regulatory requirements to receive Federal funding; capacity limitations; structural failure; and indirect evidence of excessive I/I in the overall system. I/I problems are often abated by the construction of relief sewers, larger lift stations and treatment plants, and by the use of wastewater bypasses throughout the system. This last approach, however, often results in untreated wastewater flows being discharged into rivers, streams, lakes and open ditches which is no longer acceptable as a solution. An effective sewer system evaluation and rehabilitation plan will be required for effective protection of the infrastructure in nearly all cases regardless of the initial reasons for the evaluation.

3.2.1 Regulatory Requirements

Regulations promulgated as a result of Public Law 92-500 require that any engineer or public official concerned with the design of improvements to existing sewer system infrastructure components or wastewater treatment plants become familiar with and follow certain procedures to insure that excessive I/I was not present in order to become eligible for U.S. EPA grant funding.

Although many changes in the regulations have since been made, the underlying importance of preserving sewer system capacity and structural integrity remains. As shown in Table 2-1, many state regulatory officials still follow a rigorous state review and approval process for improvements to sewer system infrastructure components.

3.2.2 Structural Failure

Wastewater collection system structural failures often occur due to H_2S crown corrosion, natural ageing, and factors such as defective design, excessive overburden, soil settlement, and earthquakes. The historical method for repairing structural problems in sewer systems was to excavate and replace the pipe. With the advent of new technologies, described herein, rehabilitation of wastewater collection lines has became more cost effective and can often be accomplished without extensive excavation and replacement.

3.2.3 Capacity Limitations

With the natural increase in population and industrial growth within a city, the capacity of the wastewater pipes often become insufficient. Sewer collection lines and treatment plants become inadequate to handle the increase in sanitary flows. Without the correction of excessive I/I, existing sewer lines, are unable to carry the increased flows, thus prohibiting expansion and growth within the existing tributary area.

3.2.4 Citizens' Complaints

Citizens' complaints are often reported during periods of extensive rainfall because sewers surcharge and cause local, area, and residential flooding. When such phenomena occur on a regular basis, a preliminary analysis of the sewer system is necessary because these complaints indicate that the sewer lines exhibit excessive amounts of I/I during periods of rainfall.

3.3 Financial Reasons for Evaluation of Sewer Infrastructure Needs

3.3.1 Need to Enlarge Service Area

Traditional planning of sewer systems has included allowances for growth and expansion within specific drainage basins or within specific geographical or political subdivisions of communities. As existing systems continue to expand, however, the demands on the existing sewer infrastructure continue to grow and the capacity and condition of existing interceptor sewers, lift stations, and appurtenant structures must be continually evaluated. During these planning activities, it often becomes apparent that existing facilities have experienced deterioration and require rehabilitation or replacement to remain serviceable and to accommodate the flow of expanding service areas.

Evaluation of many existing systems as a part of federally-funded I/I and SSES investigations has often shown that severe deterioration has occurred, thus creating additional financial pressures for future sewer system planning and expansion. Since sewer systems are designed for service lifetimes of 30-50 years or more and the planning of these systems do not normally include replacement financing, future expansion and development planning must take into account the cost of this replacement. The continued expansion of existing collection systems normally continues until the capacity of the critical components of existing collection and treatment systems are reached. Because of the high cost of increasing interceptor and collection system capacity especially in fully developed areas, it is important that I/I be minimized and that the necessary investment be made over the lifetime of existing facilities to preserve their condition and capacity. It is for this reason that the major federal funding sources for sewer construction have emphasized the importance of I/I control and protection of systems from major deterioration due to corrosion.

At any given point in time within a sewered community, there is a continuing need to recognize the: 1) value of the existing sewer infrastructure; 2) condition of the system; 3) rate of deterioration; 4) cost of mitigation of deterioration; 5) estimated remaining service lifetime; and 6) ultimate system capacity. A realistic evaluation of the above factors is a crucial element of sound public works management and a fundamental requirement for effective financial planning of sewer system infrastructure improvements.

3.3.2 Budgetary Planning Needs

Sewer system budgetary planning normally includes the following major cost categories:

- Legal and administrative
- Long term and short term debt
- Short term capital financing
- Operations and maintenance labor
- Operations materials and utilities
- Contingency or reserve funds

These budgets are often prepared on an annual or bi-annual basis and are presented to city council or other governing bodies for approval. Whether wholly or partly financed by sewer or sewer and water revenue bonds, some elements of the sewer system budgets compete with other municipal infrastructure needs.

Evaluation of the age and condition of existing sewer systems allows inclusion of the total system needs into the sewer system operations budget. A well planned sewer system survey will provide information such as:

- Sewer line manhole (other structure) replacement needs and costs
- Lift station equipment needs
- Extent of corrosion of lift station equipment and structures, force mains and down stream receiving sewers
- Immediate and longer term rehabilitation needs
- Long and short term maintenance needs

Although all needs cannot be met by annual operating budgets, the budgeting and expenditure of funds annually for repair, maintenance rehabilitation and replacement of critical sewer system components in many cases can eliminate or reduce the need for major capital expenses at a later date. For example, early identification of deterioration due to corrosion may save over 60 percent of the cost of eventual repair or replacement.

3.3.3 Financial Planning

Financial planning to satisfy infrastructure needs includes the consideration of both the short- and long-term budgetary needs as described in Section 3.3.2, as well as the growth needs as described in Section 3.3.1. Effective planning must recognize not only the importance of an accurate and realistic assessment of needs, but also knowledge of the alternative financing mechanism that are available. These elements should be considered over a planning period of 15-25 years. It should be recognized that even though the estimated lifetime of major portions of the sewer system infrastructure is 30-50 years, it is necessary to assess the capital improvement needs of existing systems on a routine basis at least every 5-10 years. Sewer system needs should be forecast for 10-25 years and should include short term rehabilitation needs and longer term capital improvements needs.

A major element of financial planning includes the analysis of a wide variety of financing mechanisms available to municipalities, as well as a clear understanding of the required financial resources.

Table 3-1 outlines the advantages and disadvantages of the more common infrastructure financing mechanisms.

3.3.4 Benefits Versus Cost of Sewer System Evaluation

Since the early 1970's, over 90 percent of sewer system evaluations were performed in response to Federal Grant funding requirements as now defined by 40CFR35.2120.

The experience gained during the past 15 years with sewer system evaluation efforts (either I/I or SSES) has proved extremely valuable in identifying the need for precise information regarding the condition of the nation's sewer system infrastructure. Equally important has been the development and refinement of a wide range of cost effective sewer evaluation and rehabilitation techniques. These include: 1) improved sewer system monitoring, analysis and inspection techniques; 2) testing and grouting techniques; 3) slip-lining technology; 4) cured in-place linings; 5) fold and fomed; 6) specialty concrete products and grouting techniques; 7) new coatings; 8) new service lateral techniques; 9) new liners; and 10) new manhole rehabilitation techniques.

Another major finding of sewer system evaluations has been the realization of the extent, impact, and monetary significance of corrosion on existing sewer systems. This alone prompted U.S. EPA to undertake a series of investigations and to publish a design manual in 1985 on sewer system odor and corrosion control techniques.[1] Further concerns over the impact of sewer system corrosion led the U.S. Congress to require U.S. EPA to undertake additional studies and to submit a report to Congress on the costs and impacts of corrosion on the sewer system infrastructure and the effects of rainfall induced infiltration (RII) on sewer systems.[2,3]

Although the costs and benefits of sewer system evaluation have not been explicitly defined on a national basis in the United States, some level of routine sewer system evaluation is cost effective for all of the nation's sewer systems. Experience over the past 15 years has shown that rehabilitation cost are significantly less than replacement costs in most instances. As shown in Chapter 6, rehabilitation costs are 20-25 percent of replacement cost for specialty concrete, cement mortar, and epoxy coatings; 60-80 percent of replacement costs for grouting; and 55-85 percent of replacement costs for sliplining and inversion lining. Comprehensive sewer system surveys including cleaning and inspection are 5-7 percent of sewer replacement costs. Given the fact that comprehensive sewer system evaluation plus rehabilitation costs are 25-92 percent of sewer replacement costs, sewer system evaluation and rehabilitation is extremely cost effective in maintaining the capital asset value of this infrastructure system.

This cost advantage is in addition to the benefit of maintaining existing flows and future capacities due to reduction of infiltration and inflow. The highest benefit/cost ratios are found in areas where the sewer corrosion potential is the highest.

Deterioration rates in systems due to corrosion have been shown to decrease sewer life times from the normal 30-50 years to as low as 2-4 years in extreme cases and 9-14 years in moderate cases.

3.4 Methodology for Preliminary Sewer System Analysis

3.4.1 Sources of Information and Preliminary Methods of Analysis

The extent of the preliminary sewer system analysis depends on the size of the system and the amount of information available. A diagram outlining the major steps to be taken in a preliminary survey is presented in Figure 3-1. Each of these steps are discussed below.

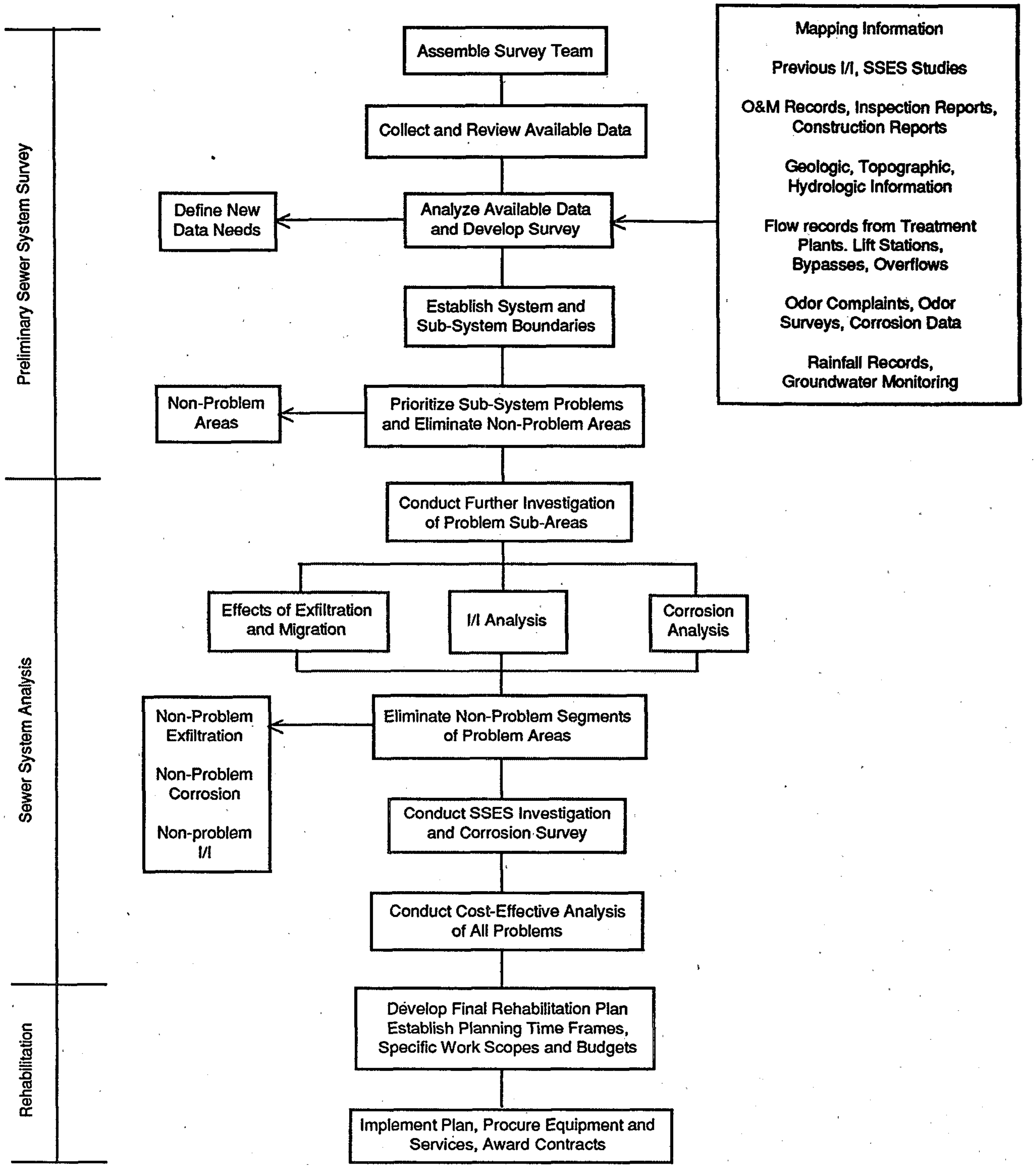
A preliminary sewer system survey is normally conducted by municipal personnel and their consultants. The first step in the procedure is to assemble the survey team. The team usually consists of the city's consultants, representatives from the city or municipal administration departments, central engineering staff, sewer and wastewater superintendent, and key sewer system operating and maintenance personnel. Other staff that have pertinent knowledge and experience with the major sewer system components should be assigned. It is

Table 3-1. Advantages and Disadvantages of Major Infrastructure Financing Mechanisms

Advantages	Disadvantages	
General fund appropriation	**Administrative:** appropriations reflect current legislative priorities **Equity:** all taxpayers contribute to capital projects **Fiscal:** no debt incurred, so projects cost less during periods of inflation	**Administrative:** infrastructure must compete with other spending priorities each year; cannot plan long-term project around uncertain funding **Equity:** no direct link between beneficiary and who pays, and current generation pays for capital projects that benefit future generations.
General obligation bonds	**Equity:** capital costs shared by current and future users **Fiscal:** bonds can raise large amounts of capital; general obligation bonds usually carry lowest available interest rates	**Administrative:** States often impose debt ceilings and requires voter approval **Fiscal:** adds to tax burden, especially if interest rates are high
Revenue bonds	**Administrative:** do not require voter approval and are not subject to legislative limits **Equity:** debt service paid by users fees, rather than from general revenues	**Administrative:** require increased reporting and restricted by Tax Reform Act limitations **Fiscal:** usually demand higher interest rates than general obligation bond
State gas tax	**Administrative:** established structure allows tax increase without additional administrative expense **Equity:** revenues are usually earmarked for transportation, so users pay **Fiscal:** revenues relatively high compared to other user taxes	**Administrative:** revenue fluctuates with use of gas **Equity:** fiscal burdens are not evenly distributed between urban and rural areas **Fiscal:** revenue does not rise with inflation or reflect differences
Other dedicated taxes	**Administrative:** voters prefer dedicated taxes **Fiscal:** provides relatively reliable funding source not subject to annual budgeting	**Administrative:** reduces districts ability to meet changing needs **Fiscal:** major economic downturns can reduce revenues significantly
State revolving funds	**Administrative:** promote greater State independence in project selection **Fiscal:** debt service requirements provide incentives for charging full cost for services; loans can leverage other sources of funds; loan repayments provide capital for new loans	**Administrative:** States bear increased administrative and financial responsibility **Equity:** poor districts cannot afford loans **Fiscal:** repaying loans will mean increases in use charges or taxes

Source-Office of Technology Assessment 1990

Figure 3-1. **Approach to conducting sewer system evaluation.**



important that all staff assigned be able to commit the necessary time for proper planning and implementation of the survey. The major purposes for conducting a preliminary sewer system survey are to identify, localize and prioritize those areas of the sewer system sub-areas with the greatest potential problems, and to identify the preliminary scope of the subsequent investigations. A preliminary survey is a forerunner to the traditional I/I and SSES procedures. The major sources of information used in the preliminary survey are outlined below:

- As-built sewer maps
- Sewer system operation and maintenance (O&M) records
- Existing geographical, geological, climatological and topographical records
- Existing city or municipal planning documents
- Existing treatment plant performance records
- Sewer system monitoring records such as treatment plant flow records, lift station flow records, overflows and by-passes
- Interview information from public officials and supervisory sewer system O&M staff
- Historical sewer system and treatment plant flow and performance information
- Rainfall and groundwater data
- Water use records
- Population and user history
- Industrial survey information

The more important of the above data sources are: available sewer maps, information from previous I/I and SSES studies, along with system and sub-flow monitoring information. The preliminary information also includes the normal data sources used for I/I analysis including flow monitoring, rainfall, groundwater levels, and anecdotal evidence of exfiltration.

The proper assignment of data collection responsibilities to individuals that have access to the required information, and the organization of responsibilities by the survey team leader is a major factor in the success and efficiency of the preliminary survey.

The goal of this preliminary survey, however, is to utilize the available data to make the best judgments possible regarding the condition of the existing sewer system and to define the specific problems within the system and sub-system areas. The final plan resulting from the analysis of available data should, as a minimum, provide the following information:

- Clear delineation of all sub-areas, and location of monitoring points
- Clear understanding and preliminary ranking of the problems within each sub-area. This may include the relative severity of infiltration and inflow, suspected sources of each, identification of major areas of corrosion, the impact of lift stations on sulfide generation and corrosion, evidence of structural failures, sewer blockages or other damage to the sewer system infrastructure
- Identification of all non-problem sewer sub-areas
- Identification of sewer system monitoring and data needs for all priority problems in each sub-area selected for study
- Schedule for establishing system monitoring requirements. For example monitoring for inflow would be conducted during high-groundwater conditions while monitoring for corrosion or exfiltration would be conducted during low-flow, dry weather conditions.

An estimate of resources needed to conduct the investigation of the sub-systems should include:

- Permanent or temporary sampling and flow measurement equipment
- Sewer cleaning and inspection equipment
- Sulfide and corrosion measurement and monitoring equipment
- Groundwater monitoring needs
- Rainfall simulation equipment

The resource estimate should include a summary of all activities to be conducted by municipal employees and all activities to be completed by contract services. A summary work scope, budget and schedule should be prepared for all service contracts.

The preliminary survey differs from the initial stages of an I/I analysis or SSES investigation in the following respects:

- The scope of the preliminary sewer system survey is broader than I/I or SSES and includes surveys of physical damage to the sewer system infrastructure, capacity limitations, effects of corrosion and sewer system deterioration rates, and excessive I/I, including those areas that would possibly be affected by groundwater migration and exfiltration.
- The preliminary survey establishes the problem priorities for the entire system and sub-systems and defines the overall work scope of subsequent investigations
- The preliminary survey defines the costs, objectives, and time frames for implementing all investigations necessary for a complete infrastructure analysis.

3.4.2 Monitoring and Equipment Needs for Preliminary Analysis

The monitoring and equipment needs for a preliminary sewer system survey depend on the size of system or sub-systems under investigation and the schedule for conducting the survey. Sub-systems may vary in size from a few tenths of a square mile to several square miles and may include up to 20 or more separate monitoring stations. The preliminary survey includes flow monitoring at critical junctions, limited physical surveys, preliminary corrosion surveys and information to correlate flows with rainfall and groundwater information.

Although equipment needs vary depending on the size of the sub-system, typical equipment needs for a single sub-system investigation are:

- 2-3 fully automatic recording flow meters
- 1-2 velocity meters
- 1-2 depth sensors
- 2-3 20- to 76-cm (8-30-in) weirs
- 1 metal detector
- pH ORP meters
- Recording DO meters
- Smoke bombs, and a gasoline driven blower (1,500-3,000 cfm)
- Camera and film
- Sand bags and plugs, 20-76 cm (8-30 in)
- 60-90 m (200-300 ft) of fire hose and fluorescent dye
- 1-2 tipping bucket rain gauges
- 2 proportional samplers and sample containers
- Device for measuring corrosion such as a sonic caliper
- 1 extendable penetration rod
- 4-6 sulfide test kits
- Miscellaneous sewer and manhole sampling and access equipment including ladders, lights, buckets, sample containers, rope, tapes, hand tools, and safety equipment

Of the above equipment, selection of the appropriate flow measuring devices (flow meter or weirs) and the equipment for the preliminary corrosion survey is the most important. The above list does not include preparatory sewer cleaning or TV inspection equipment since the preliminary survey does not extend to that level of detail.

3.5 Infiltration and Inflow Analysis

3.5.1 Introduction

Infiltration is that volume of water that enters sewers and building sewer connections from the soil through foundation drains, defective joints, broken or cracked pipes, faulty connections, etc.[4]

Inflow is that volume of water that is discharged into existing sewer lines from such sources as roof leaders, cellar and yard area drains, commercial and industrial discharges, drains from springs and swampy areas, etc.[4]

I/I is the major deterrent to the successful performance of a wastewater conveyance or treatment system.[5] Excessive I/I in a sanitary sewer system can hydraulically overload sewer lines and wastewater treatment plants, resulting in surcharging, basement backups, sewer bypasses, and reduced treatment efficiency.[6] It also adversely affects the urban environment and the quality of the water resources. Some detrimental effects of I/I are: utilization of sewer facility capacity that could be reserved for present sanitary wastewater flows and future urban growth; need for construction of relief sewer facilities before originally scheduled dates; surcharging and backflooding of sewers into streets and private properties; bypassing of raw wastewater at various points or diversion into storm drains or nearby watercourses; surcharging of pump stations resulting in excessive wear on equipment, high power costs, bypassing of flows to adjacent waterways, diversion of flow away from secondary or tertiary treatment stages, or bypassing of volumes of untreated wastewater into receiving waters; and increases in the incidence and duration of stormwater overflows at combined sewer regulators.[7] Proper analysis of I/I is thus required to demonstrate possibly excessive or nonexcessive flows in a sewer collection system and to identify sources for later correction.

Correction of infiltration in existing sewer systems involves:

- Evaluation and interpretation of wastewater flow conditions to determine the presence and extent of excessive extraneous water
- The location and measurement of such infiltration flows
- The elimination of these flows by various repair and replacement methods; and
- A diligent, continuous maintenance and monitoring program.

Correction of inflow involves:

- Discovery of locations of inflow, determination of their legitimacy, assignment of the responsibility for correction of such conditions
- Establishment of inflow control policies where none have been in effect; and
- Institution of corrective policies and measures backed by monitoring and enforcement procedures.

Control of I/I in all existing and new sewer systems is an essential part of sewer system management. A sewer system cannot be rehabilitated and then be expected to never develop additional points of I/I. Proper preventive maintenance programs must be established to monitor and control excessive I/I as an integral part of the rehabilitation program.

The procedures involved in conducting an I/I analysis should be listed as an orderly sequence of tasks. Step-by-step actions should be designed to explore the scope and details of the problem.[6] This exploration will ascertain the need and the techniques required for the subsequent evaluation of causes, effects and corrective actions. Information must be gathered for making separate cost estimates for transportation and treatment of the infiltration and inflow components versus elimination through corrective action. Figure 3-2 provides the sequence of events that should be considered to properly analyze and reduce I/I. If this initial analysis indicates that the I/I is excessive, the next phase should be the SSES, which should determine the specific locations of inflow, flow rates, and rehabilitation costs for each I/I source. In general, the main goals of an I/I analysis report are to:

- Identify which sewer systems have reliable data available to conclusively demonstrate nonexcessive or excessive I/I.
- Generate sufficient flow data and characteristics of the sewer system to enable a sound engineering decision to be made regarding excessive and nonexcessive flow.
- Obtain realistic cost estimates for rehabilitation of sewers that contain excessive I/I and compare these costs to the cost of transporting and treating extraneous water.
- Enable the engineer, in the event of excessive I/I, to detail the work tasks for the new evaluation i.e., the SSES.

I/I analysis thus provides the fundamental evaluation and indication of the existence of excessive flows in sewer lines.

3.5.2 Preliminary Information Needed

Prior to conducting an I/I analysis, all pertinent information and data should be collected on the specific wastewater treatment and collection system under investigation. This preliminary information should be enough to allow the investigator to make a judgement of nonexcessive or possibly excessive I/I.[6,7]

3.5.2.1 Interviews

Much of the basic data required for the I/I analysis can be obtained from local sources by carefully planned and executed interview programs. It is generally found that the people who are most familiar with the sewer system are public officials (both present and retired) and local residents who will know from experience where many defects may be located, where hidden interconnections exist, what the history of performance has been, and what the community's planning and growth needs have been and will be. They know both permitted and non-permitted points of flow into sewers as well as the applicable regulations for plumbing and sewer connections.

Results from well-conducted interviews may save the engineer considerable field work and also give a clear overview of the problems to be faced. The results from the interviews may be utilized along with other findings to make a proper judgement as to the seriousness of the I/I problem in the study area, the major problem areas in the system, the percentage of the I/I which can possibly be removed, and the areas which may require further investigation. A specific interview pattern and form is used by many consultants and municipal officials; this form includes a broad spectrum of subjects, such as:

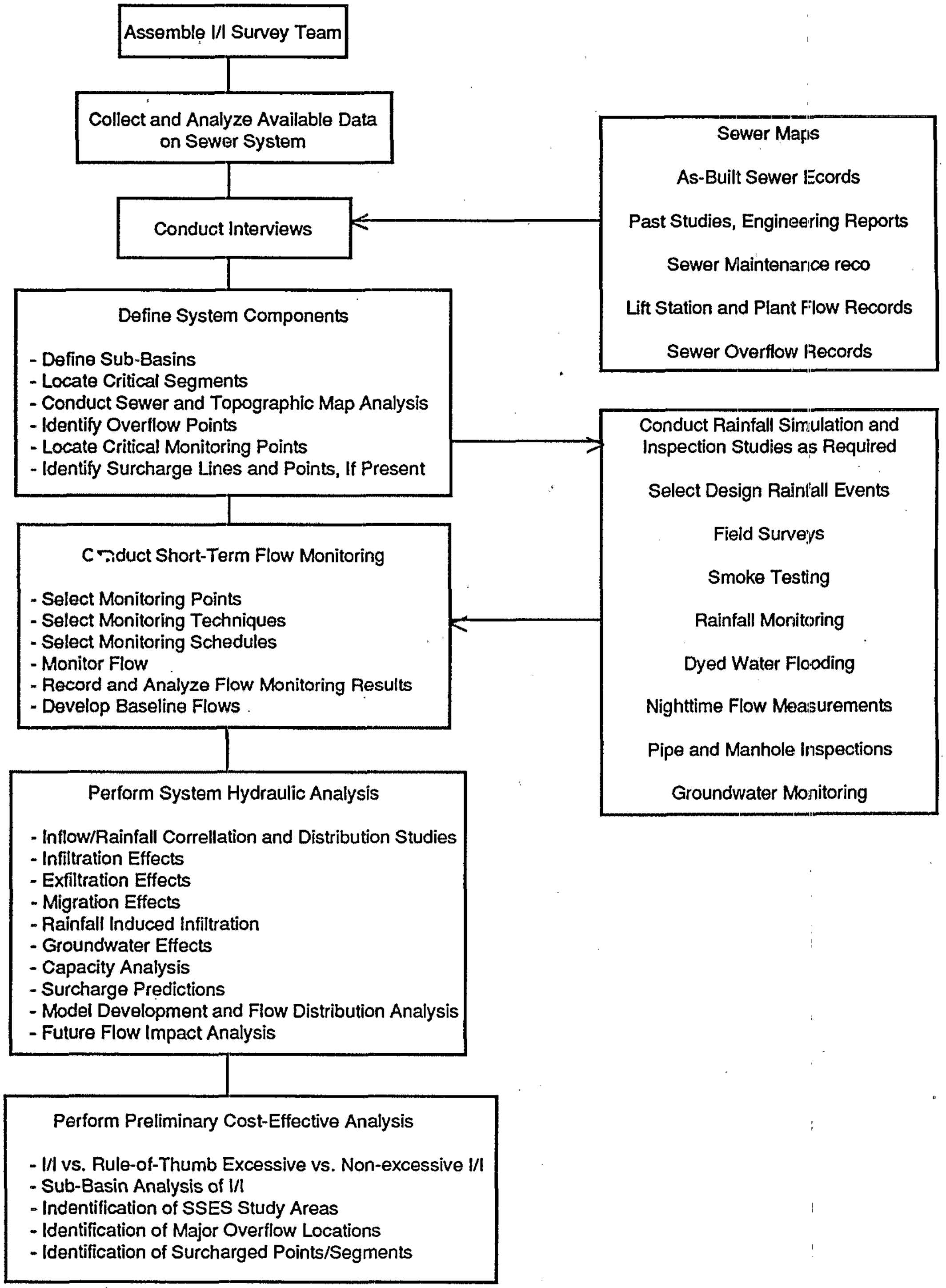
- Sanitary sewer system
- Storm sewer system
- Existing and historical sewer maintenance program
- Problem areas in and around the sewer system
- Geological and geographical conditions in the sewered area
- Population and water consumption data
- Legal and jurisdictional aspects of the sewer system.

A thorough interview form is included in the *Handbook of Sewer System Evaluation and Rehabilitation*.[4] This interview form should be used as a guide and should be adapted and/or modified to the system under study.

The purpose, nature and significance of the study should be explained to the individuals being interviewed to avoid any misunderstandings and to obtain full cooperation. Good public relations should be practiced at all times. Before an interview, maps of the study area should be studied by the interviewer to become familiar with the area. This will enable the interviewer to mark important information on the maps to supplement the description recorded in the interview forms.

Summary information from the interview should be plotted on the map for easy identification. Discrepancies among interviewees and/or between the interview results and existing records should be evaluated. Some spot checking should be performed to substantiate the interview results. From the analysis of the collected information, a plan of action can be made to gather more data needed for the completion of the I/I analysis.

Figure 3-2. **I/I analysis major activity flow chart.**



The patterned interview involves the first look at the extraneous water problem in the community. A professional who is experienced in the area of I/I should interview everyone who is or has been connected with the sewer system. Subsequent analysis of the data will answer questions and give the analyst a feel for the overall problem. The general objective of the interview is to focus on the more important problem areas. The questions should cover a broad spectrum of subjects, ranging from technical matters to municipal performance capabilities as well as questions regarding the socio-economic profile of the city. A well-planned interview also helps the municipality to think about its problems in an orderly fashion and to recognize alternate methods for solution.

3.5.2.2 Mapping and Map Analysis

a. Mapping

- All sewer lines and appurtenant structures should be recorded on authenticated maps. As-built drawings should be available for all new sewer systems and some of the older sewers.

b. Updating or preparation of maps

- Augmentation of existing maps with details of new construction and revisions
- Preparation of new maps from as-built records, additional underground surveys and other data
- Sewer maps, as a minimum, should be drawn to scale and should indicate sewer sizes, slopes, direction of flow, manhole locations, as well as other major sewer system elements, e.g., pumping stations, treatment plants, bypasses, points of overflow, force mains, force main discharge points, etc.

In sewer systems where sewer maps are available, it may be advisable to verify some of the critical points in the field before total acceptance. Sewer maps should also be updated to include new sewer extensions, sewer line changes, buried manholes, and any other pertinent data.[7]

In systems where maps are not available or are incomplete, they must be developed before the study can continue.

A street map is generally useful for the preparation of a sewer map. In cases where street maps are not available, a schematic layout of the sewer system may be suitable, or a map may be developed. Sewer location and direction of flow can also be determined by dye tracers, floats, smoke, metal detectors and interviews with people having considerable knowledge of the sewer system.

c. Map Analysis[4]

Map analysis normally includes the following elements:

- Establishment of rational major sub-basins based on system layout, drainage areas, main sewers and tributary lines, system configuration and other local factors and system conditions
- Determination of sub-sections when and where they are required to cover a more detailed study of conditions in specific parts of any sub-basins
- Preparation of sewer system flow diagrams and flow sheets
- Selection of key junction manholes for monitoring and gaging flows in each sub-basin which will reflect I/I conditions in constituent parts of the sewer system

Based on the sewer maps, the following information pertinent to I/I can be indicated and overlaid on the sewer maps:

- Topography of the study area
- Soil and hydrogeologic formations
- Groundwater mapping
- Sewer age, type, and size
- Known or potential problem areas such as areas subject to flooding during rainfalls, surcharged sewers, overflowing manholes, overloaded pumping stations, houses with sewer backup problems, obvious inflow sources, existing and historical swampy areas, etc.

This information, along with the sewer maps, may enable one to gain valuable information into the I/I problems of the area such as:[7]

- Storm sewers crossing, parallel to, or in the same trenches as the sanitary sewers are likely I/I sources
- Sewers constructed near rivers, streams, ditch sections, ponding areas and swamps may present serious I/I problems due to groundwater seepage or direct drainage.
- Sewers constructed in unsuitable soils that may be subjected to settling resulting in open joints and/or cracked piping
- Older sewers or ones of particular materials, joints or construction practices may present greater potential for I/I. Manholes with perforated covers may present serious inflow problems in low lying street areas.
- Sewers constructed above seasonal high groundwater level should present few infiltration problems.

3.5.3 Rainfall Information

3.5.3.1 Sources of Information and Methods of Analysis

The measurement of precipitation as a part of sewer system evaluation is undertaken to correlate rainfall with flow metering data. Several items are generally of interest: rainfall intensity, total volume per event, and duration of the event. These data can be obtained from tipping buckets or continuous weighing rain gauges. Charts that record rainfall for several events and a totalizer that provides a check against recorded data is useful. Snow melting devices for colder climates are also available with the precipitation measuring devices. Less sophisticated devices such as graduated cylinders may also be appropriate to provide crude, supplemental information in some cases.

Prior to the implementation of a precipitation measurement program, other less site-specific data should be obtained and evaluated. Sources of precipitation data are the National Oceanic and Atmospheric Association (NOAA), airports, state weather observers, electronic media weather observers, other public works and research agencies and private citizens. NOAA has an extensive nationwide network of recording rain gauges. Those gauges with hourly rainfall data are summarized by state in a monthly publication entitled *Hourly Precipitation Data*. Another useful publication containing daily precipitation quantities from NOAA stations is *Climatological Data*, which is also published monthly for each state.

Rainfall causes inflow and can also cause infiltration by the following mechanisms:[6]

- Rainfall and/or surface run-off may be carried directly through the cracks in a clay soil surrounding shallow sewer lines and manholes and leak through the deteriorated manhole walls and sewers to cause an infiltration problem.
- During and immediately after heavy rainfall, the rainwater reaches the groundwater by percolating through overlying soils and causes an increase in groundwater level. The amount and rate of piezometric head increase is a function of the soil type and structure. This increases the potential hydraulic head. If the level is above the sewer pipes it increases the driving force, which can cause the water to enter the pipes through defective joints, etc.
- In locations where the sewer pipes are cut in underlying bedrock, the rainwater, after percolating through the overlying soils, will likely flow in the same trench and thereby cause an increased infiltration problem in the sewers.
- During heavy rainfalls, another phenomenon may occur in the soil and increase the infiltration rate in the sewers. This is the case when a large ground surface is covered by impounded rainwater: as this large blanket of impounded water percolates through the soils underneath, it leaves little chance for the air in the soil to escape. Because of this, the air is subjected to increased pressure. The pressure is transmitted to the groundwater above the sewer pipe and may cause an increased infiltration rate through defective pipe joints, etc.[3]

3.5.4 Topographic and Geologic Information

3.5.4.1 Sources of Information and Method of Analysis

Soil conditions in the sewer system study area often affect the I/I problems. Sewers constructed on unsuitable soils may be subjected to settling, expansion, or contraction resulting in open joints or cracked pipes. Soil chracteristics that affect I/I response are:[4]

- Permeability, among other soil characteristics, affects the rate of movement of groundwater through the soil matrix adjacent to sewers and sewer trench backfill materials.
- Backfill and bedding materials immediately surrounding the sewer affect the structural integrity of sewers. Granular sewer bedding materials are quite porous and often act as a secondary conduit that transmits groundwater along the sewer line thus providing additional opportunities for infiltration at downstream locations.
- Impermeable soils such as clays that are used as backfill above the granular bedding layer reduce the vertical penetration of surface waters entering the sewer envelope.

Information on soil distribution and soil characteristics in an area can be obtained from the following sources:[7]

- Soil Conservation Service, U.S. Department of Agriculture. The Soil Conservation Service has published many soil maps with descriptions of soil characteristics. They have offices in most counties throughout the country.
- Boring logs in sewer construction contract documents. Boring logs contained in the sewer construction contract document provide certain details about the soils along the sewer construction route.
- State Agricultural Extension Service. Data on soil types and soil characteristics may have been collected by the State Agricultural Extension Service.
- Local Construction Companies or Contractors. Local construction companies or contractors, particularly well drilling firms, should have some information about the area's soils.

- Field Investigation. For locations where no soil information is available or existing information is contradictory or indicative of serious problems, a field soil study may be needed. The study may include the test borings at key points and interpretation of the collected soil samples. For complex and unusual cases, the soil samples should be interpreted by a soil scientist. Assistance may be available from the Soil Conservation Service, Agricultural Extension Service representatives, consulting soil scientists or agronomists.

3.5.5 *Ground Water Information*

3.5.5.1 Sources of Information and Methods of Analysis

Information is required to determine the variations in the groundwater level. Most of the infiltration phenomena in sewers are groundwater related. Determination of infiltration in the sewer system should be based on a comparison of the wastewater flow data collected in the high groundwater periods with data collected in the low groundwater periods. Sewer line inspections should be conducted during high groundwater periods. Groundwater monitoring should be conducted if no data are available. The level and, in certain cases the chemical characterization of the groundwater affect the degree of infiltration in the sewers. General groundwater information can be obtained from a number of sources:[4,7]

- State Water Resource Agencies
- U.S. Geological Survey
- Local or County Water Conservation Districts
- Groundwater users, including municipalities, water companies and individuals
- Local construction companies or contractors

Two types of groundwater level measurement gauges are commonly used for sewer evaluation studies: the manhole gauge and the piezometer. The manhole gauge shown in Figure 3-3 is used to determine groundwater levels adjacent to manholes. These gauges are inexpensive and fairly easy to install; however, they do clog easily from mineral deposits. The piezometer shown in Figure 3-4 is generally installed in a hole excavated by a powered flight auger. Piezometers are more permanent and are far less prone to clogging. They are also more expensive, but with proper maintenance should last for years and provide higher quality data than manhole gauges

Installation sites for groundwater gauges should be away from underground utilities and streets to prevent damage from street maintenance equipment. Groundwater levels can be recorded on a periodic basis. A plot of groundwater levels versus time is helpful in interpreting meter data and determining levels of infiltration. The recorded data obtained from groundwater gauges should be reviewed and screened carefully before being used. Pumping water from nearby wells may cause a temporary drawdown of the groundwater surface at the monitoring stations, which may give biased groundwater levels. Groundwater levels should be measured during periods of the day when groundwater pumping in the study area is at a minimum.

3.5.6 *Baseline Sewer Flows*

3.5.6.1 Population and Flow Projection Methods

Population and flow data are essential for the determination of I/I. They determine the theoretical (or base) wastewater production rate in the study area. The theoretical wastewater production represents the total quantity of wastewater including domestic, commercial, and industrial wastewater flows, but excluding all infiltration and inflow. Flow rates are expressed as gal/capita/day (gpcd).

Monitoring of flows at treatment plants, lift stations, and properly located junction manholes is essential. Flow monitoring should be carried out at different times of the day as necessary to permit differentiation between normal expected sanitary flows and I/I volumes. Treatment plant and lift station flow records should be evaluated and necessary information should be gathered to produce an adequate I/I analysis. The baseline sewer flow monitoring tasks should include the following:[4]

- Verify flows from plant records, pumping or lift station charts or log sheets, or from previous sewer monitoring at the same or nearby locations involved in the current analytical procedure.
- Gauge flows at key junctions, manholes, pumping stations and overflow points during hours of minimal flow to determine the presence and amounts of infiltration volumes in various subsections of the sewer network.
- Determine daily and hourly flow variations in a limited number of locations for the purpose of monitoring the effect of rainfall on the flow characteristics in various sub-systems and to ascertain the quantity of infiltration and inflow and to differentiate between the two components.

The population data should be gathered only for the periods in which records for water consumption, wastewater flow, groundwater and rainfall are all available. Both the total population and the sewered population should be known for the determination of I/I. In areas where there are seasonal fluctuations in populations, a detailed breakdown of the population according to season

Figure 3-3. **Static groundwater gauge installation elevation.**

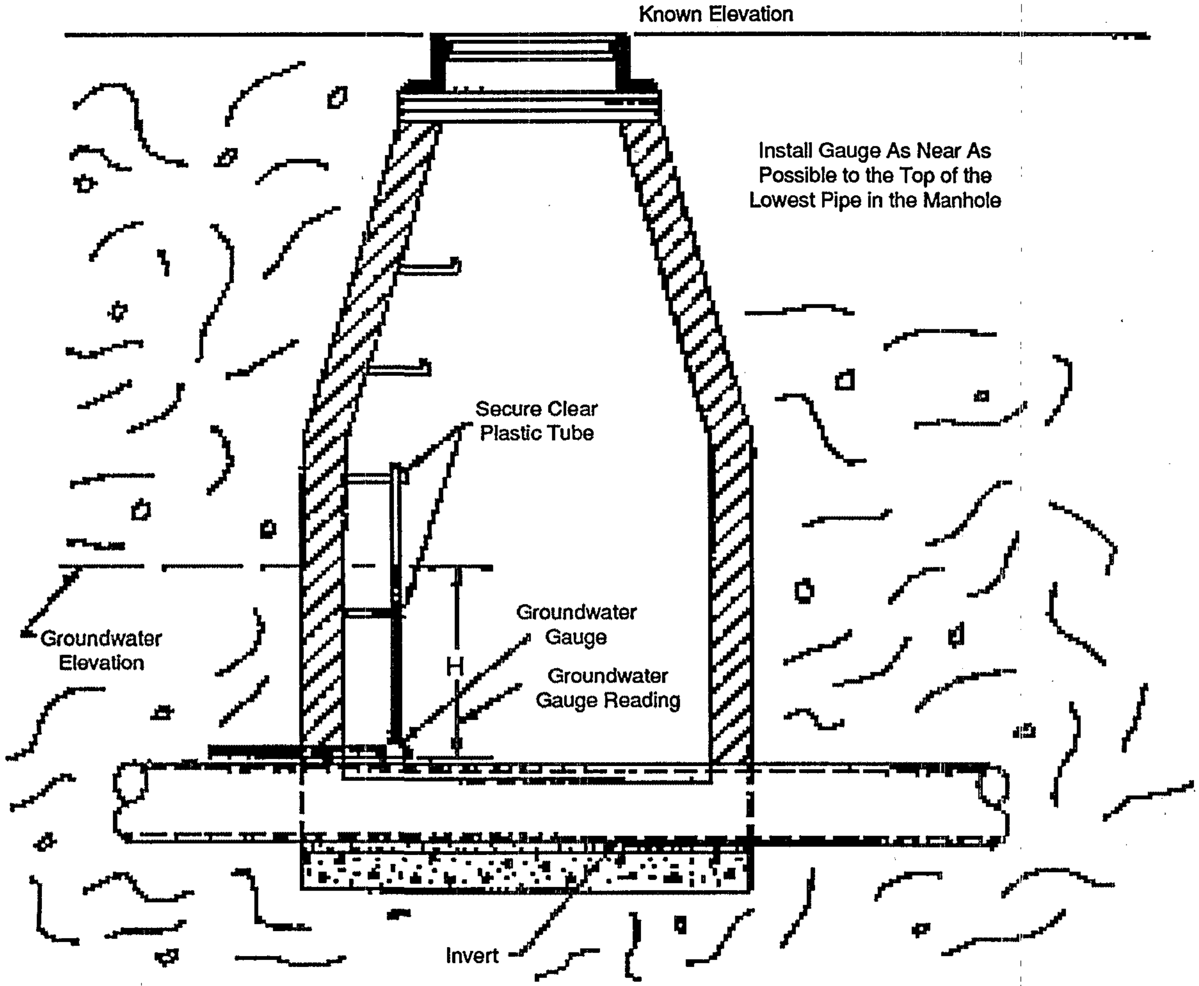
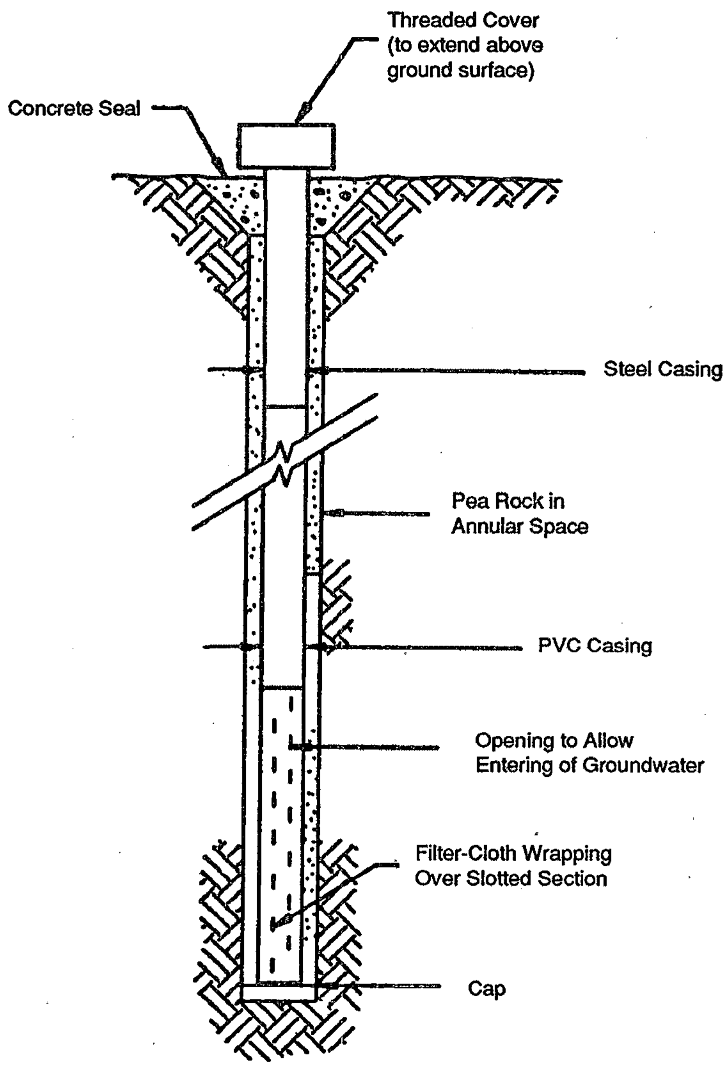


Figure 3-4. **Groundwater gauge installation detail.**



or month should be provided. Population records are available from the U.S. Census Bureau, local government offices and sanitary districts. Such data may also be reported in previous engineering study reports. If no data are available, a physical survey to include census, house count, and aerial maps may have to be performed to determine the population.[6,7] Preference should be given to wastewater flow records. All water use does not end up in the sewer. Water consumption (metered) is also measured on a cumulative basis (e.g., 100 cu ft/mo).

3.5.6.2 Water Use and Wastewater Generation Estimates

The water consumption data to be obtained should coincide with the available records for wastewater flow, groundwater and rainfall. Metered water data available for all users in the study area should be collected and used for the estimation of the wastewater production rate. Water consumption records can usually be obtained from local water departments, private water companies, industrial plants and individual well users. Water consumption estimates can be made based on population and an inventory of the residential, commercial and industrial establishments in the study area using typical water use rates. Water production records can also be used where water consumption data are not available. If water production data are used, allowances for consumptive use should be made so baseline wastewater flows are not overstated.

Wastewater flow records covering the entire sewer system over a period of 1-2 years should be used for I/I analysis. These records should include and represent groundwater and rainfall conditions in the study area. For larger sewer systems, flow records may have to be gathered from more than one treatment plant, pump station or flow measuring station in the system. Flow records for overflows, bypasses and emergency pumping should be gathered for the I/I analysis. Wastewater flow records can be obtained from wastewater treatment plants, sanitary districts or sewer departments in local governments.

The water consumption and wastewater flow records should be checked for accuracy before being used. The accuracy can be determined by checking the accuracy of the instruments used for recording and totalizing the flows.

3.5.7 Analysis of Infiltration and Inflow

3.5.7.1 Purpose of Analysis

Proper analysis of the data to determine I/I flow rates into the sewer system is essential for accurate estimation of the effectiveness of sewer rehabilitation. Discrepancies between estimated and actual I/I reductions are likely if improper I/I analysis occurs. Establishing the quantities of I/I entering a collection system is far from being an exact science. I/I analysis should consider various inaccuracies of flow measurement in sewer systems. The procedures for interpreting I/I data should recognize the impact of rainfall events, groundwater levels, antecedent soil and weather conditions and monitoring schedules on the overall component flows.

Baseline wastewater flow data are normally collected during dry-weather conditions. Groundwater infiltration should be measured during high groundwater since it will be significantly impacted by groundwater levels throughout the sewer systems. Inflow and RII component flow information are strongly related to the characteristics of the rainfall events occurring during the monitoring period. As discussed in Section 3.5.7.3, RII flows are strongly rainfall dependent even though they do not enter the sewer system directly.

In many cases it is not possible to clearly distinguish inflow, groundwater infiltration and RII. The sum of these components however can be estimated by subtracting the baseline flow from the total flow. These numbers can be used and compared to the accepted rules of thumb of 450 Lpcd (120 gpcd) of domestic plus non-excessive I/I flow and the storm flow of 1,000 Lpcd (275 gpcd). The cost-effective analysis for infiltration and inflow requires that these two components be separated. The cost of transportation and treatment requires that peak flows be determined. A proper cost-effective analysis generally requires that the following flows be determined:

- Peak infiltration
- Peak inflow
- Peak I/I
- Total yearly infiltration
- Total yearly inflow
- Total yearly I/I

3.5.7.2 Groundwater Migration

It is believed that much of the infiltration removed by rehabilitation of a source "migrates" to other sources that were either inactive or less active before rehabilitation. This phenomenon, known as migration, has led to disappointing results in typical rehabilitation programs, which have demonstrated a disparity between anticipated and actual reduction of infiltration.[8]

Sanitary sewer rehabilitation has seldom resulted in the infiltration reduction projected by sewer system surveys. Studies performed at two sites in the Washington Suburban Sanitary Commission (WSSC) sought to determine whether the assumed removable infiltration migrates to sources which were inactive or less active before rehabilitation.[8] To investigate the impact of migration on rehabilitation, 43 groundwater wells were installed in two study areas with a recording flow meter at each site. Well level readings, nighttime flow, isolation measurements, and local rainfall data were obtained.

After all sewer system defects were inventoried, selective rehabilitation consisting of line and manhole grouting, excavation and repair of sewer segments and grouting of service connections was conducted. Rehabilitation was implemented in two phases in each study area with groundwater and infiltration response measured before, during, and after each phase of rehabilitation. Migration of groundwater infiltration to previously inactive locations was documented at both study sites. This migration effect was accompanied by a corresponding increase in groundwater level at one of the two study sites. Based on an analysis of the data, it was observed that migration effects travelled as much as 60 m (200 ft) to reach unrehabilitated sources. Results of this study indicate that the traditional point source method of I/I analysis is only about half as accurate as it would be if migration were properly integrated.

Migration of groundwater infiltration to previously inactive sources can be documented by a corresponding increase in groundwater level at the study sites. One documented occurrence of groundwater level increasing after rehabilitation is illustrated in Figure 3-5. In this figure, Well 03 was located away from the sewer trench and Well E was located on the trench.[8]

One factor that affects migration phenomena is soil permeability. An important characteristic of existing SSES methodology is the reliance on individual line section nighttime isolation and measurement to identify sewer reaches subject to excessive infiltration. This fragmented approach provides an opportunity for migration since this process identifies conditions at one point in time, eliminating potentially defective elements of the system from further study. To effectively account for migration, the flow monitoring procedure must be revised to expand the data on an individual line segment basis. This will involve initially monitoring sub-areas with extended duration metering.[9]

Migration of infiltration from rehabilitated to unrehabilitated sources was observed and documented under work carried out by the WSSC. The extent of migration was primarily dependent on the number and location of rehabilitated sources in addition to differences in permeability between trench material and surrounding soil. Results of the study by WSSC indicate that rehabilitation should be clustered in areas conducive to migration to achieve net flow reductions. If rehabilitation is not generally concentrated then flow removed from one source would essentially migrate to nearby unrehabilitated sources. General conclusions applied to the WSSC study on migration were:[8]

- Migration is probably not significant for a sewer system constructed substantially below the groundwater level since increases in in-trench groundwater as a result of rehabilitation would probably result in only a minor increase in head compared to the existing head on the sewer system. Interceptors that run along the banks of creeks and rivers are typical of sewer lines below groundwater levels.
- Sewers located in highly granular areas would not be subject to significant migration because groundwater movement would not be restricted by low permeability, thereby allowing exfiltration from the trench.
- Topographically flat areas would be less subject to migration since the lack of steep gradients would result in some outward dissipation rather than exclusive in-trench movement.
- Sewers in soils of low permeability are highly conducive to migration. Despite backfill consolidated during construction the sewer trench would be considerably more permeable than the surrounding soil since sewers are normally supported by granular material such as gravel and sand.

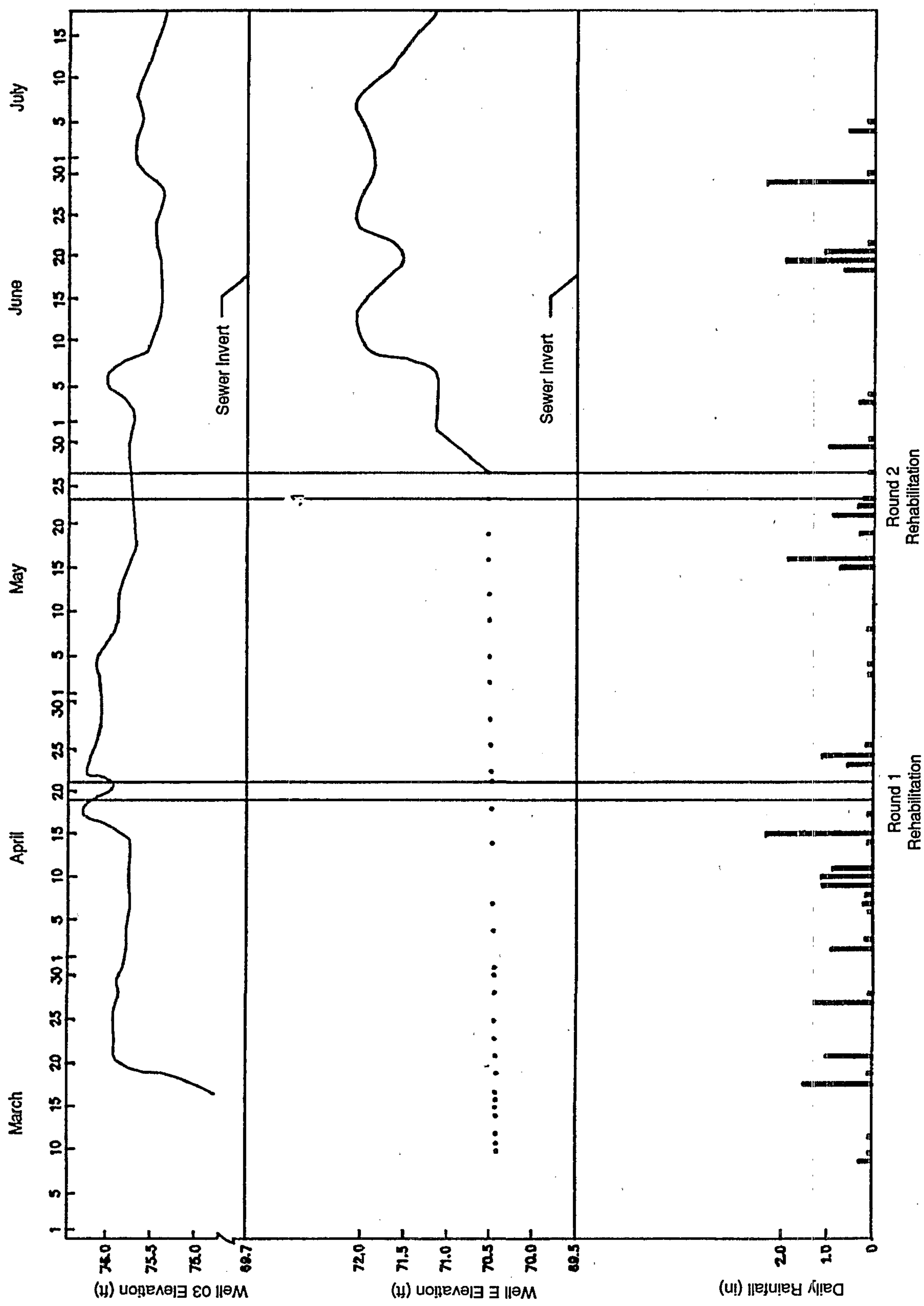
In a comprehensive rehabilitation program, it would be desirable to eliminate sources located on private property, especially house services. Here rehabilitation tends to be more expensive on the basis of unit flow rates. Private sector rehabilitation has political implications when part or all of the rehabilitation is paid by the property owners.

3.5.7.3 Rainfall Induced Infiltration (RII)

Rainfall Induced Infiltration (RII) is a form of infiltration that behaves somewhat similar to and is sometimes confused with storm water inflow. RII generally occurs during or immediately after rainfall events. It is caused by the seepage of percolating rainwater into manhole, pipe, and lateral defects that lie near or are readily reached from the ground surface. Foundation drains are a special case which has been classified as both inflow and infiltration by regulatory authorities. The quick rainfall response of RII causes a more rapid build-up of flow in sewers than normal I/I flows thus creating a greater potential for sewer surcharging and overflow.

An ancillary problem associated with RII as with any infiltration problem is that there is the potential for exfiltration of untreated wastewater at these same pipe and manhole defects. In some cases, discharged wastewater may cause groundwater contamination; in

Figure 3-5. **Effects of groundwater on migration.**



other cases it might be channelled by sewer trenches to potential points of direct human exposure. Data based on a study conducted by the U.S. EPA indicates the following conclusions and findings regarding the impact of RII:[3]

- RII is a type of infiltration since it enters the sewer system through defects. However, its flow characteristics resemble those of inflow i.e., there is a rapid increase in flow which mirrors the rainfall event followed by a decrease as the rain stops.
- Because of its flow characteristics, RII has occasionally been misidentified as inflow in many cases. Consequently, rehabilitation programs aimed at inflow sources have not achieved the anticipated reduction in extraneous flows in these cases.
- RII appears to represent a significant portion of the flow to some wastewater treatment plants during wet weather periods. In the 10 case studies conducted by U.S. EPA, the peak wet weather flows were 3.5-20 times the dry weather flow. The contribution from RII was estimated to be between 60-90 percent of the wet weather flows, the remainder being groundwater infiltration and inflow.
- Collection and treatment systems often do not have the capacity to handle peak wet weather flows. Peak flows, therefore, can cause wastewater backups into buildings, overflows and treatment system bypasses. Such occurrences are a hazard to public health and a violation of the municipality's discharge permit.
- Sewer trenches can act as collectors of rainfall percolating into the soil. The trenches channel the water, thus providing multiple opportunities for the water to seep into the collection system at defective points.
- The shallow portions of a collection system, e.g. building laterals, manhole defects, etc. are more vulnerable to RII. Interceptors sewers, which are typically deeper, do not appear to be a significant entry point for RII, but are more likely sources of groundwater infiltration, which normally minimizes peak to average flow ratios.
- The extent of RII problems in sanitary sewer systems is related to the age and condition of the sewers, material of construction, pipe, lateral and manhole defects, climate, geology, groundwater levels, and depth of sewers.

Figure 3-6 presents the typical entry points of RII.

3.5.7.4 Method of Analysis

The following techniques can be used to estimate the total infiltration in a sewer system:

a. Water Use Evaluation

This method uses the water supply records for the purpose of estimating the amount of domestic wastewater discharged to the sanitary sewer system. Monthly water use records are obtained. As an estimate, the percentage of the water that would reach the sanitary sewer would range from 70 percent in summer to 90 percent in winter. Given these facts, the rates at which domestic, industrial and commercial wastewater should flow into the sanitary sewers can be determined. These calculated flow rates can be subtracted from the total flow measured at the wastewater treatment plant to obtain an estimate of the infiltration entering the sewer system. Factors that should be considered when using this method for infiltration analysis are:

- Confirmation of the consumptive use mentioned above
- The amount of unaccounted water supplied through the system through wells, springs, or reservoirs that would not be accurately measured due to faulty or inaccurate meters or lack of metering. Unaccounted for water also includes illegal taps and unmetered withdrawals from fire fighting lines, street flushing fire lines, or hydrants.
- For areas supplied with a secondary water system, the water balance must include this source.

b. BOD Evaluation

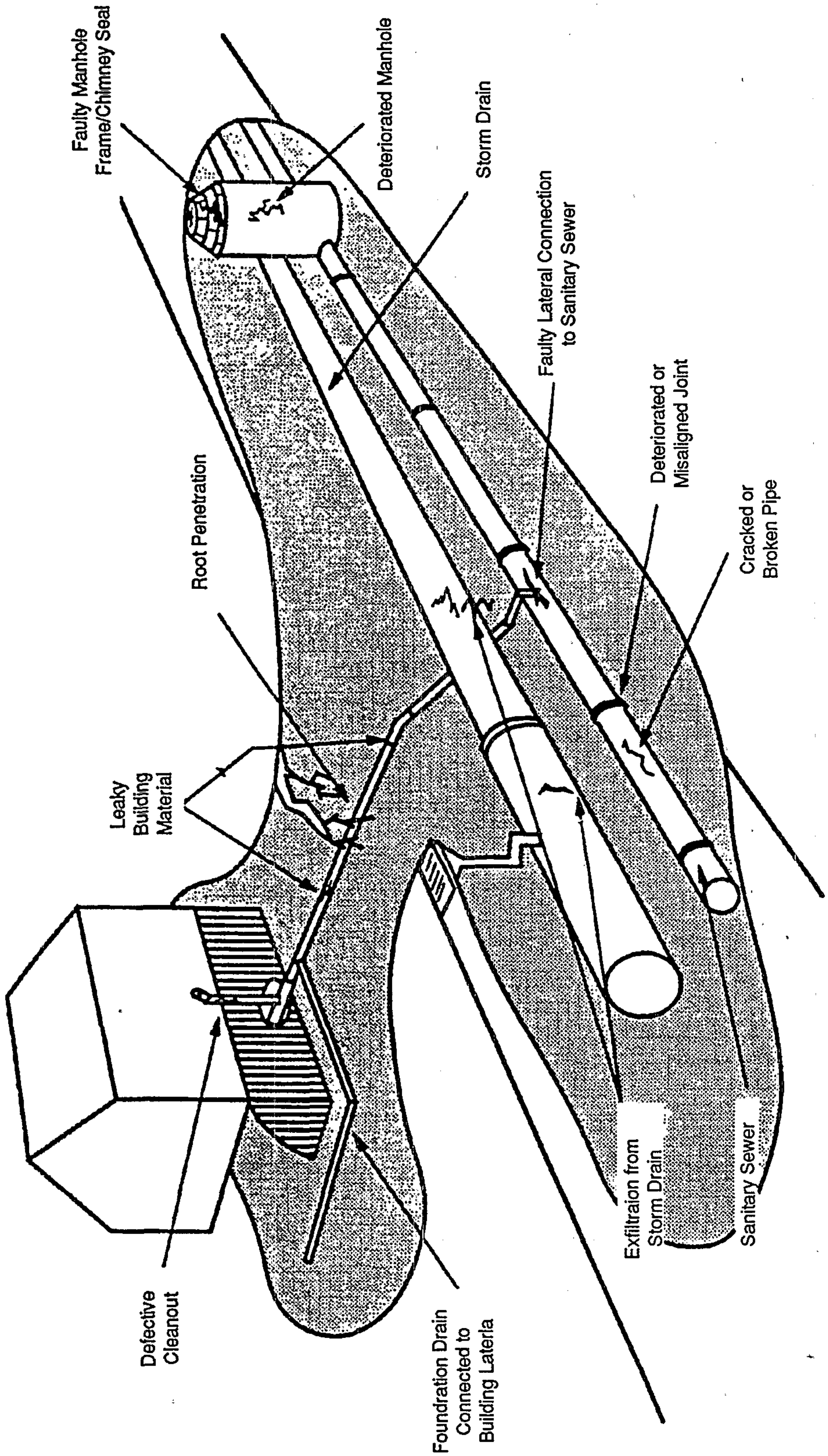
The mass BOD loading from domestic and industrial sources are used in this method. The method assumes that the average BOD of domestic waste without infiltration is 200 mg/L. Monthly treatment plant flow records are used to determine total flow and average actual BOD daily loading. The industrial flow and BOD loading must also be estimated in order to use this method.

First, the total BOD load to the treatment plant is calculated in mass/d from the plant influent flow and actual influent BOD. Next the industrial flow and BOD load is estimated and subtracted from the total plant load. The normal domestic flow is calculated by knowing the domestic BOD load and using an influent BOD concentration of 200 mg/L. The infiltration is then calculated by subtracting the calculated domestic flow plus the estimated industrial flow from the actual plant flow. The procedure can be completed on a daily, monthly or annual basis. The accuracy of the procedure depends on the accuracy of estimating industrial flow and BOD load. It should be applied to the total system rather than to sub-systems because of limitations due to unequal distribution of domestic and industrial flows in smaller sub-systems.

c. Maximum-Minimum Daily Flow Comparison

This method assumes that infiltration will be constant throughout the day if there is no precipitation. Industrial flows are also assumed to be constant throughout the day, so the daily flow variations measured are strictly attributed to the domestic flow contribution. Treatment plant influent data can be evaluated to obtain the domestic

Figure 3-6. **Typical entry points of rainfall induced infiltration.**



flow rate. The domestic flow rate and the industrial flow rate are subtracted from the total flow rate, which gives the resultant quantity as the rate of infiltration. This procedure can be carried out using monthly averages to obtain the estimated infiltration for the entire year.

d. Determination of Total Yearly I/I

The following procedure is used to estimate the yearly I/I in the sewer system:

- Obtain the average daily, weekly, and monthly wastewater flow data from treatment plants for the time period of interest. A minimum of one year of data should be used.
- Obtain and/or calculate the theoretical wastewater production rates; also the rainfall and groundwater levels throughout the sewer system area should be noted throughout the study period.
- Plot the rainfall duration and intensity along with groundwater levels.
- For each storm, plot the average wastewater flows and the theoretical wastewater production rate as a function of time, as shown in Figure 3-7.
- The area in the plot which is between the theoretical wastewater production rate and the recorded wastewater flow rate represents an estimate of the yearly I/I.

An estimate of yearly infiltration can be estimated as follows:

- Select several months of data from the total yearly I/I plot (Figure 3-7) and plot rainfall duration and intensity, total recorded wastewater flow and theoretical wastewater production rate.
- Draw a line through the lower limit of the recorded wastewater flow as shown in Figure 3-8.
- The distance between this line and the theoretical wastewater production provides an estimate of the infiltration.

Total yearly inflow can be estimated by the following procedure:

- The total yearly inflow can be obtained by subtracting the total yearly infiltration from the total yearly I/I. The total yearly inflow obtained may contain some amounts of infiltration which is induced by rainfall and is known as RII.

3.6 Exfiltration and Its Impacts

3.6.1 Introduction

Exfiltration is a relatively new topic in the sewer system rehabilitation field. Exfiltration occurs when deteriorated or poorly designed or constructed sewer lines allow wastewater to escape from the sewer into the surrounding soil. An exfiltration study was initiated by the U.S. EPA because it was not known what effect exfiltration from sewers had on the groundwater in the area. It was believed that industrial and domestic wastes flowing in the sewers could be escaping into the nearby soil and possibly percolating to the groundwater and contaminating it. *Results of the Evaluation of Groundwater Impacts of Sewer Exfiltration*[10] summarizes the activities and findings of this study. The U.S. EPA study showed that it was impossible to correlate infiltration with exfiltration. Previously exfiltration has been used to estimate infiltration. This practice appears to have limited applicability unless a special case can be demonstrated where such a correlation does exists.

3.6.2 Summary of Information on Impacts

The U.S. EPA study showed that substantial exfiltration does exist in locations where the groundwater level is sometimes or always below the sewer. In fact, in the two field studies which were performed, exfiltration rates were found to be greater than infiltration rates in locations where fluctuating groundwater levels allowed for both infiltration and exfiltration.

As a part of the U.S. EPA exfiltration study, the groundwater was sampled and analyzed in areas where sewer exfiltration existed. The results of the groundwater analyses were inconclusive. Tests performed in one area indicated that exfiltration was not contaminating the local groundwater. Tests in a second area showed slightly higher levels of several contaminants but the study could not prove that these contaminants were a result of exfiltration.

3.6.3 Consideration in I/I Analysis

It is important that the possible effects of exfiltration be considered in an I/I analysis. Ignoring exfiltration could lead to the calculation of inaccurate infiltration rates.

3.6.4 Present and Future Environmental Impacts

Even though the results of the exfiltration study were inconclusive, the environmental impacts of exfiltration are potentially significant. If exfiltration of wastewater is contaminating groundwater, it could have a serious impact on the environment. More research is required before the environmental impact of exfiltration can be determined, but the potential for contamination of groundwater is greatest in coarse soils above unconfined aquifers.

3.6.5 Exfiltration Tests and Methods

Exfiltration tests have historically been used as an indirect method of estimating infiltration potential for both old and

Figure 3-7. Determination of total yearly infiltration/inflow.

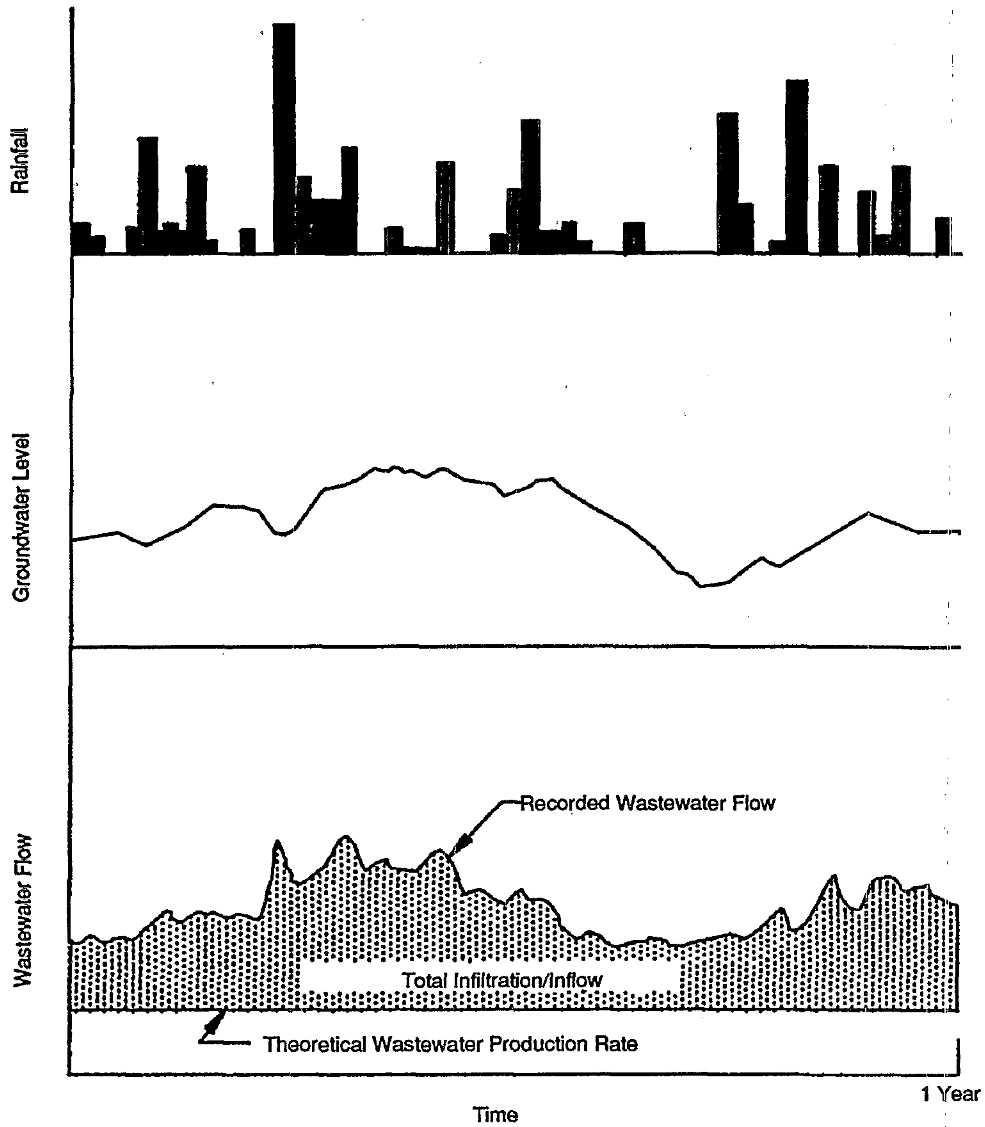
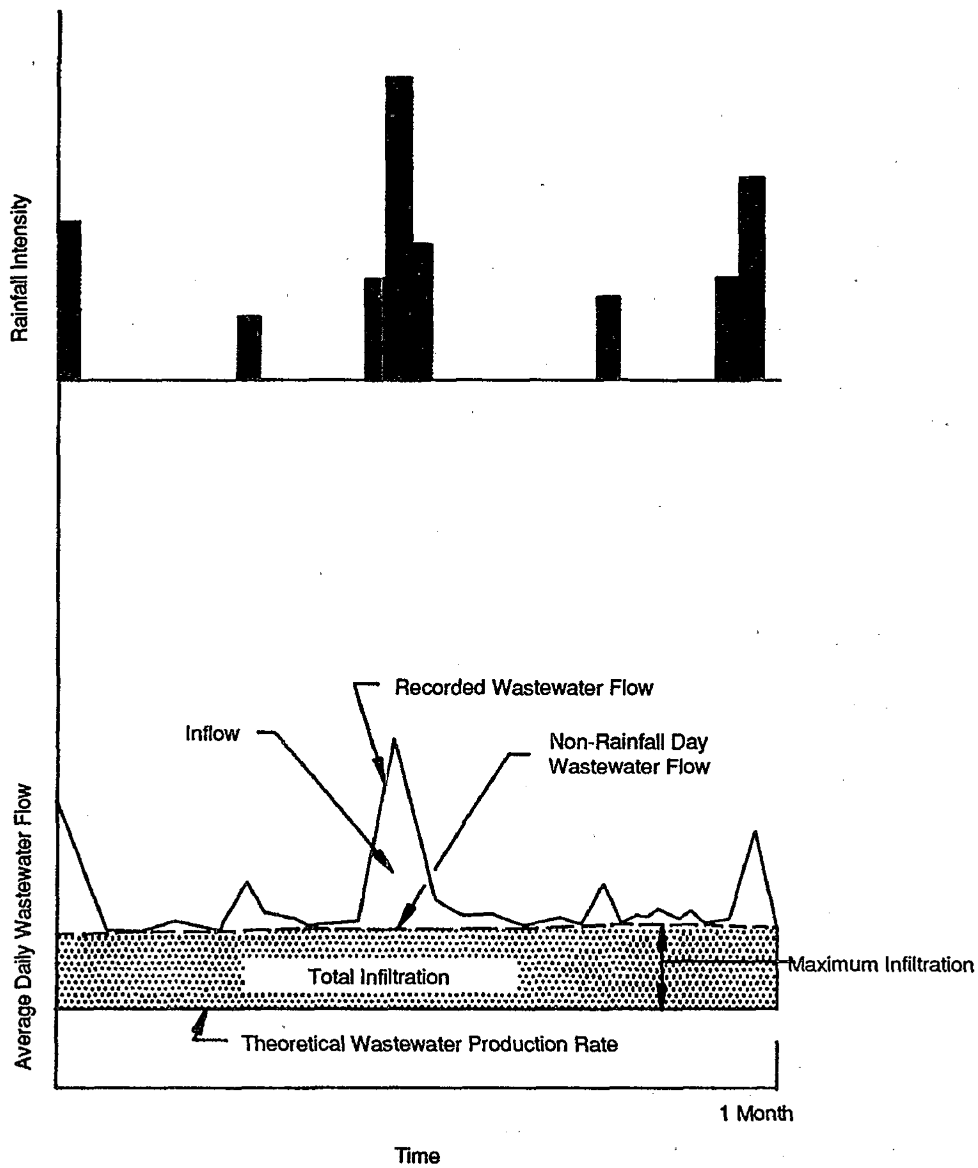


Figure 3-8. **Determination of total yearly infiltration.**



new sewer systems. It is most commonly applied to new sewers and is normally a part of new sewer construction specifications. Accurate exfiltration tests requires a knowledge of ground water levels, adequate pre-soak times and maintenance of adequate head differentials on the system.

Prior to the initiation of an exfiltration test, the level of groundwater adjacent to each section undergoing the testing must be measured and recorded. The exfiltration test works on the basis that a certain pressure will force water out of the line into the soil surrounding the pipe. The following is an outline of an exfiltration test procedure:

- Clean the pipe section from manhole to manhole for each reach of sewer being tested (applies to old sewers).
- Seal the upstream pipe inlet of the upstream manhole and the upstream pipe of the downstream manhole with plugs to ensure tight seals against water leakage. Since the exfiltration test can take several hours, the need for temporary wastewater bypassing around the test section should be anticipated.

The exfiltration test is based on the loss of water from the section of sewer being tested and thus requires a method of establishing a specific pressure head on the system. The upstream manhole is often used as a reservoir for maintaining the pressure head. A standpipe may be used instead of the upstream manhole for providing the pressure head on the system.

- After properly sealing and isolating the test section, the sewer and manhole or standpipe must be filled with water. The upstream manhole or stand pipe is used to introduce test water into the system and for maintaining an adequate pressure head. The test head should be 60 cm (2 ft) above the pipe crown at the highest point or 60 cm (2 ft) above the groundwater level.
- Water should be allowed to stand in the test section for a period long enough to allow water absorption in the pipe. This time should be as much as 6 hours for concrete pipe depending upon the degree of saturation prior to testing. After the absorption period, the pipe, upstream manhole, or stand pipe is refilled and the test begun. This step is not necessary for vitrified clay or plastic pipe.
- Determination of the actual exfiltration is based upon the method used for providing pressure head on the system, either by standpipe or the upstream manhole.
- Use of the standpipe requires that a constant water level be maintained in the standpipe to maintain the specified pressure head on the sewer section under test. Therefore, the volume of water added to the standpipe over the one hour test period is the actual exfiltration rate from the section under test.
- When using the manhole, the exfiltration rate will be determined by measuring the difference of the final water elevation and the initial water elevation and converting this to actual gallons lost through the pipe in a one hour period.
- If the pipe being tested does not meet the permissible loss, the section of sewer is considered unacceptable. Another exfiltration test should not be conducted until the groundwater conditions surrounding the pipe return to a condition similar to those existing at the beginning of the test period. The groundwater elevation should be determined prior to initiation of the second test.

A less commonly used exfiltration test is the continuous flow monitoring technique. Continuous flow monitoring should be performed in a 300-m (1,000-ft) section of sewer or greater which contains nothing that could interfere with the test results. The groundwater level must be below the sewer to ensure that no infiltration occurs and there must be no laterals or cross connections. Certain characteristics of the test section must be constant for the entire section: the size, type and age of sewer pipe and the type of soil surrounding the pipe. The flow rates at the beginning and end of the test section are continuously measured and the difference between the two is the amount of exfiltration. In the exfiltration study, the flow measurements were made using a weir and differential pressure sensing bubbler flow meter and flows were measured and recorded for at least 48 hours.[5] Other types of flow measurement schemes would also work, based on the same physical principles.

If a 300-m (1,000-ft) section of sewer that meets the above criteria cannot be found, a shorter sewer or one which contains a few disturbances may be used. The effect of the disturbances would need to be measured and analyzed, however, and would introduce significant errors into the calculation of the exfiltration.

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When an NTIS number is cited in a reference, that reference is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

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CHAPTER 4

Sewer System Evaluation

4.1 Introduction

The Sewer System Evaluation Survey (SSES) is the third phase of an overall sewer system evaluation (See Figure 3-1). The purpose of the SSES is to quantify the amount of infiltration/inflow (I/I) and rainfall induced infiltration (RII) that can be reduced and the cost of such reduction on a source-by-source and sub-system basis. The SSES confirms and refines the overall findings of the I/I analysis. The SSES employs TV inspection, rainfall simulation and other techniques to identify specific sources as required to develop the detailed cost-effectiveness analysis for I/I.

The findings of the SSES should be sufficiently specific to describe the corrective actions that need to be taken along with the amount of infiltration, RII, and inflow that will be eliminated from each major source, sewer segment and sub-basin . The SSES must separately define the cost effectiveness of infiltration removal and inflow removal.

Where corrosion is present, the extent of corrosion mitigation expected due to I/I rehabilitation should be noted. Specific corrosion potential should also be defined and recommendations made to reduce this potential to acceptable levels. The procedure for conducting a corrosion survey as a part of an SSES is presented in Chapter 5.

The following tasks are usually included in the SSES:[1-3]

- Survey Planning and Cost Estimating
- Physical Survey
- Rainfall Simulation
- Preparatory Cleaning
- Internal Inspection
- Preparation of Survey Report and Cost Effective Analysis

Table 4-1. Sewer System Testing and Inspection Methods

Method	Application
Smoke testing	Most common routine source detection method to identify inflow and RII sources.
	Source detection after previous lining or replacement.
Rainfall simulation (dye flooding and tracing)	Used after smoke testing to confirm suspected storm drainage connections, and other inflow and RII connections.
Building plumbing inspection	As needed after smoke testing to confirm suspected inflow sources, such as roof leaders and foundation drains.
Manhole inspection	Primary source detection to evaluate I/I sources and structural condition.
	Inspection performed along with other investigation procedures.
Flow isolation	Follow-up source detection after sealing; used to verify migration, identify I/I.
	Used where flow monitoring indicates high infiltration in large areas.
	Used where smoke testing indicates potentially major infiltration sources.
TV inspection	Primary internal inspection technique for SSES, degree of inspection areas for pipes as determined by I/I analysis.
	Routine inspection for pipes rehabilitated by sealing if interim detection does not reveal I/I sources
	Used after grouting and sealing techniques.
	Used to verify smoke testing, flow isolation or when temporary flow monitoring indicates excessive I/I.
Lateral testing	Used where smoke testing indicates major defects
	Used where building inspection indicates major defects.

Table 4-1 describes the most commonly used sewer system testing and inspection methods.

4.2 Planning the Survey and Use of Sub-System Approach

The SSES must be planned and executed to produce accurate estimates of flow reduction and estimated costs. An overall block diagram for the conduct of a preliminary sewer system evaluation plan was presented in Figure 3-1. Figure 3-2 presented the sequence of steps for conducting an I/I analysis. Figure 4-1 presents a diagram of the methodology to be followed in the conduct of an SSES. The following sections of this chapter presents the detailed procedure for an SSES.

The physical survey is performed to isolate the problem areas and to determine the general physical conditions of the sewer sections selected for future study. Rainfall simulation is conducted to locate the rainfall-associated I/I sources in the sewer lines.

Preparatory cleaning of the sewers is necessary prior to internal inspection. Internal inspection locates the I/I sources, the flow rate from each source and the structural defects in the pipe. Finally, the survey report summarizes the results obtained during the survey and presents a cost-effectiveness analysis of the I/I sources which can be economically corrected.

4.3 Physical Survey

The physical survey of the sewer collection system is performed to isolate the obvious problem areas, to determine the general condition of the sewer sections selected for further study. The following tasks are normally included in the physical survey:[2,3]

4.3.1 Aboveground Inspection

This should include the investigation of the general conditions of the study area such as topography, streets, alleys, access to manholes, etc. Potential problem areas, such as waterways, river crossings, natural ponding areas, should also be located. Key manholes are identified for additional flow measurements and groundwater monitoring. Manhole access problems, such as easement, access, buried structures, traffic interferences, should be noted. The accuracy and completeness of sanitary sewer maps should be verified. The proximity of storm and sanitary sewers, inflow sources, such as roof downspouts, yard and area drains, creeks, low or inundated manhole covers and frames, and foundation drains, etc. are all indications that rainfall simulation tests in the form of smoke testing and/or dyed water testing should be planned. A program for uncovering manholes, improving and raising frames to above grade should be planned.

4.3.2 Flow Monitoring

This should include determining and isolating areas where I/I exists. During the I/I analysis, flow monitoring work would have already been performed in a few selected manholes. The additional flow monitoring work performed during the physical survey is actually a continued effort to further reduce the number of areas to be investigated. Flow monitoring should be conducted during the highest groundwater conditions to identify maximum infiltration flow. Monitoring for inflow should be conducted during storm events under wet weather conditions. Dry weather and wet weather flows should be monitored for comparison. To minimize the effects of normal wastewater flows, the flow monitoring should be conducted during the early morning hours. Sub-system and plant flow monitoring should be conducted on a 24-hr/d basis.

4.3.3 Flow Measurement

Flow in sanitary sewer systems consists of base flows, infiltration and inflow. Separation and quantification of these components is the prime objective of flow monitoring. Flow measurement in sewer systems is undertaken to define variations of certain flow components with time or to define peak and/or minimum flow conditions. Sewers should be cleaned thoroughly before velocity measurements are undertaken.

Many techniques are used for the measurement of flows in sanitary sewers. The equipment and techniques selected will depend upon the resources available, the degree of precision required, and the physical conditions within the sewers.

a. Manual Methods

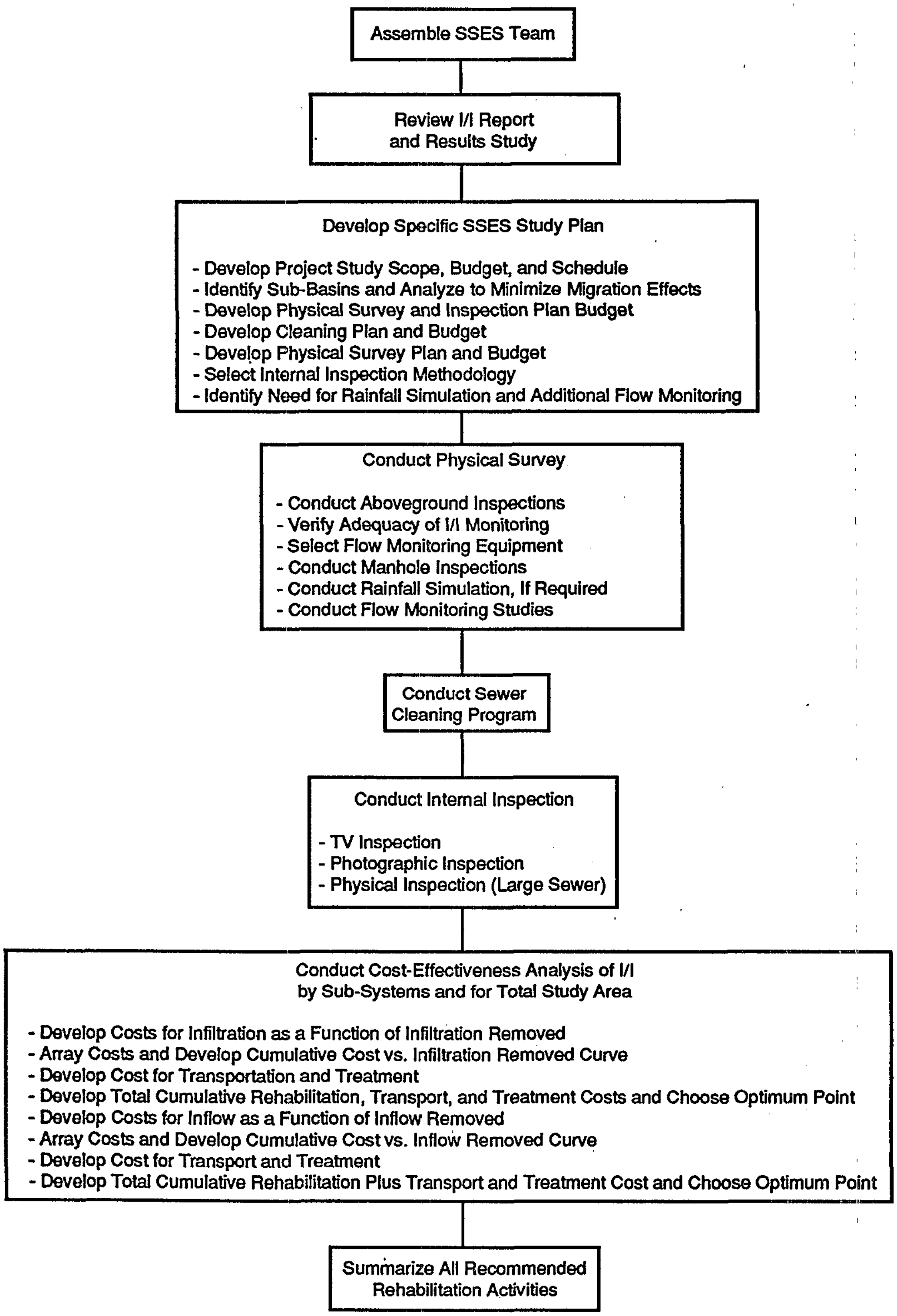
This is the most widely used technique for measurement of instantaneous or short term flow. Generally, the equipment is portable and flows can be determined immediately using published curves, nomographs or tables.

<u>Weirs</u>

The weir is a common device for measuring low wastewater flows because of its ease of installation and low cost. Flow measurements through weirs are obtained by recording the head (water level) above the weir crest and determining flow rates by calculations, nomographs or tables. Advantages and disadvantages of weirs are:

<u>Advantages</u>	<u>Disadvantages</u>
• Low costs	• Fairly high head loss

Figure 4-1. Sewer system evaluation flow diagram.



• Easy to install	• Must be periodically cleaned; must be suitable for channels carrying excessive solids
• Easy to obtain flow by standard equations, nomographs, etc.	• Accuracy affected by excessive flows and debris
• Direct flow reading	• May be difficult to make accurate manual measurements in sewers because of limited access
• Many designs available for flexibility	• Cannot be used in sewers flowing full
• Generally accurate	

Additional information on the measurements of flow through weirs is provided in the report *Existing Sewer System Evaluation and Rehabilitation.*[3]

Flumes

Flumes operate on the Venturi principal. In flumes, the constriction of the throat causes the flow to have a critical depth. This is followed by a hydraulic jump if the slope allows subcritical (low velocity) flow. There are several types of open channel flumes, including the Parshall, Palmer-Bowles, H-Flume and Trapezoidal configurations. Flumes are capable of providing results accurate to within 3-5 percent. Advantages and disadvantages of flow measurements by flumes are as follows:

Advantages	Disadvantages
• Self-cleaning to a certain degree	• High cost
• Relatively low head loss	• May be difficult to install
• Accuracy less affected by approach velocity than it is with weirs	
• Data easily converted to flow using tables or nomographs	

Manual Depth Measurement

An instantaneous flow measurement in sewers can be obtained by the following formula: Q = AV, where Q is the volumetric flow rate, V is the mean velocity of flow, and A is the cross-sectional area of the pipe. The mean velocity of flow must be measured or obtained theoretically through the Kutter's formula:

$$V = 1.486\ R^{2/3}\ S^{1/2}/N$$

Where,

N = Mannings Coefficient

R = Hydraulic Radius, ft
S = Slope, ft/ft

Staff gauges marked to the nearest 3 mm (1/8-in) are used to measure depth. In manholes that are relatively clean and accessible, the staff gauge may be inserted into the invert of the manhole channel and the depth of flow measured. The depth of sediment in the pipe should be noted and the depth of flow corrected accordingly. Advantages and disadvantages of this technique are as follows:

Advantages	Disadvantages
• Inexpensive	• Instantaneous result that may not be representative
• Rapid results	• Determination of mean velocity is critical
• Ease of operation	• Cannot be used in surcharged sewers
	• Low degree of accuracy

Timed Volume

This method is used to determine flow rates from leaking manhole walls, wet well walls and accessible point sources of inflow. The method involves the use of a vessel of known volume; the time to fill this vessel is measured with a stop watch or a watch. Equipment required for flow measurement by this technique includes plastic containers or 208-L (55-gal) drums, depending on the amount of flow. A stop watch or a watch with a sweep second hand is suitable for measuring time. Advantages and disadvantages to this method are:

Advantages	Disadvantages
• Accurate	• Generally cannot be used for flow in any but the smallest sewer pipes
• Inexpensive	• Not adequate for high velocity flows
• No specific expertise required	

Dye-Dilution Method

This technique is a simple, potentially accurate, and quick method for the determination of flows in sanitary sewers. The method is based on measuring the concentration of dye in a waste stream into which has been added a known concentration of dye, then calculating the flow. Flows can be measured under partial or full flow conditions without entering manholes. This method is employed to obtain instantaneous flow rates but with added equipment it can be used to monitor flow on a continuous basis. Advantages and disadvantages to this method are:

Advantages	Disadvantages
• No entering of manholes	• Samples must be analyzed as soon as possible (most dyes decay in sunlight).
• Saves time and provides instantaneous flow data on many sewer sections	• Temperature correction may be required • Instrumentation is expensive • Dye is expensive
• Independent of sewer site,dimensions, velocity and surcharging	• Need at least 100 sewer diameters for dye mixing before sampling.

Three water soluble fluorescent tracer dyes are extensively used: Rhodamine B, Rhodamine WT, and Fluorescein. For accurate flow measurements in sewers, a dye which has a low sorptive tendency with the solids in the wastewater should always be used. The fluorescence of the Rhodamine dyes is not suitable outside of the pH of 5-10. Since the fluorescence of the dye is also affected by temperature, a correction factor should be applied to the measured concentrations if the temperature of the sample is different than the room temperature.

Commercial solution feeders are available for feeding the dye at a constant rate to the manhole. Collection of the samples at the downstream manholes can be achieved by lowering a container with a rope attached to the sampler. To minimize the loss of dye due to absorption, the sample container should be made of high quality glass or other similar material. The samples should be allowed to stand to reach room temperature and to settle the suspended solids before measurements are taken

b. Automatic Flow Measurement

Automatic flowmeters can continuously monitor flows with a minimum of labor. Data collected can be displayed, recorded on charts, sorted on magnetic tapes or solid state memory, or even transmitted from the field to the office by telephone or radio. These meters save considerable time and effort compared to manually recorded flow data, but proper installation, calibration, and maintenance require individuals with a basic knowledge of hydraulics and proper maintenance procedures for the meter in use. Following are the capabilities of various automatic meters:

Depth Measurement

Depth recorders are used to measure liquid levels in a pipe, head over a weir, depth in a flume, or other applications. Commonly used equipment for recording liquid depths includes probes, bubbler, pressure sensors, floats, ultrasonic devices and capacitance/electronic probes.

Velocity Measurements

Automatic flow monitors that use velocity measurements can provide accurate data even under highly fluctuating liquid levels. Velocity may be automatically recorded using ultrasonic doppler methods, magnetic methods, mechanical current meters, or other methods. In most cases the depth of flow is recorded along with the velocity in order to utilize the flow equation $Q = AV$.

Electromagnetic/Doppler meters

Velocity measurements by these methods are usually taken by connecting the probe to the outside of the pipe to be monitored. This is generally used for pipes flowing full and having sufficient suspended solids to be transmitted back to the receiver. The advantage to this type of flow measurement is the ability to record flows in closed pipes without obstructing the fluid flows.

Orifice/Nozzle/and Venturi meters

These types of flow meters are used for measuring flows in completely full pipes. The basic concept is to form a constriction in the flow so that the velocity increases and the pressure decreases. The constriction provides an opportunity for solids to accumulate.

4.3.4 Manhole and Sewer Inspection

This task is required to determine the actual condition of the sewer system. Inspection should include descending and examining conditions of manholes and lamping of sewer lines to ascertain sub-system I/I conditions. Each manhole should be numbered and its physical condition noted in log sheets and standardized field forms. Safety precautions should be taken at all times before entering the manholes and proper NIOSH-OSHA procedures and references should be consulted. Sewer inspection should be carried out and identified on the manholes numbered. An inventory of the length, size, type, depth and the general conditions of the sewer pipes provides a basis for the estimation of the amount of work required for the preparatory cleaning and internal inspection. Depth of flow in sewers provides a rough indication of the capacity of the sewer pipe and whether or not I/I is present in the sewer section. Temperature can also be used as an indicator for the detection of extraneous water entering the sewer section being investigated since temperature near the point of entry for extraneous waters will be lower than the average temperature in the sewer lines, if the extraneous source represents a significant portion of the total flow. All the observations made during the manhole and sewer pipe inspection should be recorded in field log sheets and correlated with the sewer maps. Figure 4-2 indicates the typical defects found during manhole

Figure 4-2. **Typical manhole defects.**

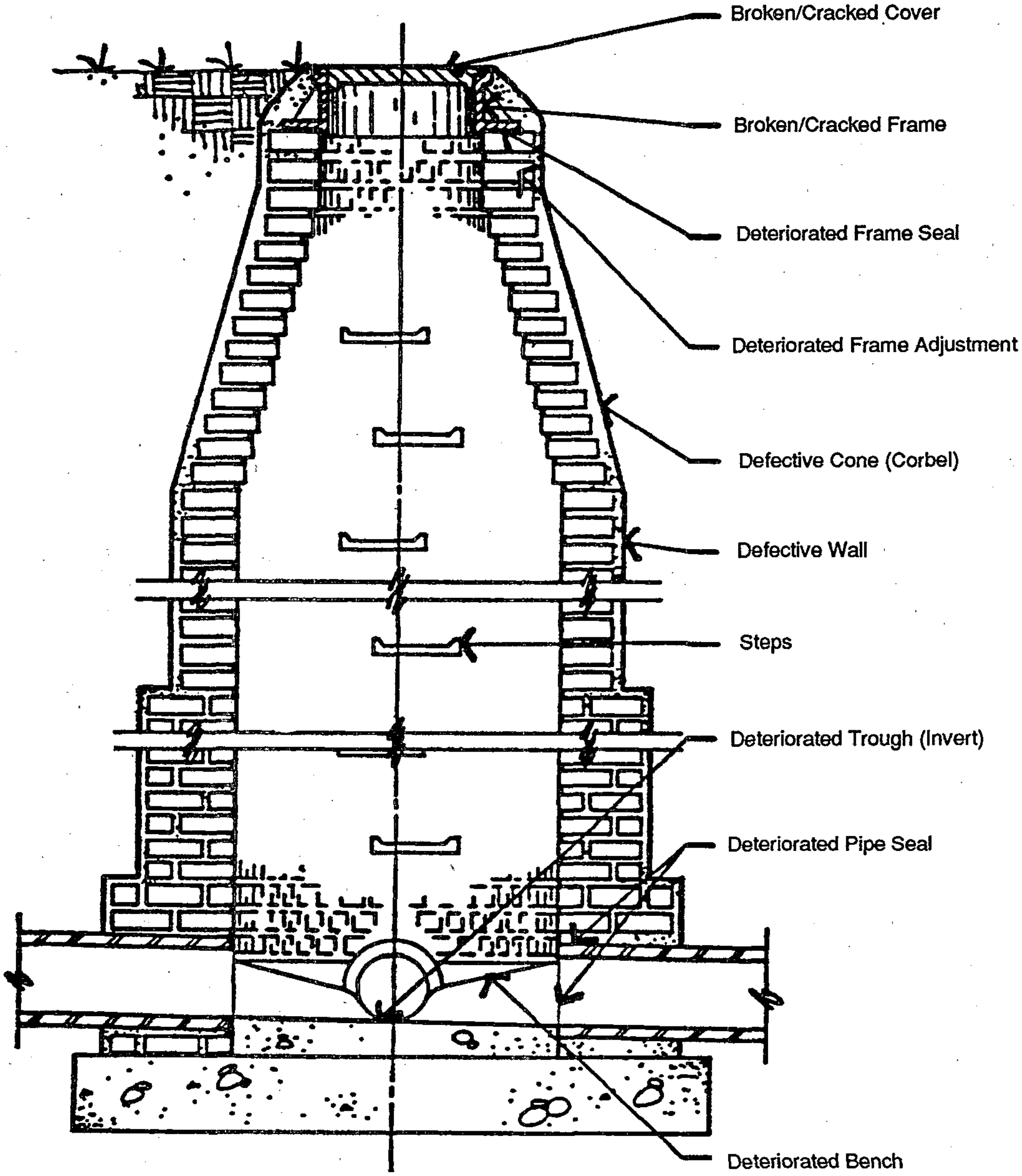
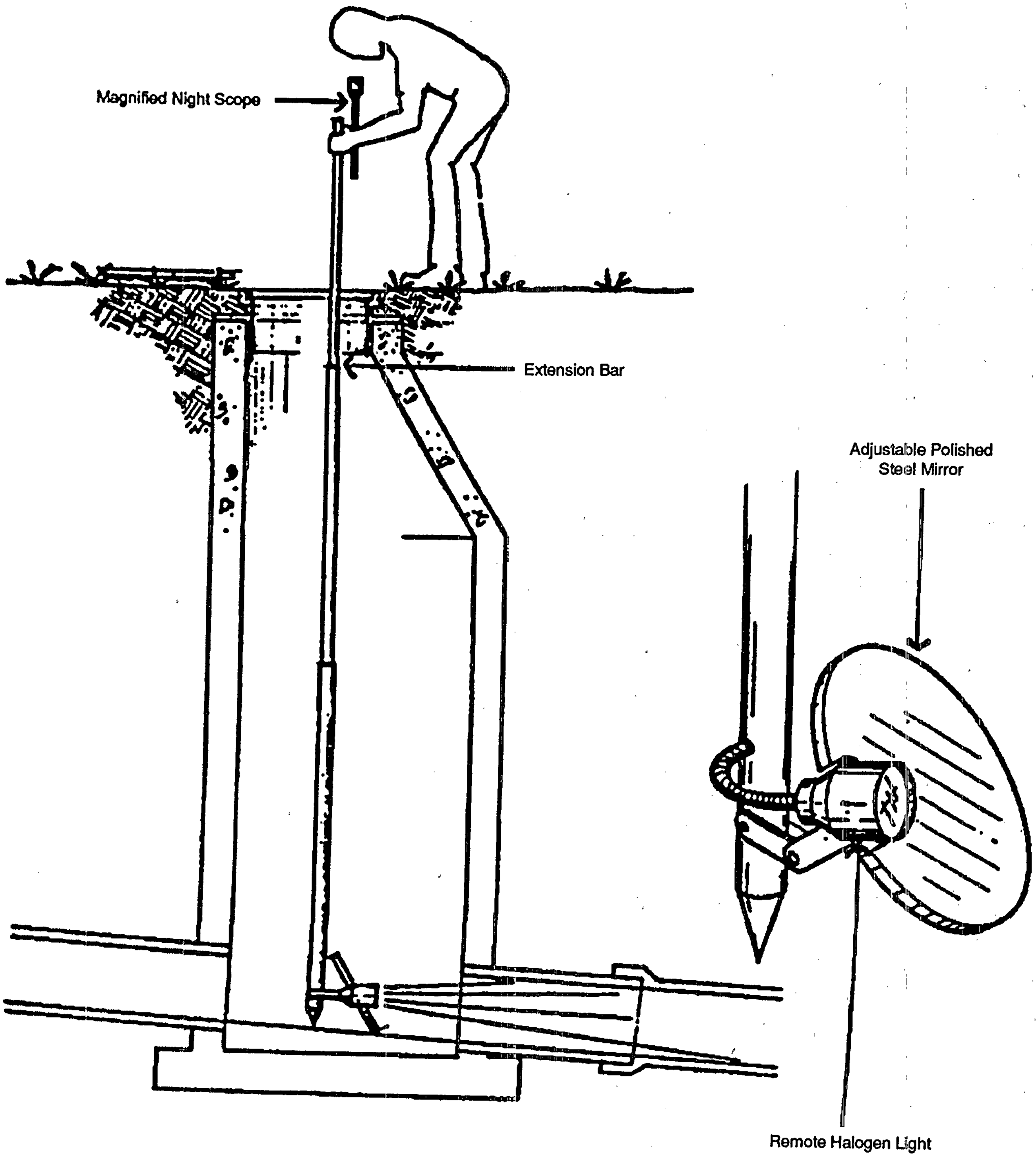


Figure 4-3. Quick method of inspecting sewer lines.



inspection and Figure 4-3 indicates a quick method of inspecting sewer lines without entering the manholes.

4.3.5 Rainfall Simulation

This task involves the identification of the sections of sewers that exhibit I/I conditions during rainfall events. Rainfall simulation does not have to be performed in every SSES. A careful study of the sewer maps and review of the I/I analysis report, smoke test results and the physical survey results indicate whether rainfall simulation is required.

4.3.6 Smoke Testing

This is an inexpensive and quick method of detecting inflow sources in sewer systems. Many inflow sources such as roof leaders, cellar, yard, and area drains; foundation drains; abandoned building sewers; faulty connections; illegal connections; sewer cross connections, structural damages and leaking joints can be identified by smoke testing under ideal conditions. Key steps for smoke testing are:

- Conduct smoke tests in selected sanitary lines (adequate notification must be made before smoke testing is done. This requires notification to residents, the local fire department, public meetings, etc.)
- Record, both in written and photographic form, all sources from which smoke emissions are noted.
- Visually inspect manholes suspected of having direct inflow connections into sanitary sewers.
- Identify direct inflow connections to sanitary sewers.
- Identify interconnections between sanitary and storm systems as evidenced by smoke emissions during the smoke test.

Smoke testing should not be conducted on sewer lines which contain sags, or are flowing full. Smoke testing cannot detect structural damage, or leaking joints in buried sewers and service connections when the soils surrounding and above the pipes are saturated, frozen or snow covered. Smoke testing should not be performed on windy days when the smoke coming out of the ground may be blown away so quickly as to escape visual detection. The following equipment is usually required to conduct smoke testing:

- Smoke bombs
- Air blowers
- Camera and film
- Sand bags and/or plugs
- Two-way radios

The smoke bombs used should be non-toxic, odorless and non-staining. An air blower is used to force the smoke into the sewer pipes. The camera is used to take pictures of the smoke coming out of the ground, catch basins, pipes and other sources during the test. Sand bags and/or plugs are used to block the sewer sections to prevent the smoke from escaping through the manholes and adjacent sewer pipes. It is important to coordinate with the fire department to prevent false alarm if for some reason the smoke would enter a house and would trigger a false alarm.

4.3.7 Dyed Water Testing

Dyed-water testing is used primarily to detect infiltration and RII sources in storm sewer sections, stream sections, and ditch sections. It can also be used to verify the results of smoke testing. This method of testing is more expensive and time consuming than smoke testing and requires large quantities of water.

Fluorescent dyes are used for this testing technique. The dyes should be safe to handle, biodegradable and inert to the soil and debris in sewers. Further information on the common types of dyes can be obtained from Reference 5.

The procedure for dyed water testing includes:

- Plug and flood with dyed water any storm sewer sections which are parallel to or cross sanitary sewers and house service lines which have shown evidence of smoke when nearby sections have been smoke tested.
- Where applicable, flood catch basins, ditches and ponding areas in close proximity to sanitary sewers with dyed water.
- The presence of dye or absence in adjacent downstream manhole indicates the infiltration potential.
- The response time of the appearance of the dye and in some cases the visual increase in flow provides additional insight into the infiltration or RII pathway.
- Analyze findings and recommend appropriate sewer sections for cleaning and internal inspection.

4.3.8 Water Flooding Test

This test is similar to dyed water testing, except that no dyes are used. With accurate flow measurement, pipe imperfections can be detected with this technique. The water flooding tests can be conducted by the following methods:

- Sprinkler test - Inflow and/or RII under unpaved areas, particularly in service connections during wet weather conditions, can be determined by the sprinkler test. Irrigation sprinkler pipes with spray nozzles are used to simulate rainfall conditions, and the rate of application of the water and the total water distributed are monitored.
- Exfiltration test - The exfiltration test is used to check the sewer lines and manholes for possible leakage.

The procedures involved in the exfiltration test are covered in Chapter 3.

4.4 Cleaning

Internal inspection of lines suspected of having I/I sources and any flow velocity measurement requires clean pipes. Debris in sewer inverts, grease accumulation and heavy root infestations not only obstruct visual or video inspection but they also may hide or mask actual infiltration sources. Preparatory cleaning is an essential first step in any meaningful internal examination procedure. The cleaning procedure should clean the sludge, mud, sand, gravel, rocks, bricks, grease and roots from the sewer pipes, manholes and pumping station wet wells to be inspected. The pipe walls should be clean enough for the camera used in the inspection to discover structural defects, misalignment and I/I sources. The following steps are required for cleaning:

- Clean all sewer lines by appropriate means and with proper equipment immediately prior to internal inspection or velocity measurement.
- Determine, if possible, all obstructions or other physical alignment, joint or connection conditions which could interfere with or prevent the insertion and movement of inspection equipment.

The equipment required for cleaning includes:[2,3]

- Rodding machines, bucket machines, high-velocity water machines and other hydraulically propelled devices
- Debris removal equipment, such as vacuum machines and trash pumps
- Debris transport vehicles
- A proper debris disposal site

For proper cleaning, factors to be considered are: access and condition of manholes, depth of sewer, size of pipe, depth and type of solid materials to be removed, degree of root intrusion, amount of flow, structural integrity of pipe, availability of hydrant water and the degree of cleanliness required. Figure 4-4 indicates some techniques involved in preparatory cleaning. Direct observation and camera are the usual forms of internal inspection equipment used for sewer lines. Direct observation is used for large lines that can be walked or crawled, while cameras are used on small-diameter sewers.

4.5 Internal Inspection

Internal inspection involves the following tasks:[3,4]

- Set up TV camera or other equipment in the sewer lines under investigation.
- Plug and flood all storm sewers in close proximity to sanitary sewers under inspection, if recommended by rainfall simulation findings.
- Internally inspect, designate footage, and note all structural defects and all leaks in terms of location and flow rates.
- If services are found to be running, verify whether the flow is caused by infiltration or actual water usage.
- Record findings on log sheets and support with video tapes.

Internal inspections can be accomplished in the following ways:[3,4]

4.5.1 TV Inspection

The TV inspection technique utilizes a closed-circuit TV camera to observe the conditions in the sewer lines. The TV cameras used are specially designed to detect the sewer conditions.

The camera is mounted in a casing and is pulled through the sewer with cables. Recently self propelled cameras have been used, but the disadvantage of this type of camera is required service and recovery if they fail or get stuck in the middle of the pipe run. The results are shown on the TV monitor and documentation can be made by a videotape or by photographs of the monitor. A light source is provided by the camera for illumination purposes.

4.5.2 Photographic Inspection

This technique utilizes a camera to take a series of color photographs along the inside of sewer lines. This technique is best for analyzing the structural conditions of the sewers. A camera is pulled through the sewer line being inspected. Pictures are taken at equidistant intervals or at some predetermined problem sections.

4.5.3 Physical Inspection

This technique involves the direct inspection of larger sewers not in service. Before inspection, the safety of the person entering the line should be carefully considered and the sewer section thoroughly ventilated to remove H_2S and other harmful gases that might be present.

Proper NIOSH-OSHA safety practices and procedures should be followed to properly carry out physical inspections.

Figure 4-5 shows the technique involved in TV inspection.

4.6 Cost Effectiveness Analysis

Figure 4-4. **Preparatory cleaning.**

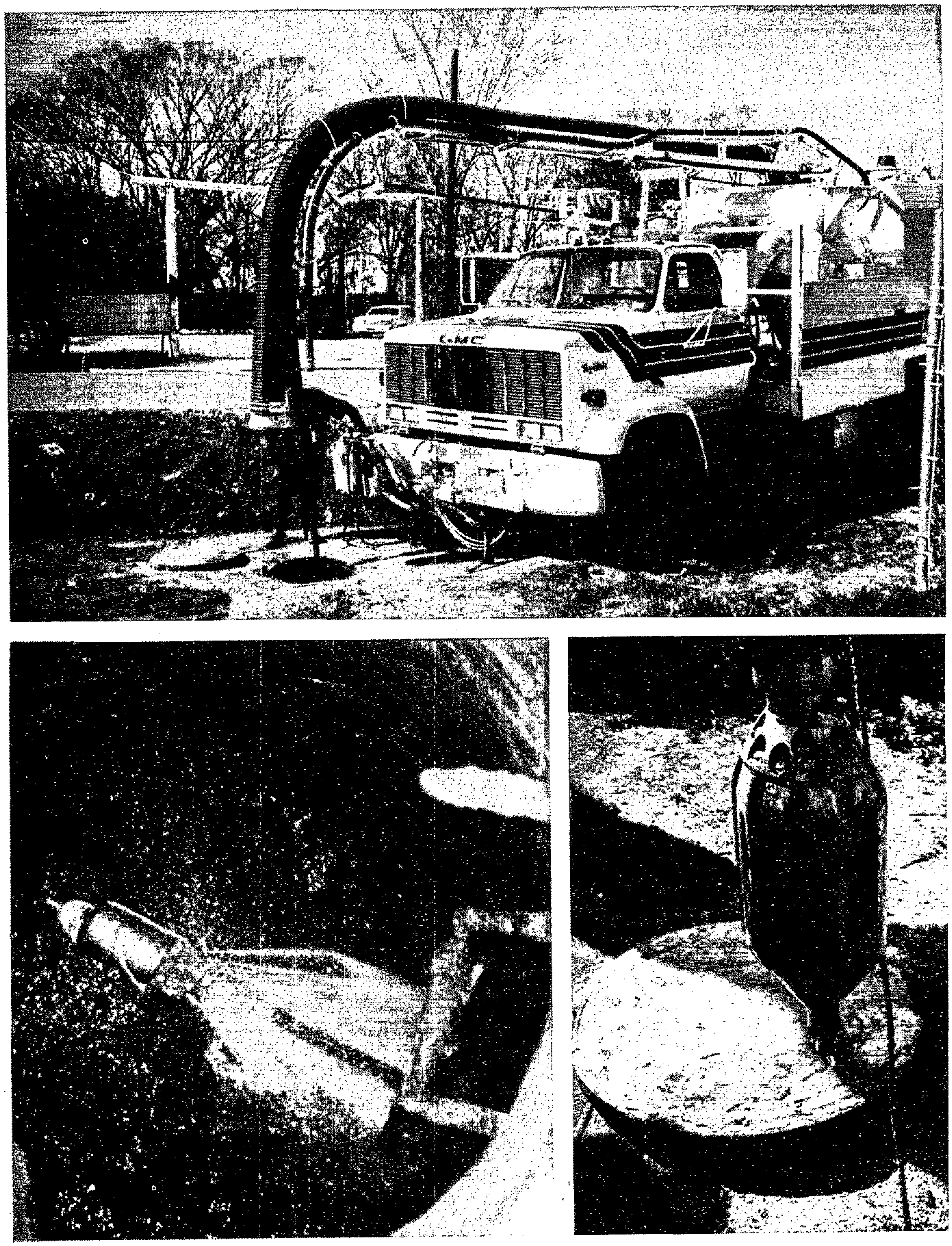
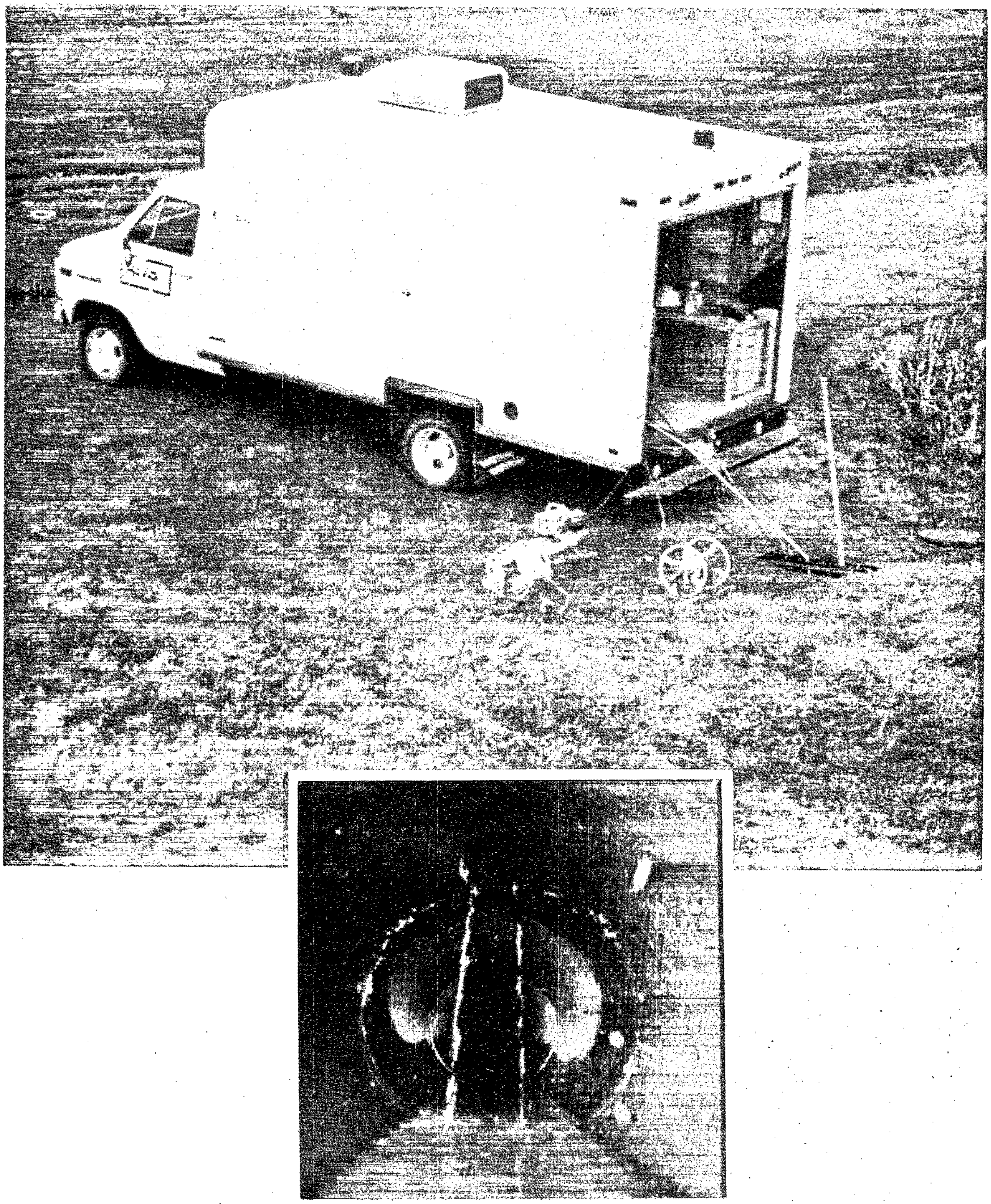


Figure 4-5. Internal color TV inspection.



Based on the results and findings of the SSES, a detailed evaluation and analysis should be carried out to determine the most cost-effective means of correcting or alleviating excessive I/I conditions found in the system.

Cost-effectiveness analysis for SSES is similar to the cost-effectiveness analyses for I/I. However, the SSES cost-effectiveness analysis provides a detailed and thorough analysis of the sewer system including the flow rates from each source, and the best method for rehabilitation of each source. For an effective cost analysis, the cost of correction for infiltration, inflow, RII and groundwater migration must be considered. Existing SSES methodologies rely on individual line segment nighttime isolation and measurements to identify excessive infiltration.

Subarea SSES analysis including migration effects is an improved approach to the traditional point source approach for evaluating sewer systems. (See Section 4.7 for a description of the subarea approach to rehabilitation). Flow adjustments for infiltration should be carried out before the cost-effectiveness analysis is conducted.[2]

Costs for the evaluation survey should be based on the total actual expenditure for the survey. Costs for rehabilitation should be based on the actual physical conditions discovered. The costs for transportation and treatment of wastewater should then be developed for at least four typical flow conditions so that a cost curve can be drawn to indicate the general cost pattern.[3]

A cost summary similar to that shown in Table 4-2 can be prepared to summarize the overall cost of a sewer system evaluation and rehabilitation program. The presentation of the costs for Infiltration and Inflow must be separately developed. The general procedures outlined below should be followed to develop both Infiltration and Inflow costs in a format for the cost effectiveness analysis curve preparation:

- Determine the total correction cost for each Infiltration and Inflow source and calculate the cost required for eliminating each unit of flow.
- Arrange the costs in a descending order with lower costs ahead of the higher costs.
- Arrange the costs in groups and determine the total correction cost for each group. Add costs for engineering services, administrative costs, contingency costs, interest during construction, etc. to derive the total required cost to eliminate the I/I from all sources within each group.
- Calculate the total accumulative cost (Curve B of Figures 4-6 and 4-7) against the total accumulative infiltration and inflow separately to be reduced and draw a curve passing through all data points. Plot a curve showing the relationship between the cost of transportation and treatment and the total infiltration and inflow (separate) to be reduced (Curve A). Derive a composite cost curve (Curve C) by adding the costs of each of the two derived curves (curves A and B). Locate the minimum cost point on the composite curve, and draw a straight line passing this point and parallel to the cost axis. The line intercepts the cost curve for infiltration and rehabilitation (Figure 4-6) and inflow rehabilitation (Figure 4-7) at a point which represents the optimal point for sewer rehabilitation. The flow figure corresponding to these points on each curve represents the infiltration or inflow which can be cost-effectively removed from the sewer system, and the cost figure corresponding to this represents the total cost which will be needed for the corrective actions.

4.7 Case Study Example and Detailed Method of Analysis

This section outlines a detailed method of analysis for SSES taking into account migration and rainfall-induced-infiltration. This detailed analysis was performed by the WSSC to develop a new approach to sewer system evaluation and rehabilitation known as the System Approach to evaluate Subarea Rehabilitation (SASR).[4] The subarea approach represents a large area (6,000-30,000 lineal m [20,000-100,000 lineal ft] of sewer) undergoing a sewer system evaluation survey as opposed to the traditional method of evaluating smaller segments and single sources. Field activities incorporated in this study included the following:

Rainfall Monitoring - Monitoring was conducted by four continuous recording gauges to measure precipitation to 1/100th of an inch versus time, to allow for correlation of inflow to rainfall intensity.

Continuous Flow Monitoring - This was performed at each subarea outlet utilizing flow meters to record depth and velocity.

Internal Night-Time Flow Measurements - Flow measurements conducted within each subarea to identify mini-systems subject to infiltration.

Manhole and Visual Pipe Inspections - Inspection for each manhole began at the surface by identifying potential for ponding and concluded with evaluation of the condition of the bench and trough, and lamping of connecting pipes.

Table 4-2. Cost Summary for SSES and Sewer Rehabilitation[1]

Description	Est. Quantity		Estimated Cost	
	Quantity	Unit	$/Unit	Total
SEWER SYSTEM EVALUATION SURVEY				
1. PHYSICAL SURVEY				
Above Ground Inspection	____	manhour	____	____
Flow Monitoring	____	manhour	____	____
Manhole and sewer inspection	____	ft (m)	____	____
Subtotal				
			____	
2. RAINFALL SIMULATION				
Smoke Testing	____	ft (m)	____	____
Dyed Water Testing	____	ft (m)	____	____
Water Flooding Tests	____	ft (m)	____	____
Subtotal				
			____	
3. PHYSICAL SURVEY REPORT	____	manhour	____	____
4. PREPARATORY CLEANING	____	ft (m)	____	____
5. INTERNAL INSPECTION	____	ft (m)	____	____
6. ENGINEERING	____	manhour	____	____
7. OTHERS	____			
TOTAL SSES COSTS				____
SEWER SYSTEM REHABILITATION				
• <u>CORRECTION FOR INFILTRATION</u>				
1. SEWER EXCAVATE AND REPLACE	____	ft (m)	____	____
2. CHEMICAL GROUTING	____	ft (m) Lump	____	____
3. SLIPLINING OR INSERTION	____	ft (m)	____	____
4. CURED-IN-PLACE INVERSION LINING	____	ft (m)	____	____
5. SPECIALTY CONCRETE	____	ft (m) or Lump	____	____
6. LINERS	____	ft (m) or Lump	____	____
7. COATINGS	____	ft (m) or Lump	____	____
8. MANHOLE WET WELL REPLACEMENT	____	Lump	____	____
9. MANHOLE WET WELL REPAIR	____	Lump	____	____
10. FAULTY TAPS REPAIR	____	Lump	____	____
11. HOUSE SERVICE PIPE REPLACEMENT	____	ft (m) or Lump	____	____
12. HOUSE SERVICE PIPE REPAIR	____	ft (m) or Lump	____	____
• <u>CORRECTION FOR INFLOW</u>				
1. LOW LYING MANHOLE RAISING	____	Lump	____	____
2. MANHOLE COVER REPLACEMENT	____	Lump	____	____
3. CROSS CONNECTION PLUGGING	____	Lump	____	____
4. ROOF LEADER DRAIN DISCONNECTION	____	Lump	____	____
5. FOUNDATION DRAIN DISCONNECTION	____	Lump	____	____
6. CELLAR DRAIN DISCONNECTION	____	Lump	____	____
7. YARD DRAIN DISCONNECTION	____	Lump	____	____
8. AREA DRAIN DISCONNECTION	____	Lump	____	____
9. COOLING WATER DISCHARGE DISCONNECTION	____	Lump	____	____
10. DRAINS FROM SPRINGS AND SWAMPY AREAS TO BE PLUGGED	____	Lump	____	____
• <u>OTHERS</u>				
1. ENGINEERING SERVICES	____	Lump or Manhours	____	____
2. LEGAL AND ADMINISTRATIVE SERVICES	____	Lump	____	____
3. CONTINGENCY	____	Percent	____	____
4. INTEREST DURING CONSTRUCTION	____	Percent	____	____
5. SALVAGE VALUE	____	Lump	____	____
TOTAL REHABILITATION COST				____

Figure 4-6. Cost-effectiveness analysis curve for infiltraion.

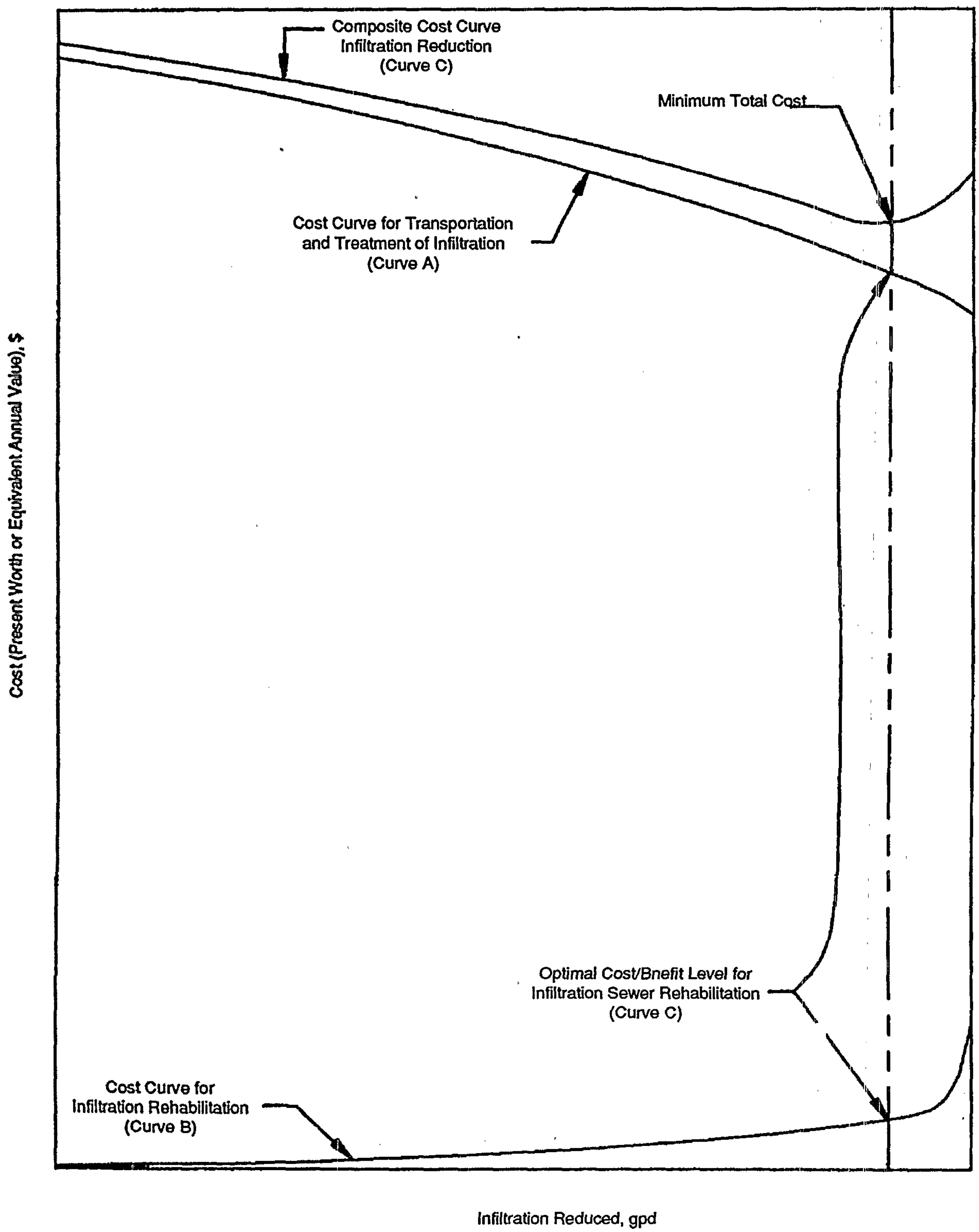
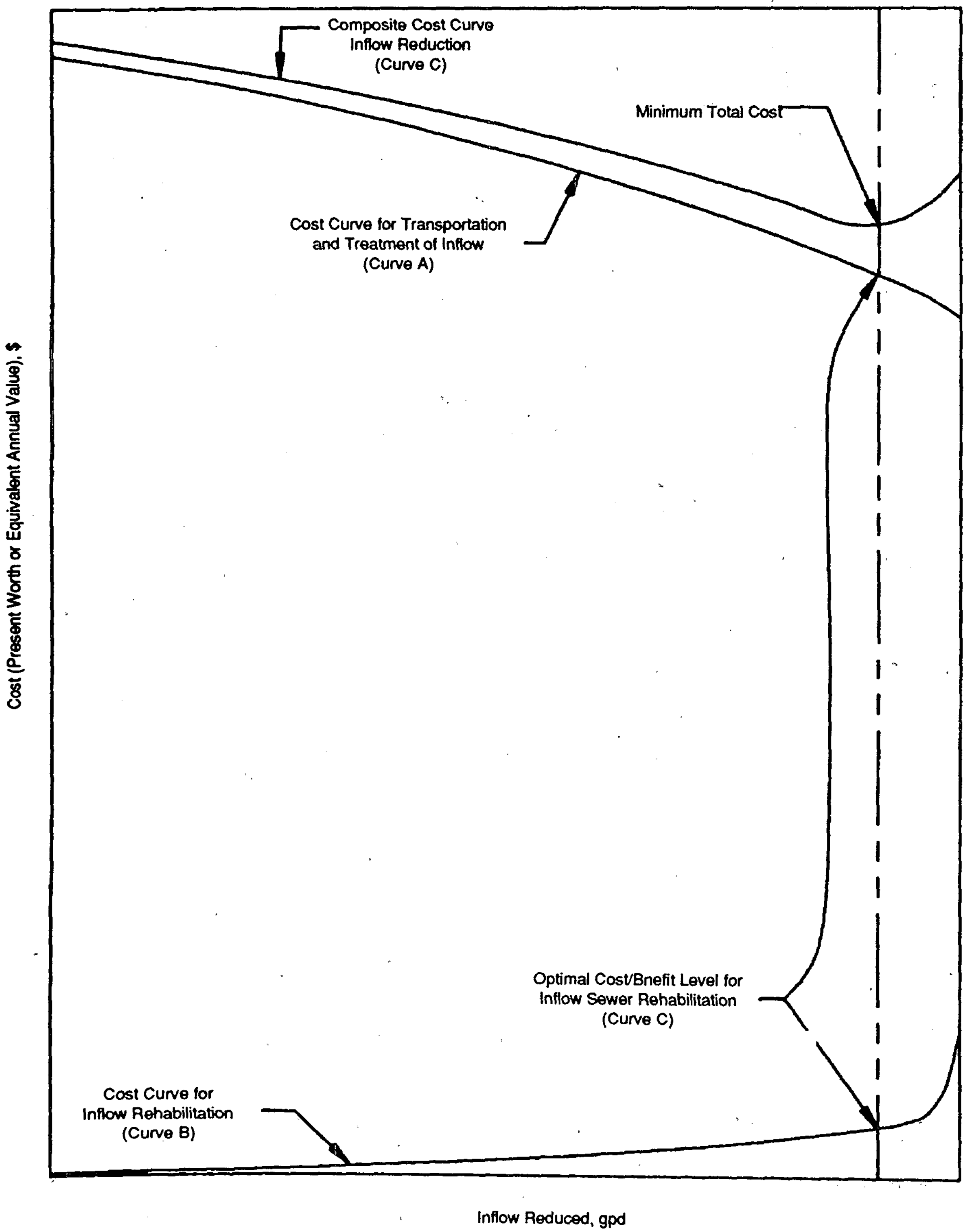


Figure 4-7. Cost-effectiveness analysis curve for inflow.



Smoke Testing - Performed with an intensive technique requiring isolation of each segment by blocking flow and injecting smoke using blowers, one on each of two adjacent manholes.

Dyed Water Flooding - Inflow sources identified during smoke testing were quantified by the dyed water flooding technique.

TV Inspection - As a result of nighttime flow measurements, certain sewers were identified for TV inspection.

Building Inspections - This consisted primarily of determining inflow connections to the service laterals, such as storm and combination sump pumps, and external drains such as areaway and roof drains.

The total of the assigned flows from all of the identified inflow sources was then compared to and balanced with the measured flow of each subarea at a 1-yr storm event. Inflow at a 1 year storm event was determined by linear regression of moderate storms, when the system was not in a hydraulically restricted or surcharged state. Infiltration sources were quantified and monitored at the outlet flow meters. Quantification of inflow and infiltration obtained during the subarea evaluation is presented in Table 4-3.

A cost-effectiveness analysis for the WSSC example was performed on a subarea basis incorporating the effects of migration, capital cost of treatment, O&M cost for treatment, cost of relief lines, and cost of rehabilitation. As a result of the analysis, clustered rehabilitation was recommended by subarea. This type of rehabilitation minimizes the migration effect. Also, the effectiveness of rehabilitation can be measured more rapidly because flow reduction is concentrated instead of dispersed over a wide area. I/I rehabilitation was then recommended for the entire subarea

A summary of the cost effective analysis for the subarea is presented in Table 4-4. Anticipated flow reductions after implementation of the recommended rehabilitation provides the estimated unit construction cost ($/gpd). Finally, a comparison of point-source rehabilitation with the sub-system approach was performed for each method and is presented in Table 4-5.

The point-source analysis initially resulted in a unit rehabilitation cost of $0.25/L/d ($0.95/gpd), but by incorporating the effect of migration, less infiltration would actually be removed, thus resulting in an actual

Table 4-3. **Quantification of I/I Through the Subarea System Approach for the Washington Suburban Sanitary Commission[4] (Reprinted with Permission from Water Engineering and Management**

Source	Flow (mgd)	Percent of Total
INFLOW		
Public Sector Inflow		
Manhole Defects		
Cover/rim leaks, ponding(1)	0.020	0.8
Frame seals	0.261	10.1
Corbels and broken frames	0.078	3.0
Cross connections	0.026	1.0
Subtotal	0.385	14.9
Private Sector Inflow		
Downspouts	0.288	11.2
Area-wide drains	0.539	20.9
Foundation drain connection	0.011	0.4
Suspect foundation drain connection	0.773	30.0
Defective lateral clean outs	0.009	0.3
Suspect defective service laterals	0.364	14.0
Storm sump pump connection	0.212	8.2
Subtotal	2.196	85.1
Total	2.581	100.0
INFILTRATION		
Manhole Defects		
Cracked/defective walls	0.039	4.2
Defective pipe seals	0.024	2.6
Bench/trough leaks	0.004	0.4
Pipe Defects		
Groutable defective joints/pipes	0.387	41.5
Non-groutable defective pipes and groutable service connection	0.34	36.6
Infiltration in line segments and manholes not inspected	0.137	14.7
Total	0.932	100.0

Table 4-4. **Cost-Effective Analysis for I/I Reduction for the Washington Suburban Sanitary Commission[4] (Reprinted with Permission from Water Engineering and Management)**

SUMMARY OF RECOMMENDED PLAN

Rehabilitation Item	Estimated Quantity	Estimated Construction Cost, $ (1986)
Inflow		
Manhole cover/frame replacement	38	17,710
Manhole frame seals/raising	121	96,800
Manholes corbel	16	9,900
Cross-connection	1	4,000
Subtotal		127,800
Infiltration		
Manhole walls, pipe seals, bench/trough	22	14,996
Relining/replacement	20	386,015
Line grouting	27	20,082
Pipe replacement	7	35,000
Connection grouting, lateral repair	25	45,000
Subtotal		501,091
Total		628,891

ESTIMATED FLOW REDUCTION

Source Type	Estimated Flow Reduction, mgd (1986)	Estimated Construction Cost, $/gpd (1986)
Inflow	0.385	$0.33
Infiltration	0.297	$1.69

Table 4-5. **Cost-Effective Analysis by Point Source for I/I Reduction for the Washington Suburban Sanitary Commission[4] (Reprinted with Permission from Water Engineering and Management)**

Approach	Removable Infiltration, mgd	Rehabilitation Costs Total $	Rehabilitation Costs $/gpd
Point Source Approach			
Assumed without migration	0.164	$156,000	0.95
Estimated, with migration	0.081	$156,000	1.93
Sub System Approach	0.143	$238,000	1.66

unit rehabilitation cost of $0.51/L/d ($1.93/gpd). I/I cost effective analysis utilizing the subarea approach was found to be $0.44/L/d ($1.66/gpd).[4]

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When an NTIS number is cited in a reference, that reference is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

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CHAPTER 5

Corrosion Analysis and Control

5.1 Introduction and Background

Structural problems in wastewater collection systems can sometimes occur as a result of corrosion, and thus it is important to consider corrosion when designing, rehabilitating, or analyzing sewer systems. This chapter discusses the types of sewer corrosion, explains how a corrosion survey is conducted, and describes methods for controlling corrosion. Major emphasis is placed on hydrogen sulfide (H_2S) corrosion, as it is the most prevalent form of corrosion in sewer systems.

Internal corrosion in sewer systems is normally related to the characteristics of the wastes being transported and is caused by chemical, electrochemical, and biochemical reactions. External corrosion is primarily caused by thermal, physical, structural or electrochemical stresses.

5.2 Types and Mechanisms of Corrosion

5.2.1 Common Types of Pipe Corrosion

Internal pipe corrosion in sewer systems is primarily caused by two mechanisms: 1) direct attack by corrosive gases released from the wastewater, such as H_2S and SO_2; and 2) bacterial oxidation of H_2S to sulfuric acid in the unsubmerged portions of the pipes. H_2S and SO_2 in their gaseous forms are directly corrosive to metals. It is important to note that the presence of H_2S raises concerns for safety, as H_2S gas is toxic to humans. H_2S represents an imminent life threat at a concentration of 300 ppm by volume in air. OSHA recommends a time weighted average exposure during an 8-hr period of less than 10 ppm by volume.[1]

Corrosive wastes (e.g. industrial acidic wastes) discharged to the sewer can cause direct corrosion in submerged portions of the sewer. Furthermore, certain chemicals which are used in wastewater treatment and collection systems can be corrosive.

5.2.2 Other Types of Corrosion

Electrochemical corrosion may occur due to electrical currents created between dissimilar metals or when an electrolytic waste removes one or more metals from an alloy.[2]

Hydrogenation occurs when hydrogen ions react with metal pipes. This however occurs under high temperature, pressure, stress and anaerobic conditions, and is not commonly found in sewer systems.

Fatigue corrosion and stress corrosion are similar, as both are caused by external stresses applied to the pipe and occur inside of the pipe. Fatigue corrosion occurs when pipes are exposed to repeated stresses.

Filiform corrosion occurs on metal piping with organic coatings. It is characterized by filament-like corrosion in the metal surface originating at pinpoint penetrations of the surface. It is important to note that corrosion is often the result of more than one mechanism. For example, if iron pipe is already experiencing hydrogen sulfide corrosion, it becomes more brittle and is more prone to cracking when stress is applied.

Further information on the mechanisms of both internal and external corrosion may be found in Reference 2.

5.3 Conducting a Corrosion Survey

5.3.1 Factors Affecting Corrosion

As a part of a Sewer System Evaluation Survey (SSES), sewer systems should be examined for certain characteristics that encourage corrosion. Corrosion is more likely to occur when the dissolved oxygen (DO) is below 0.5 mg/L, since these conditions favor the anaerobic bacteria that convert sulfate to sulfide. In gravity sewers, DO levels are likely to decrease when the wastewater velocity decreases, because the lower velocity: 1) decreases the scouring of the microbial slime growing on the submerged pipe walls and invert; 2) promotes solids deposition; and 3) increases the residence time. In force mains, inverted siphons, and surcharged sewers, anaerobic conditions often exist since the pipe is full, thereby precluding surface aeration by oxygen addition from the sewer atmosphere.

The depth of flow in sewers, the amount of exposed surface area, BOD of the waste, and pipe slope also affect the DO. Turbulence (which is found at pipe junctions and places where the pipe changes direction or slope) can add oxygen to the water, preventing sulfide generation. However, if sulfide is present, turbulence has an overall negative effect as it allows H_2S gas to be released from the wastewater making it available for corrosion above the water level.

5.3.2 Identifying Likely Locations for Corrosion

The first step in a corrosion survey is to interview people involved in design, cleaning, inspection, and repair of the sewer system to identify locations where corrosion may have been observed. Collection system maps should be available that include sizes and type of pipes, slopes of lines, flows, manhole locations, frequency of pumping operations, and locations of force main discharges and surcharged sewers. Maintenance records, odor complaint files, and TV inspection logs can also be informative. Likely field locations to check include:

- Locations of low velocities or solids deposits
- Force main discharge points
- Transition manholes
- Sewage lift stations
- Areas of high turbulence
- Sewers with flat slopes and long detention times
- Inverted siphon discharges
- Headworks of wastewater treatment plants
- Junction chambers and metering stations

5.3.3 Performing Visual Inspections

A visual inspection of the condition of manholes, metering stations, wet wells, headworks, and other structures as a part of the SSES physical survey, is essential to identify corrosion problems. Areas that are accessible can be entered and inspected, However, hazardous atmospheres can exist in such confined spaces, and proper safety procedures for confined space entry must be strictly followed.

Items noted in a visual inspection include:

- Condition of ladder rungs, bolts, conduit, and other metal components
- Presence of protruding concrete aggregate
- Presence of exposed reinforcing steel
- Development of black coating (copper sulfate) on copper pipes and electrical contacts
- Loss of concrete from pipe crown or walls
- Soundness of concrete
- Depth of penetration, using screwdriver or a sharp tool to expose uncorroded material

A quick method of inspecting the general condition of sewers can be performed with a telescoping rod onto which are attached a halogen light and adjustable mirror at one end, and a low-magnification (e.g., 4x) sight scope at the other end. The rod is inserted into a manhole, and by slightly tilting the rod and flashing the light beam down the sewer, its condition can be observed. This procedure is useful when small-diameter sewers are involved. Also, because entry into a confined space is not required, there is little risk of being overcome by potentially harmful sewer gas.

5.3.4 Collecting Data

Useful data which can be collected to assess the presence of, or the potential for corrosion include the following:[1]

- Concentration of gaseous H_2S in manholes and sewer atmospheres
- Wastewater pH
- Total and dissolved sulfide in wastewater
- DO and Oxidation Reduction Potential (ORP)
- Surface pH on manhole and sewer walls
- Total and soluble BOD
- Temperature
- Depth of corrosion penetration

One of the most useful "early warning" indicators of potential H_2S corrosion problems is the pH of the pipe crown or structure wall. This is a simple test using color sensitive pH paper which is applied to the moist crown of the pipe. New concrete pipe has a pH of 10-11. After aging the pH of the crown under non-corrosive conditions may drop to near neutral. Pipe experiencing severe H_2S corrosion may have a pH of 2 or lower. pH levels below 4 are generally indicative of corrosion problems.

If it is possible to estimate the amount of concrete lost from sewers or manholes and their age is known, the rate of corrosion can be approximated.[1] Estimates of the remaining useful life of a structure (e.g., to exposure of reinforcing steel) can then be used to prioritize sewer segments or structures for further action.

5.3.5 Predicting Sulfide Corrosion

Models have been developed which allow the prediction of the rate of sulfide accumulation in sewers as well as the rate of hydrogen sulfide corrosion of concrete pipe. The predictive equations can be found in References 1 through 4.

5.4 Rehabilitating Corroded Sewers

If it is determined that a sewer is severely corroded and will require rehabilitation, an appropriate rehabilitation method must be chosen. Table 5-1 lists common sewer

Table 5-1. Common Sewer Corrosion Problems and Applicable Rehabilitation Methods

Problem	Rehabilitation Method
1. Severe corrosion and poor structural integrity	a. Excavation and replacement b. Sliplining c. Some specialty concretes
2. Severe corrosion; minor structural reinforcement needed	a. Cured-in-place inversion lining b. Sliplining c. Some specialty concretes d. Fold and formed pipe
3. Corrosion in structurally sound pipes with diameters 76 cm (2.5 ft) or greater	a. PVC or other corrosion resistant liners b. Sliplining c. Cured-in-place inversion lining d. Some specialty concrete e. Fold and formed pipe
4. Corrosion in non-circular pipes	a. Cured-in-place inversion lining b. Some specialty concretes
5. Corroded pipes under busy streets	a. Cured-in-place inversion lining b. Fold and formed c. Sliplining (may be applicable)

problems involving corrosion and provides applicable rehabilitation methods for each. Rehabilitation techniques are discussed in detail in Chapter 6.

5.5 Controlling Corrosion

5.5.1 Sulfide Corrosion Control

H_2S corrosion can be controlled by reducing the levels of dissolved sulfide in the wastewater. Common control techniques include oxygenation, oxidation, precipitation, and pH elevation.[2]

If the concentration of DO in the wastewater exceeds 1.0 mg/L, sulfides will not be generated. Therefore, maintaining a high DO concentration is an effective method of sulfide corrosion control. Common methods of H_2S control in sewer systems are summarized below.

5.5.1.1 Aeration

Aeration can be a cost effective method for controlling sulfide generation, but unless air is introduced by passive means, such as the presence of turbulent conditions in the system, equipment must be provided to compress the air and to introduce it into the wastewater. An advantage of using air injection can be the simplicity of equipment when compared to other sulfide control methods.[1,3] Often, compressed air is added to the discharge side of the wastewater pumps at the upstream end of a force main. The major disadvantages of this approach are: 1) the potential for gas pocket formation and air binding, and 2) the relatively short duration for which aerobic conditions can be maintained due to DO uptake by bacteria.

5.5.1.2 Pure Oxygen

Because pure oxygen is five times more soluble in water than air, it is possible to achieve higher DO levels in wastewater by injecting pure oxygen into wastewater instead of air. As with air injection, use of pure oxygen as a sulfide control measure is particularly advantageous in pressurized systems, because dissolution of oxygen is greater at higher pressures. However, since less oxygen gas is required than air to achieve the desired DO levels, the potential for gas pocket generation in force mains is substantially reduced. Maintaining the DO above 1 mg/L is usually sufficient to prevent sulfate reduction.

5.5.1.3 Hydrogen Peroxide

When hydrogen peroxide (H_2O_2) is added to wastewater, it oxidizes dissolved sulfide. Excess H_2O_2 decomposes to water and oxygen. Common dosage rates are 1-5 lb H_2O_2/lb H_2S, depending upon the degree of control desired, wastewater characteristics, sulfide levels and length of time involved between the injection and sulfide control point. Equipment used for H_2O_2 addition is relatively simple, consisting mainly of a storage vessel and metering pumps. Materials for storage and feed equipment must be compatible with H_2O_2.[1,3]

5.5.1.4 Potassium Permanganate

Potassium permanganate ($KMnO_4$) is a strong oxidizing agent which has a reaction similar to that of H_2O_2. It is normally supplied in a dry state, and is fed as a 6-percent solution in water. Therefore, equipment for dissolving and feeding it must be supplied. Because of its high costs, it is not commonly used for sulfide control in wastewater collection systems.

5.5.1.5 Chlorine

Chlorine will oxidize sulfide to sulfate or to elemental sulfur, depending on pH. It is commonly added at a dosage rate of 10-15 lb Cl_2/lb H_2S removed. It may be added as sodium hypochlorite or a chlorine solution using equipment similar to that installed in wastewater treatment plants for effluent disinfection.

5.5.1.6 Iron Salts

Iron salts react with sulfide to produce insoluble precipitates, and are added after the generation of sulfides has occurred to tie up the dissolved sulfide and prevent the release of H_2S into the sewer atmosphere. Dosages are usually dependent on initial sulfide levels and the targeted level of control, but will generally be 4-15 lb Fe/lb H_2S. Iron salts may be purchased as dry chemicals and dissolved in water for ease of injection, but are commonly purchased as a solution. Ferrous chloride and ferrous sulfate are often purchased in bulk, usually as a 40-percent solution, and being acidic in nature, they must be handled in corrosion-resistant materials. As with other sulfide control chemicals (such as hydrogen peroxide), a typical feed system involves feeding the iron solution at multiple rates in relation to diurnal fluctuations in dissolved sulfide and flow rate.[1,5]

5.5.1.7 Sodium Hydroxide

H_2S corrosion may also be controlled by inactivating the sulfate-reducing bacteria. Sewer systems in Los Angeles, as well as other cities, have used pH elevation to control sulfide corrosion. A caustic solution is added as a shock dosage for 20-30 minutes, raising the pH in the sewer to 12-13. Soon after the high-pH slug has passed, the sulfate-reducing bacteria will become re-established so that dosing with caustic must be repeated when sulfide levels begin to increase. Typically, the caustic will be added at intervals which vary from several days to two weeks.[1,5]

With this approach, caution must be taken to avoid upsetting the biological treatment system with the slug of high pH wastewater. The slug may be diluted as it passes through the sewer system, in which case there is no problem. If this in not the case, the slug can be diluted by directing it to spare tankage and slowly adding it to treatment plant influent.[1,5]

Although a pH above 8.0 will result in lower levels of dissolved H_2S gas, continuously adding caustic to maintain a high pH is not generally practical.

5.5.1.8 Sodium Nitrate

The addition of sodium nitrate to sulfate-containing wastewaters will suppress the generation of H_2S. This occurs because bacteria will preferentially reduce nitrates before sulfates. Thus, no sulfides will be produced until the sodium nitrate has all been reduced.[1,5]

5.5.1.9 Designing to Avoid Corrosion

Sulfide corrosion can be minimized through careful design of the sewer system. The corrosion resistance of the materials used is an important factor. The characteristics of many typical materials are described in detail in several references. Other aspects of the design are also discussed in these references. The most important considerations when designing for sulfide control are:[1]

- Minimizing the occurrence of force mains, siphons and surcharged sewers
- Designing for velocities which are sufficient to prevent the accumulation of solids and which provide surface aeration of the wastewater.
- Prohibiting the direct addition of sulfides from any source

Further details on each of these sulfide control recommendations can be found in the *Design Manual: Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants,*[3] *Sulfide in Wastewater Collection and Treatment Systems,*[4] and *Detection, Control, and Correction of Hydrogen Sulfide Corrosion in Existing Wastewater Systems.*[6] These referencse are also an excellent source of information on designing sewer systems to avoid corrosion problems.

Design practices can affect the degree of corrosion found in a sewer system. If pipes are oversized, wastewater flow rates will be reduced and organic materials may accumulate. This condition is favorable for the production of sulfide and can lead to corrosion problems. O&M practices also affect corrosion. Since accumulation of organic solids is favorable to initiation of sulfide generation, regular cleaning of oversized segments will help prevent these problems. Prolonged surcharging, or other conditions which result in full pipes, should be avoided since lack of air in the pipes can increase sulfide production. Short periods of surcharging, however, can be beneficial since the increased flow rates may wash out accumulated solids.[1] Lift station and force main designs that allow long pipeline detention times increase the pressure of H_2S.

5.5.2 Control of Other Forms of Corrosion

Where industrial wastes contribute to H_2S generation, industries which discharge to the sewer should be required to meet some type of pretreatment standards. If the wastewater in the sewers is found to be significantly acidic or basic, the pH should be adjusted.

Moisture must be present for most types of corrosion to occur. For example, a moist atmosphere allows corrosive vapors to condense on pipe walls and on other fixtures in the sewer system. Ventilation systems have been used to reduce moisture and corrosion in sewers. Some general guidelines for these systems can be found in the *Design Manual: Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants.*[3]

When designing a new system or making replacements in an old system, materials should be chosen which are resistant to the types of waste present. Guidelines for selecting resistant materials are provided in Table 5-2.[4]

If electrochemical corrosion of iron or steel is the problem, cathodic protection may be appropriate. One type of

Table 5-2. Guidelines to Select Pipe Materials to Resist Corrosion (4)

Various types of pipe material can be specified as part of the overall design strategy. Either corrosion-resistant or corrosion-sensitive materials can be employed, depending on predicted sulfide levels, required service life, and economic considerations. The designer has the option of simply specifying an acid-resistant material or specifying an acid-sensitive material together with other corrosion control strategies, such as:

- Providing O_2 to water.
- Providing chemical control of sulfide generation.
- Designing system hydraulics to avoid sulfide generation.
- Providing sacrificial concrete cover.
- Providing sacrificial metal thickness (steel or ductile iron).
- Using concrete modification, such as calcareous aggregate.
- Using a protective liner or coating.

The following materials, varying in sensitivity to acid corrosion, are available for sanitary sewer construction:

- Vitrified Clay Pipe (VCP) is virtually immune to acid attack. In older VCP lines, cement mortar joints expanded, and sometimes broke the bells. Other types of gasketed joints now in general use avoid this problem. However, VCP is brittle, and so needs special installation practice and care in handling and transport.
- Steel pipe is susceptible to direct corrosion by H_2SO_4, H_2S corrosion of the iron component, and the normal oxidation of iron.
- Cast Iron Pipe (CIP) is also susceptible to H_2SO_4 and H_2S, and normal oxidation corrosion. It generally lasts longer than steel, simply because a thicker pipe wall is used.
- Reinforced Concrete Pipe (RCP) is susceptible to acid corrosion. However, despite its vulnerability, concrete represents an important sewer pipe material, particularly for large trunk sewers. Concrete can be fortified against attack by using calcareous aggregate, increasing the cement content, or both, which provides additional alkalinity and acid neutralizing capacity where severely corrosive conditions are anticipated, PVC liners can be employed.
- Asbestos Cement Pipe (ACP) is susceptible to acid corrosion. Due to its higher cement content, it corrodes at a slower rate than granitic aggregate concrete, although this attribute is offset by a generally thinner pipe wall.
- Thermoplastic pipes, such as Polyvinyl Chloride (PVC), Polyethylene (PE), and Acrylonitrile-Butadiene-Styrene (ABS), are resistant to acid corrosion, although subject to strain corrosion in the presence of some materials, such as detergents, organic solvents, and fats and oils.
- Thermoset plastic pipes, such as Reinforced Plastic Mortar (RPM) and Reinforced Thermosetting Resins (RTR), are resistant to acid attack.

cathodic protection involves impressing an electrical current on the corroding surface. The metal surface which is to be protected is electrically connected to the negative terminal of a current source and a "sacrificial" anode is connected to the positive terminal. The sacrificial anode must be in the electrolytic wastewater and must be constructed of a material which has a higher electrical potential than the protected material. Cathodic protection does not always work well, so an experienced corrosion control engineer should be consulted before such a system is attempted.[1]

5.6 References

When an NTIS number is cited in a reference, that reference is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

1. *Odor and Corrosion Control in Sanitary Sewerage System and Treatment Plants.* EPA/625/1-85/018. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1985.

2. *Report to Congress: Hydrogen Sulfide Corrosion in Wastewater Collection and Treatment Systems.* EPA/430/9-91/009. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. in preparation.

3. *Odor and Corrosion Control in Sanitary Sewerage System and Treatment Plants.* EPA/625/1-85/018, EPA, Cincinnati, Ohio, 1985.

4. *Sulfide in Wastewater Collection and Treatment Systems.* ASCE Manual and Reports on Engineering Practice No. 69, ASCE, New York, 1989.

5. *Sulfide and Corrosion Prediction and Control.* American Concrete Pipe Association, Vienna, VA., 1984.

6. *Detection, Control, and Correction of Hydrogen Sulfide Corrosion in Existing Wastewater Systems.* EPA/430/9-91/019. U.S. Environmental Protection Agency, Office of Water, Washington, DC. 1991.

CHAPTER 6

Sewer System Rehabilitation

6.1 Introduction

Many methods of sewer system rehabilitation are available. This chapter examines contemporary methods and provides guidance on the situations where each method is applicable. A general description of each rehabilitation technique, and the procedures, equipment, and cost estimates are discussed in the following sections.

The reader is cautioned in the use of the costs for various rehabilitation techniques presented herein. Although the cost information presented is from the best available sources, there are some major differences in the basis of these costs since all cost components are not included in every rehabilitation technique. Some costs have been extracted from earlier reports and indexed to the present time while other costs are from recent sources. Some costs include engineering and some do not. An attempt was made to present the cost on a consistent basis ($/length of sewer), but this may be misleading for some techniques such as chemical grouting since these costs vary depending on the number of joints grouted.

It should further be recognized that there are some rather strong geographical differences in cost for some of the techniques such, as sliplining and cured-in-place inversion lining. Also the reported cost of some techniques exhibits a wide cost range for the same size of pipe due to site-specific factors. The actual cost ranges are reported where available. Examination of the cost tables will show, for example, that the high side of the reported cost ranges for some techniques such as sliplining and inversion lining are higher than replacement costs. The basis of the cost for each rehabilitation technique is described at the bottom of each cost table. All costs have been indexed to a March 1991 *Engineering News Record* Construction Cost Index (ENRCCI=4773).

6.2 Excavation and Replacement

6.2.1 Description

Replacement of deteriorated pipelines was once the most common rehabilitation practice but is becoming more limited due to the availability of trenchless technologies. Excavation and replacement of defective pipe segments is normally undertaken under the following conditions:[1]

- When the structural integrity of the pipe has deteriorated severely; for example, when pieces of pipe are missing, pipe is crushed or collapsed, or the pipe has large cracks, especially longitudinal cracks
- When the pipe is significantly misaligned
- When additional pipeline capacity is also needed.
- When trenchless rehabilitation methods that would be adequate to restore pipeline structural integrity would produce an unacceptable reduction in service capacity
- For point repair where short lengths of pipeline are too seriously damaged to be effectively rehabilitated by any other means
- Where entire reaches of pipeline are too seriously damaged to be rehabilitated
- Where removal and replacement is less costly than other rehabilitation methods

The following are the disadvantages of pipeline removal and replacement as a method of sewer line rehabilitation:

- Removal and replacement is usually more expensive than other rehabilitation methods.
- Removal and replacement construction causes considerably greater and longer-lasting traffic and urban disruption than does rehabilitation.
- Removal and replacement construction involves a greater threat of damage to, or interruption of, other utilities than does pipeline rehabilitation.

6.2.2 Procedures and Equipment

Sewer pipe rehabilitation through pipeline replacement can be carried out in the following two general forms:

- Excavation and replacement where the existing pipeline is removed and a new pipeline is placed in the same alignment
- Abandonment and parallel replacement where the existing pipeline is abandoned in place and replaced by a new pipeline in either: 1) physically parallel alignment

adjacent to the existing line, or 2) a functionally parallel alignment along a different route

Pipeline replacement materials include traditional materials such as reinforced concrete, clay, ductile iron and a variety of plastics.

Removal of an existing pipeline and replacement with new pipe involves all of the problems which occur in construction of new pipelines in new alignments, plus special problems which are unique to removal and replacement. The problems unique to removal and replacement are:

- Maintaining tributary system and/or service flows during construction
- Removal and disposal of old pipes
- Fill up old abandoned pipes with structurally sound material to prevent potential collapse
- Working through utilities overlying or closely parallel to the pipe. These special problems usually result in added construction costs which often do not occur in new construction along a new pipe alignment.

Problems which occur in both removal and replacement and in new construction on a new alignment are:

- Disruption of street traffic
- Disruption of access to residential, commercial, and industrial properties
- Temporary loss of street parking
- Trench shoring in deep construction involving unstable soil
- Trench dewatering in areas with high groundwater

6.2.3 Costs

The cost of pipeline excavation and replacement is specific to individual job conditions. Cost factors are:

- Old pipe removal and disposal
- Manhole removal and replacement
- Trench shoring
- New pipe materials installation
- Service reconnections to sanitary sewer
- Street inlet reconnections to storm drains
- Upstream flow diversion during construction
- Maintenance of local sanitary service
- Traffic control systems and scheduling
- Pavement restoration
- Interference with other utilities

Table 6-1 presents approximate costs for the excavation and replacement method of sewer rehabilitation. The costs in this table are based on costs taken from the *Handbook for Sewer System Evaluation and Rehabilitation*[2] and from *Utility Infrastructure Rehabilitation*[3] and were adjusted to current prices through the use of the ENRCCI. Costs were also verified by contacting vendors and contractors.

Table 6-1. Rehabilitation Costs for Excavation and Replacement (ENRCCI=4773)

Pipe Diameter (in)	Cost ($/LF) Reference 2*	Reference 3**
6	45 - 70	
8	50 - 75	
10	55 - 85	
12	65 - 95	40 - 55
14	70 - 105	45 - 65
16	75 - 110	50 - 75
18	80 - 120	65 - 90
20	95 - 145	70 - 105
30	135 - 205	105 - 155
40	195 - 240	150 - 225
48	235 - 285	190 - 230
54	240 - 295	235 - 285
60	275 - 340	260 - 320
72	365 - 450	325 - 360
90	465 - 555	415 - 510
102	530 - 645	495 - 605

*
- 2.7 m (9 ft) depth assumed.
- Costs include site preparation, excavation, backfill, pavement, pipe materials, removal of existing pipes, pipe installation, reconnection of one house service connection for every 6 m (20 ft) of pipe installed. Depth of cover over crown of pipe at 2.7 m (9 ft), pipe in moderately wet soil conditions. Cost to remove the existing pipe is 50 percent of that required to install a new pipe. Excludes ledge excavation.

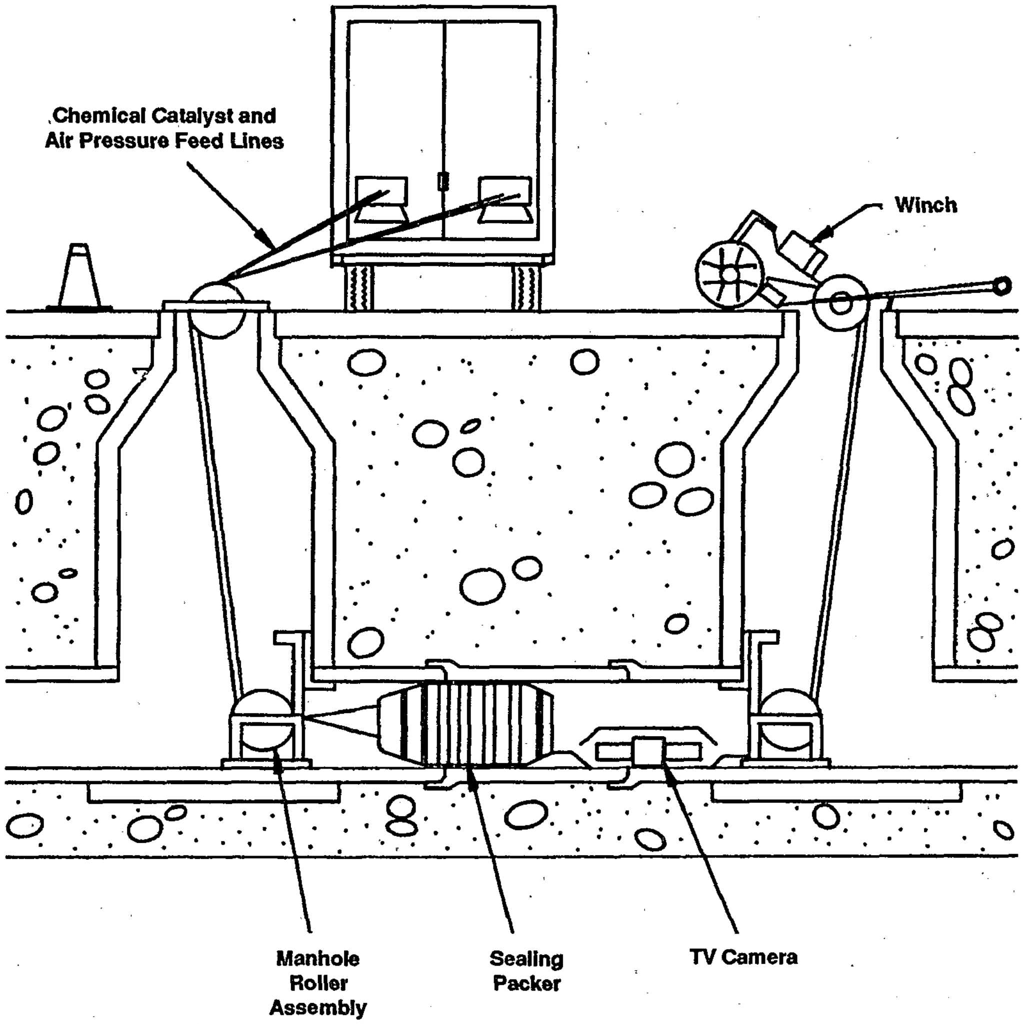
**
- 3 m (10 ft) depth assumed.
- Costs based on minimum project size of 300 m (1,000 LF).
- Costs do not include design engineering, construction management, bypassing of wastewater, reconnection of services or street drain inlets, traffic control, utility interference, or removal and replacement of manholes.
- Excludes ledge excavation.

6.3 Chemical Grouting

6.3.1 Description

Chemical grouting of sewer lines is mainly used to seal leaking joints and circumferential cracks. Small holes and radial cracks may also be sealed by chemical grouting. Chemical grouts can be applied to pipeline joints, manhole walls, wet wells in pump stations and other leaking structures using special tools and techniques.[1] One grouting procedure is illustrated in Figure 6-1. All chemical grouts are applied under pressure after appropriate cleaning and testing of the joint. Chemical grouting is used in precast concrete brick, VCP sewers and other pipe materials to fill voids in backfill outside the sewer wall. Such backfill voids can reduce lateral support

Figure 6-1. **Grouting equipment and procedures.**



of the wall and allow outward movement resulting in the rapid deterioration of the structural integrity as the arch of the top of the pipe looses its support. Chemical grouting adds no external structural properties to the pipe where joints or circumferential cracking problems are due to ongoing settlement or shifting of the pipelines. It is not effective to use chemical grouting to seal longitudinal cracks or to seal joints where the pipe near the joints is longitudinally cracked. Grouting is a joint sealing technique to be used for each joint in a pipeline segment that fails the initial leakage test. Chemical grouting is normally undertaken to control groundwater infiltration in non-pressure pipelines when these are caused by leaking pipe joints or circumferential cracking of pipe walls.

Chemical grouting is applied internally within a pipe, and thus does not damage or interfere with other underground utilities. It does not require excavation or surface restoration, such as pavement or sidewalk replacement and ground cover reseeding.

Chemical grouting does not improve the structural strength of the pipeline and thus should not be considered when the pipe is severely cracked, crushed or badly broken. Chemical grouts may also dehydrate and shrink if the groundwater drops below the pipeline and the moisture content of the surrounding soil is reduced significantly. Large joints and cracks may be difficult to seal because large quantities of grout may be required. Large cracks, badly offset joints and misaligned pipes may not be sealable. Offset joints may prevent the inflatable rubber sleeves of the sealing unit from seating properly against the walls of the pipe, making it impossible to isolate and seal the joint.

The most common chemical grouts currently available are acrylamide gel, acrylic gel, acrylate gel, urethane gel, and polyurethane foam. The use of acrylamide gel as a grout may possibly be banned by U.S. EPA since it is suspected that this grout causes health problems for the application workers. The basic characteristics of foam and gel grouts are described below.

Gel Grouts are resistant to most chemicals found in sewer lines but they may produce a gel-soil mixture which is susceptible to dehydration and shrinkage cracking. When using gel grouts, the grouting contractor and/or the grout supplier should be required to submit data supporting the non-shrink characteristics of the grout. Acrylamide gel is significantly more toxic than the acrylate polymer or urethane gel grouts. Urethane gel uses water as the catalyst. No significant water contamination of the urethane grout should be permitted prior to its injection. Gel grouts are not recommended where there are large voids outside the pipeline joints.

Foam grouts consist of liquid urethane prepolymers which are catalyzed by water during injection. The foaming reaction of the grout and water expands the materials into the joint cavity, thereby sealing the crack. The foam grouts are capable of expanding 8-12 times their initial volumes. Foam grouts are usually difficult to apply and are more expensive than gel grouts.

Before choosing to use grouting for joint rehabilitation, the pipeline should be inspected for the following:[1]

- Determine pregrouting cleaning needs and extent of root intrusions. For effective grouting, the pipeline must be relatively free of sand, sediment and other deposits. Cleaning should occur just prior to grouting.
- Identify crushed or broken sections that must be replaced. Deformed and longitudinally cracked pipe sections should not be grouted.

Joints and circumferential cracks in small- and medium-sized pipes (15-107 cm [6-42 in] diameters) can be remotely tested and grouted using a packer system monitored by closed-circuit TV.

The service life of the grout is an important consideration. Acrylamide grout has been used successfully since the 1950's to stabilize soils and help control underground water movements in tunnels, dams, dikes, pits and various other underground structures. The urethane grouts are more recent. Pipe size, joint spacing, and the percentage of joints requiring sealing are factors to consider in determining the cost of chemically sealing a line. The larger the pipe, the higher the cost because of increased manpower, equipment and materials. Chemical grouting requires rerouting of wastewater flow around the section being grouted until the grout is cured.

6.3.2 Costs

See Table 6-2 for approximate grouting costs. The costs in this table are based on costs taken from *Utility Infrastructure Rehabilitation*[3] and were adjusted to current prices through the use of a cost index. Costs were also verified by contacting vendors and contractors. Table 6-2 reflects 100 percent joint grouting with 60-cm (2-ft) pipe sections. Grouting costs may be significantly lower than that shown for grouting fewer joints based on leakage tests or for longer (1-2 m [3-6 ft]) pipe lengths.

6.4 Insertion

6.4.1 Description

Pipe insertion is used to rehabilitate sewer pipelines by sliding a flexible liner pipe of slightly smaller diameter into an existing pipeline and then reconnecting the service

Table 6-2. Rehabilitation Costs for Grouting

Pipe Diameter (in)	Grouting Prep. Cost ($/LF)	Dec. 1984 Grouting Cost ($/LF)	Total ($/LF)	Mar. 1991 Total Costs ($/LF)
6	1.00	18.00	19.00	20 - 30
8	2.00	21.00	22.00	24 - 36
10	2.00	24.50	26.50	28 - 42
12	3.50	28.00	31.50	32 - 48
15	6.00	32.00	38.00	36 - 54
18	7.50	36.00	43.50	40 - 60
21	9.50	61.00	70.50	68 - 102
24	12.00	70.00	82.00	76 - 95
27	14.50	79.00	93.50	88 - 132
30	18.00	83.00	101.00	96 - 144
33	21.50	93.00	114.50	108 - 162
36	28.00	104.00	132.00	124 - 186
39	32.50	110.00	142.50	132 - 198
42	NA	122.00		
48	NA	325.00		
54	NA	365.00		
60	NA	450.00		
66	NA	580.00		
72	NA	645.00		
78	NA	780.00		
84	NA	865.00		
90	NA	1,000.00		
96	NA	1,500.00		
102	NA	1,325.00		
108	NA	1,465.00		

Grouting Preparation Costs
- Based on minimum project size of 300 m (1,000 LF).
- Root kill includes application of herbicide inside pipe before root removal and cleaning.
- Cleaning costs apply to entire pipe reach.
- Costs are at December 1984 cost level (ENRCCI=4144); 1991 costs based on adjustment of the 1984 costs to March 1991 (ENRCCI=4773).

Unit Grouting Costs
- Based on minimum project size of 300 m (1,000 LF) and grouting 100 percent of joints.
- Remote testing and grouting packer system monitored by closed circuit TV.
- Costs are at December 1984 (ENRCCI=4144); 1991 costs based on adjustment of the 1984 costs to March 1991 (ENRCCI=4773).
- Does not include grouting preparation costs.

connection to the new liner. This is done by pulling or pushing new pipe into a deteriorated pipeline. The liner forms a continuous, watertight length within the existing pipe after installation.[1]

Pipe insertion techniques can be used to rehabilitate sewer, water and other pipe lines that may have severe structural problems such as extensive cracks, lines in unstable soil conditions, deteriorated pipes in corrosive environments, pipes with massive and destructive root intrusion problems and pipes with relatively flat grades.

Table 6-3. Advantages and Disadvantages of Sliplining

Advantages	Disadvantages
• Minimal disruption to traffic and urban activities (as compared to replacement)	• Possible reduction in pipe capacity
• Minimal disturbances to other underground utilities; affects only those in the vicinity of access pits.	• Requires excavation of an access pit.
• Significantly less costly than replacement.	• Less applicable to sewers with numerous curves or bends, since multiple pits would be required.
• Quick installation time.	• Requires obstruction removal of internal obstructions prior to sliplining.
• Good protection against acid corrosion	• Installation difficulties may be encountered during grouting of annular space.
• Does not require bypassing.	
• Wide range of pipe sizes (i.e., 3-144 in)	
• Can be used to rehabilitate pipelines with severe corrosion.	

Advantages and disadvantages of sliplining as a method of rehabilitation can be found in Table 6-3.

The most popular materials used to slipline sewer lines are polyolefins, fiberglass reinforced polyesters (FRP), reinforced thermosetting resins (RTR), polyvinyl chloride (PVC), and ductile iron (cement lined and polyvinyl lined).

Polyethylene (PE) is the most common polyolefin material used and is available in low density, medium density and high density. High-density PE (HDPE) compounds are best suited for rehabilitation applications as they have good stiffness, are hard, strong, tough and corrosion resistant. PE pipe is manufactured as either extruded or corewall.[1] Extruded pipe has smooth inner and outer surfaces and has structural characteristics that are determined by wall thickness. Corewall pipe has an exterior hollow rib which gives structural integrity to the pipe and minimizes pipe weight. Extruded PE pipe is manufactured in diameters of 5-122 cm (2-48 in) and corewall PE pipe 30-366 cm (12-144 in). Two national specifications ASTM P1248 and ASTM D3550, are available for design and reference. These standards apply to extruded PE pipe with circular cross-sections and diameters of 10-122 cm (4-48 in).

Polybutylene (PB), another polyolefin, is similar to medium density PE pipe in stiffness and chemical resistance but has better continued stress loading characteristics. It also has good temperature resistance. PB pipe is manufactured as extruded pipe in diameters of 8-107 cm (3-42 in).

Centrifugally cast FRP pipe was originally manufactured in Switzerland in the 1960's and is now being widely used in U.S. It is a composite of resin made from fiberglass and sand that is formed within a revolving mold. It is frequently specified as an acceptable alternative to polyethylene. FRP pipe has very good chemical and corrosion resistance and is suitable for use over a pH of 1-10. FRP pipe is manufactured in standard 6-m (20-ft) lengths and is available in diameters of 46-244 cm (18-96 in).

RTR pipe is a composite of fibers and resins that are either spiral wound on a rotating mandrel or composited on the inside of a rotating drum, similar to FRP pipe. RTR pipe has good axial and longitudinal strength, enabling it to be pushed into an existing pipe without buckling. Friction losses are low due to smooth interior surfaces. This pipe has high strength and a high modules of elasticity. It also has good corrosion, erosion and abrasion resistance. Manufactured sizes are lengths of 6-24 m (20-80 ft) and diameters of 10-360 cm (4-142 in).

Flexible PVC has been used successfully as a sliplining material. PVC is highly resistant to acid attack and is very smooth, exhibiting good hydraulics. Grouting of the annular space is required to give strength to the PVC.

6.4.2 Procedures and Equipment

Prior to sliplining, the sewer should be first thoroughly cleaned and inspected by closed circuit TV to identify all obstructions such as displaced joints, crushed pipes and protruding service laterals. The inspection also should locate all service connections that will need to be connected to the new liner pipe. The pipe must be thoroughly cleaned. It may at times be necessary to proof test the existing pipe by pulling a short piece of liner through the sewer section.

Sliplining is performed by either a push or a pull technique; both methods are illustrated in Figure 6-2.[1] In the pull method a pulling head is attached to the end of the pipe. A cable is run from the termination point to the access point and is connected to the pulling head. The sliplining pipe is then pulled through the existing pipe with the cable by a track mounted winch assembly. Pulling is used for extruded PE and PB pipe that is heat fused into a continuous length. The push method can be performed by either a backhoe or a jacking machine. A backhoe can be used for extruded heat fused PE or PB pipe, Corewall PE pipe, FRP pipe and RTR pipe. However, the backhoe is limited to small diameter and/or short length pipe. The jacking machine is used for larger diameter, sleeve-coupled or bell spigot jointed pipes (e.g. Corewall PE, FRP, and RTR) but it is not used for heat fused polyolefin pipe.

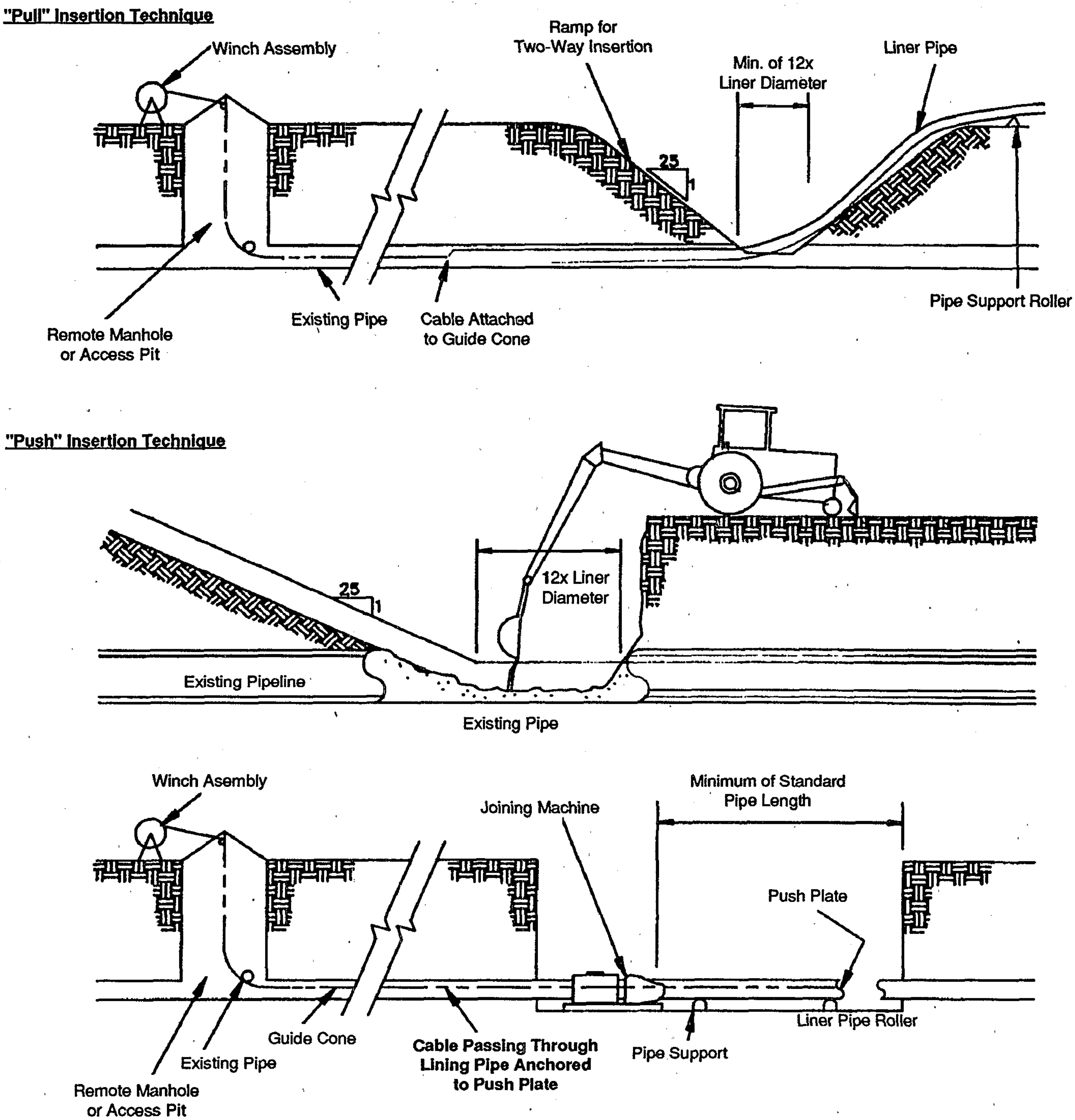
For most insertion projects it is not necessary to eliminate the entire flow stream within the existing pipe structure. Actually, some amount of flow can assist positioning of the liner by providing a lubricant along the liner length as it moves through the deteriorated pipe structure. Excessive flows can inhibit the insertion process, however, the insertion procedure should be timed to take advantage of cyclic periods of low flows that occur during the operation of most gravity piping systems. During the insertion process, often a period of 30 minutes or less, the annular space between the sliplining pipe and the existing pipe will probably carry sufficient flow to maintain a safe level in the operating section of the system being rehabilitated. Flow can then be diverted into the liner upon final positioning of the liner. During periods of extensive flow blockage, the upstream piping system should be monitored, and provisions for bypassing provided in order to avoid unexpected flooding and drainage areas.

Once the sliplining pipe has been pulled through the existing pipe, it is grouted in place. Grouting at manhole connection is required, but grouting of the entire length of the pipe is not required if the liner is strong enough to support loads in the event of collapse of the original pipe. It must be determined on a site-specific basis whether or not to grout after evaluating the severity of structural deterioration and anticipated hydrostatic and structural loadings. Grouting provides the following advantages:

- Provides structural integrity
- Increases hydrostatic and structural loading capabilities
- Prevents liner from moving
- Locks in service connections
- Extends the service life of the pipe
- Provides increased temperature resistance
- Provides support to liner when cleaning

One of the advantages of sliplining to replacing a sewer line is that it requires minimal excavation which limits traffic disruption and minimizes interferences with surface structures, such as retaining walls, landscaping, or portions of buildings. Sliplining also can be used to avoid extensive dewatering that is necessary for conventional open trench construction. Sliplining can be installed in pipelines having moderate horizontal or vertical deflection due to the flexible nature of the sliplining pipe.

Figure 6-2. Insertion methods.



Equipment required for the insertion of the sliplining pipe are: jointing equipment, pulling or pushing head, winch, rollers, proofing tool, grout tank and pump. The jointing equipment is used to join segmented pipe lengths to form a continuous pipe of desired length. This is done by aligning the two pipes together, heating the ends and butting the ends together. The pulling head is used to facilitate the pulling of the pipe into the sewer. One end of the pulling head is attached to the pipe to be pulled while the other end is attached to the pulling cable. The winch, consisting of a power operator and a pulling cable, is used to pull the pipe. The rollers are used to grout the annular space between the pipe and manhole connections to prevent groundwater migration.

6.4.3 Costs

Tables 6-4 through 6-7 indicate the approximate costs for sliplining as a method of sewer rehabilitation. The data in these tables are based on costs taken from the *Handbook for Sewer System Evaluation and Rehabilitation*[2] and

Table 6-4. Rehab Costs for Sliplining with HDPE and Polybutylene Pipe

Pipe Diameter	Dec. 1984 ENRCCI=4144 ($/LF)	March 1991 ENRCCI=4773 ($/LF)
4	8 - 17	9 - 20
8	12 - 29	15 - 35
12	19 - 38	25 - 45
16	25 - 47	30 - 55
20	30 - 60	35 - 70
24	28 - 75	35 - 90
28	44 - 92	55 - 110
32	58 - 112	70 - 130
36	68 - 132	80 - 155
40	78 - 152	90 - 180
42	85 - 156	100 - 185
48	90 - 196	105 - 230
55	105 - 209	125 - 245
63	123 - 252	145 - 295

- 1984 costs from Reference 3; 1991 costs based on adjusted 1984 costs.
- Based on min. project size of 300 m (1,000 LF).
- Polybutylene pipe not available in sizes larger than 122 cm (48 in).
- Lower cost ranges may apply to pipelines with good alignment, no need for spot repair, and no significant groundwater.
- Higher cost ranges may apply to pipe with poor alignment, some need for spot repair and need for groundwater dewatering.
- Costs do not include: preparation of insertion access pit(s); grouting or sand filling of entire liner pipe/existing pipe annual space; bypassing of wastewater; costs for design engineering, construction management or design related services.

Table 6-5. Rehab Costs for Sliplining with PE Pipe

Pipe Diameter (in)	Mid 1974 ENRCCI=1993 ($/LF)	March 1991 ENRCCI=4773 ($/LF)
6	20	35 - 60
8	21	40 - 60
10	23	45 - 70
12	25	50 - 75
14	28	55 - 80
16	32	60 - 95
18	34	65 - 80
22	39	75 - 115
26	45	90 - 130
28	54	105 - 155
32	62	120 - 180
36	72	155 - 190
42	88	190 - 230
48	102	220 - 275
52	110	250 - 290
58	135	290 - 355
68	152	330 - 400
72	174	375 - 460
80	200	430 - 530
88	225	485 - 595
92	250	540 - 660
100	275	595 - 725

- 1974 costs from Reference 2; 1991 costs based on adjusted 1974 costs.
- Costs include site preparation, insertion pit, pipe, materials, pipe welding, pipe installation, connection of one house service for every 6 m (20 ft) of pipe, pipe sealing at manholes and mobilization.

Table 6-6. Rehab Costs for Sliplining Reinforced Thermosetting Resin

Pipe Diameter (in)	Dec. 1984 ENRCCI=4144 ($/LF)	March 1991 ENRCCI=4773 ($/LF)
8	20 - 26	25 - 30
12	35 - 45	40 - 55
16	45 - 55	55 - 65
20	60 - 70	70 - 85
24	75 - 80	85 - 90
30	85 - 110	100 - 130
36	110 - 130	130 - 150
42	125 - 150	145 - 175
48	145 - 170	170 - 200
54	165 - 185	190 - 215
60	175 - 220	215 - 255
66	185 - 235	215 - 275

- Costs based on min. project size of 300 m (1,000 LF).
- 1984 costs from Reference 3 ; 1991 costs based on adjusted 1984 costs.
- Lower costs may apply for existing pipe with poor alignment, some need for spot repair, and need for groundwater dewatering during construction.
- Costs do not include preparation of insertion access pit, connection of service to new line, grouting or sand filling of the entire "liner pipe existing pipe" annular space, or bypassing of wastewater.

Table 6-7. Miscellaneous Rehab Costs for Sliplining

Service Connection Size	Dec. 1984 ENRCCI=4144 ($)	March 1991 ENRCCI=4773 ($)
4 or 6 in @ 4-8 ft depth	400/each	465/each
4 or 6 in @ 8-12 ft depth	550/each	640/each
4 or 6 in @ 12-16 ft depth	750/each	870/each
4 or 6 in @ 16-20 ft depth	1,000/each	1,165/each
Grouting	200/cu yd of grout	230/cu yd
Access Pit		
<10 ft depth	1,000/ft depth	1,165/ft depth
10-20 ft depth	800/ft depth	930/ft depth
>20 ft depth	1,000/ft depth	1,165/ft depth

- Costs are for average traffic conditions and include pit sheeting and shoring in reasonably stable soil where groundwater dewatering is not necessary.
- 1983 costs are from Reference 3; 1991 costs based on 1984 adjusted costs.

from *Utility Infrastructure Rehabilitation*[3] and were adjusted to current prices through the ENRCCI. Costs were also verified by contacting vendors and contractors.

6.5 Cured-in-Place Pipe Lining

6.5.1 Description

Inversion lining is formed by inserting a resin-impregnated felt tube into a pipe, which is inverted against the inner wall of the pipe and allowing it to cure. After the lining system has been installed and cured, a special cutting device is used with a closed-circuit TV camera to reopen service connections, which are located with the camera before the liner is installed. The pliable nature of the resin-saturated felt prior to curing allows installation around curves, filling of cracks, bridging of gaps, and maneuvering through pipe defects. After installation, the fabric cures to form a new pipe of slightly smaller diameter, but of the same shape as the original pipe. The new pipe has no joints or seams and has a very smooth interior surface which may actually improve flow capacity despite the slight decrease in diameter.

Two resin types (polyester and epoxy) are widely used in this method of pipe rehabilitation. Both these resins are liquid thermosetting resins, and have excellent resistance to domestic wastewater. Chemical resistance tests should be specified for CIPP for other than domestic wastewater in accordance with ASTM F1216x2. Vinylester resins may be used where superior corrosion resistance is required at high temperatures. Epoxy resins are used where adhesion to the existing pipeline is desired.

Table 6-8. Advantages and Disadvantages of Cured-In-Place Lining

Advantages	Disadvantages
• Applicable to all shapes	• Bypass required during installation
• Rapid installation	• Post-installation remote camera inspection required
• Minimum traffic disruption	• Maximum effluent temperature 82°C (180°F) using specially formulated resins
• Excavation normally not required	
• In-line lateral reconnections	
• Improved hydraulics	
• Bridges gaps and misaligned joints	
• Special resins are available to provide acid resistance.	
• Custom designed wall thickness to aid in structural strength	
• Only 50-70 percent of replacement costs	
• Adds some structural integrity	
• Does not interfere with or damage other utilities	
• No pavement repairs	
• Safer than some other rehabilitation methods.	

Inversion lining is successful in dealing with a number of structural problems, particularly in sewers needing minor structural reinforcement. Caution must be used, however, in the application of this method to any structural problems involving major loss of pipe wall. Inversion lining can be accomplished relatively quickly and without excavation and thus this method of pipeline rehabilitation is particularly well suited for repairing pipelines located under existing structures, large trees, or busy streets or highways where traffic disruption must be minimized. Inversion lining produces minor reductions in pipe cross-sections. It is applicable to non-circular pipes and pipes with irregular cross-sections. This method is also effective in correcting corrosion problems and can be used for misaligned pipelines or in pipelines with bends where realignment or additional access is not required. See Table 6-8 for a summary of the advantages and disadvantages of sewer rehabilitation by cured-in-place lining.

There are currently three processes that have been introduced in the United States that are classified as cured-in-place: Insituform, Paltem, and KM Inliner.

6.5.1.1 Insituform

The Insituform process was developed in England in the early seventies. Since its introduction in the United States in 1978, approximately 2,400 linear km (8,000,000 ft) have been installed in a variety of piping applications. Third party testing has been performed by several agencies verifying structural properties, design methods, corrosion resistance and the ability to enhance flow capacity. The process has been used on circular and non circular pipes in diameters of 10-275 cm (4-108 in). The maximum installation length is approximately 360-750 m (1,200-2,500 ft) depending on the diameter and wall thickness. ASTM F-1216-89, as well as other national and federal specifications, specifically covers the Insituform process. The Insituform process is installed throughout the United States by a network of licensed installers. Insituform tubes are manufactured in the United States by Insituform of North America, Inc.

6.5.1.2 Paltem

Paltem (Pipeline Automatic Lining System) was developed in Japan through a joint venture between Tokyo Gas and a private company, Ashimori Industries, for rehabilitating natural gas lines. Since being brought to the United States in 1988, there have been various demonstration projects and some full-scale municipal sewer projects. The published size range is 2-100 cm (0.75-40 in); however, in the United States, 10-60 cm (4-24 in) is available for gravity flow sanitary sewer work. Although information is available through the parent company relevant to physical testing, at this time there appears to be no third party documentation for the Paltem system. The specifications covering this process is included in ASTM F-1216.

6.5.1.3 KM Inliner II

The KM Inliner process was developed in West Germany by the Kanal Mueller Gruppe in 1985. It has been marketed in the United States since 1988. The material is being manufactured in Germany; however, there are plans to establish a manufacturing facility in the eastern United States. Diameters of 20-60 cm (8-24 in) can be reconstructed using this process, and there are indications that pipes up to 90 cm (36 in) may be available sometime in the future. The maximum installation length is approximately 180 m (600 ft). Application for inclusion in ASTM F-1216 was made in 1990 and is still pending. There is no third party testing available verifying the physical properties or design parameters used for this process.

Table 6-9. Rehab Costs for Cured-In-Place Inversion Lining

Pipe Diameter (in)	Dec. 1984 ENRCCI=4144 ($/LF)	Mar. 1991 ENRCCI=4773 ($/LF)
6	25 - 40	30 - 45
10	49 - 65	60 - 75
14	65 - 105	75 - 125
18	75 - 125	90 - 145
21	85 - 135	100 - 160
24	95 - 165	110 - 190
27	105 - 175	125 - 205
30	115 - 190	135 - 220
33	120 - 215	140 - 250
36	130 - 230	155 - 270
42	140 - 265	165 - 305
48	160 - 300	185 - 350
54	175 - 335	205 - 390
60	185 - 375	215 - 435

- Costs are based on minimum project size of 300 m (1,000 LF).
- 1984 costs from Reference 3; 1991 costs based on adjusted 1984 costs.
- Costs do not include providing temporary water or natural gas service for the curing process, design construction management, or design related services.

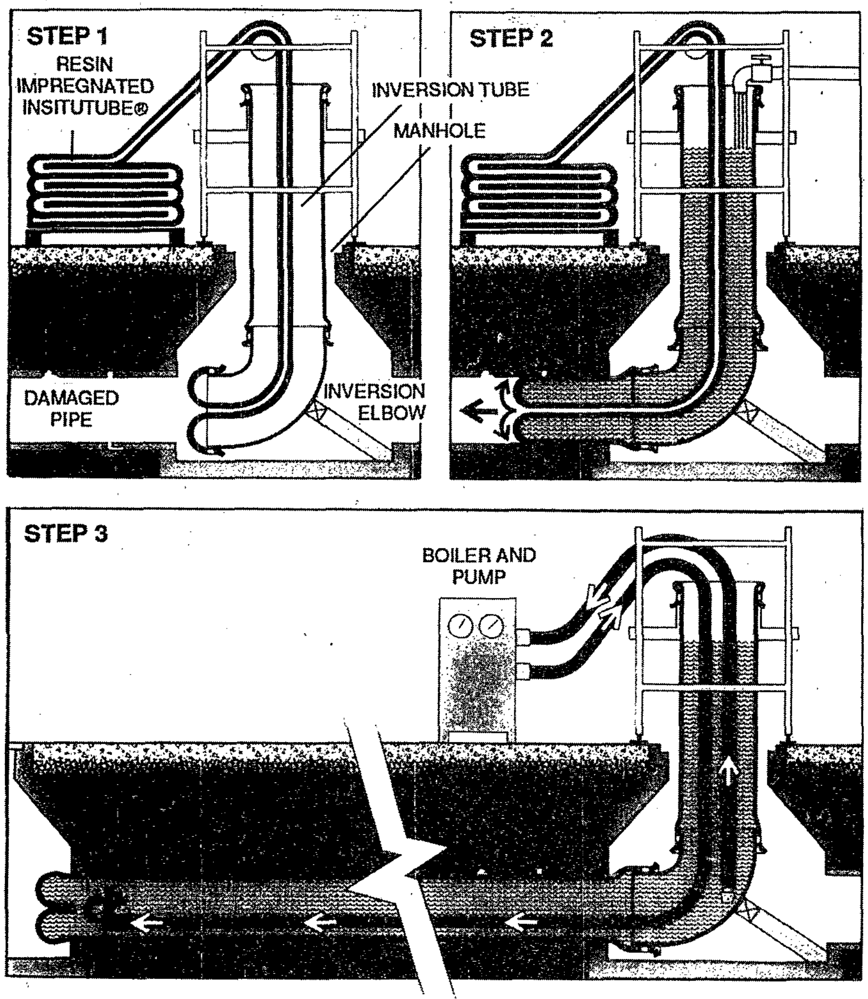
6.5.2 Procedures and Equipment

Installation of cured-in-place inversion lining is carried out by inserting the resin-impregnated fabric tube (turned inside out) into the existing pipe line and inverting it as it progresses inside the pipe. It is then cured in place through the use of heated water or air steam. Prior to the installation of the liner, the pipeline section must be cleaned to remove loose debris, roots, protruding service connections, and excessive solids. The preparation and installation procedures are illustrated in Figure 6-3.[1] The pipeline segment must be isolated from the system by bypassing flows during the installation of the inversion lining. The inversion felt tube liner is usually inserted from existing manholes. Following curing of the liner, the ends are cut and sealed and service connections are restored.

6.5.3 Costs

See Table 6-9 for approximate costs of sewer rehabilitation by cured-in-place inversion lining. The costs in these tables are based on costs taken from *Utility Infrastructure Rehabilitation*[3] and were adjusted to current prices through the use of a cost index. Costs were also verified by contacting vendors and contractors.

Figure 6-3. **Installation of Cured-In-Place inversion lining (Insituform).**



6.6 Fold and Formed

This process uses a folded thermoplastic (PE or PVC) pipe that is pulled into place and is then rounded to conform to the internal diameter of the existing pipe. This method of pipe rehabilitation can be considered as an improved version of sliplining. Excavation is not required for installation when there are existing manhole access points, and lateral reinstatement is accomplished internally. The finished pipe has no joints and produces a moderately-tight fit to the existing pipe wall. This method of pipe rehabilitation is less versatile than cured-in-place methods in terms of diameter range and installation length. Only slight offsets and bends can be negotiated.

The fold and formed method of rehabilitation does not require a long curing process in terms of speed of installation. This process of rehabilitation has been carried out in the United States for the last 2-3 years. There are currently two fold and formed processes commercially available in the United States: U-Liner and NuPipe. Some municipalities have tried them for experimental and evaluation purposes. Fold and formed method of pipeline rehabilitation are suitable for pipe diameters of 10-40 cm (4-16 in) with typical lengths of installation of 90-180 linear m (300-600 ft). Fold and formed technology is currently being developed for 60-cm (24-in) diameter pipe. Butt-fused U-Liner pipe can be used for lengths up to the stress-resistant pull force of the material.

6.6.1 U-Liner

The U-Liner technology was developed by Pipe Liners Inc. of New Orleans with the pipe material being manufactured in the United States by Quail Pipe Corporation of Roaring Springs, Texas. The U-Liner manufacturing process is specified by ASTM as deformed HPDE. This rehabilitation technology has been commercially available in the United States since 1988.

High density polyethylene resin conforming to the requirements of ASTM 1248, Type III, Class C, Category 5, Grade P34, is used, and it is currently available in SDR 32.5, 26 and 21. The selection of the appropriate wall thickness will depend on the particular loading conditions from project to project. U-Liner is extruded as round pipe, conforming to ASTM D-3350, and then through a combination of heat and pressure, is deformed into the "U" shape. It is then wound onto spools ready for installation. This technology is currently applicable for pipe sizes of 10-40 cm (4-16 in). Approximately 100 linear km (350,000 ft) of pipe has been installed in the U.S. by U-Liner Licensees. The U-Liner polyethylene material has been independently tested for material strength and physical properties and has been accepted in the *Standard Specifications for Public Works Construction*.[6]

The installation of U-Liner is basically a three step process. After cleaning and TV inspection and analysis to identify defects and to determine the applicability of U-Liner, the first step includes winching of a pre-engineered seamless coil of pipe of a precut length into place. The pipe is pulled off the spool at ambient temperature, fed through an existing manhole, and is winched through the existing pipe to the terminal point. Once it is in place, steam is fed through the inside of the folded pipe, softening the plastic to allow for the reforming process. Installation in pipes below the water table may make it difficult to heat the plastic sufficiently due to groundwater entering the system which will cool the plastic. Temperatures of 110-130°C (235-270°F) are used to soften the plastic. A diagram depicting the U-Liner installation procedure is presented in Figure 6-4. After the plastic has been heated, pressure is used to reround the pipe. The rerounding of the pipe occurs simultaneously from end to end and may trap water or air in between the U-Liner and the host pipe. The pressure required to reround the pipe will vary, depending on the wall thickness, between 170 and 240 kPa (25 and 35 psi).

Due to the relatively high coefficient of thermal expansion of polyethylene combined with the extreme temperature changes associated with the process, sufficient time should be allowed for the system to stabilize before laterals are reinstated and end treatment is finished. Laterals are recut utilizing a remote-controlled cutter head, in conjunction with a TV camera.

6.6.2 NuPipe

The NuPipe process was developed in the U.S. and has been commercially available since 1990. NuPipe is manufactured from PVC and is extruded in a folded shape. While it is still pliable, the folded PVC is wound onto spools. It is currently available in 15-30 cm (6-12 in) in SDR 35. Third party testing has shown that SDR 35 is capable of withstanding nearly all loading conditions experienced in buried pipelines.[7] The resin composition conforms to ASTM 1784, cell class 12454-B or 12454-C and the installed pipe meets the performance requirements of ASTM D-3034 which is standard specification for direct bury PVC pipe. As with polyethylene, the corrosion resistance of PVC is excellent.

The installation of NuPipe includes cleaning of existing host pipe along with a TV inspection to determine the extent of deterioration and to verify the applicability of NuPipe. A flexible reinforced liner called the Heat

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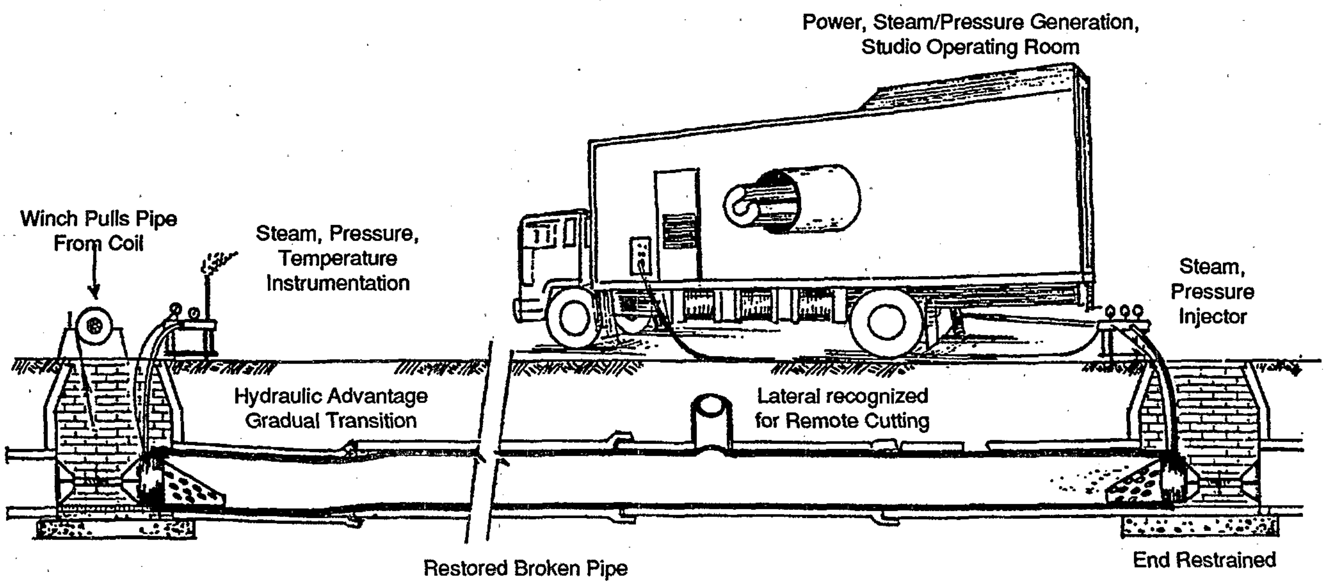
Figure 6-4. U-Liner installation method.



Containment Tube (HCT) is inserted into the host pipe. The HCT provides a closed environment in which the NuPipe is installed and processed. After the HCT has been strung through the host pipe. The folded PVC is heated while on the spool and is pulled through the host pipe. Heating the plastic reduces the forces required to pull the pipe in place. Once the folded NuPipe reaches the termination point, steam is introduced into the system both through the interior and around the exterior of the folded pipe. The use of the HCT also allows for heating both sides of the plastic to provide complete heat transfer through the pipe wall which minimizes the effect of infiltrating water. After the PVC becomes pliable, a rounding device is introduced into one end of the pipe which is then propelled through the folded pipe. The rounding device progressively rounds the NuPipe, moving standing water out of the way while also expanding the plastic tightly against the host pipe, creating a mechanical lock at joints and laterals. Approximately 35-70 kPa (5-10 psi) is needed to propel the rounding device. Cold water is then injected into the NuPipe effectively quenching the plastic. The installation process is shown in Figure 6-5.

6.6.3 Costs

The costs of U-Liner and NuPipe are not well established due to the recent entry of these two technologies into the sewer rehabilitation field. The cost of Fold and Formed installations vary widely in different geographic regions of the country depending on availability of materials, availability and experience of installation contractors, level of competition, and length and loading condition of the sewers to be rehabilitated.

Review of limited competetive bid prices received from Pipe Liners, Inc. for U-Line indicates a price range of $60-78/LF for 20- to 30-cm (8-12-in) diameter pipe, including cleaning. Laterial reinstatement costs were reported to range from $200 to $216/unit. Price information was not available from NuPipe.

Engineers and municipalities considering Fold and Formed technologies are encouraged to contact the manufacturer and local installers of the technology and to review installation costs for recently-installed projects in their locality.

6.7 Specialty Concrete[1]

6.7.1 Description

Specialty concretes containing sulfate resistant additives such as potassium silicate and calcium aluminate have shown greater resistance than typical concrete to acidic attack on sewer pipes and manhole structures.

Figure 6-5. **NuPipe installation method.**

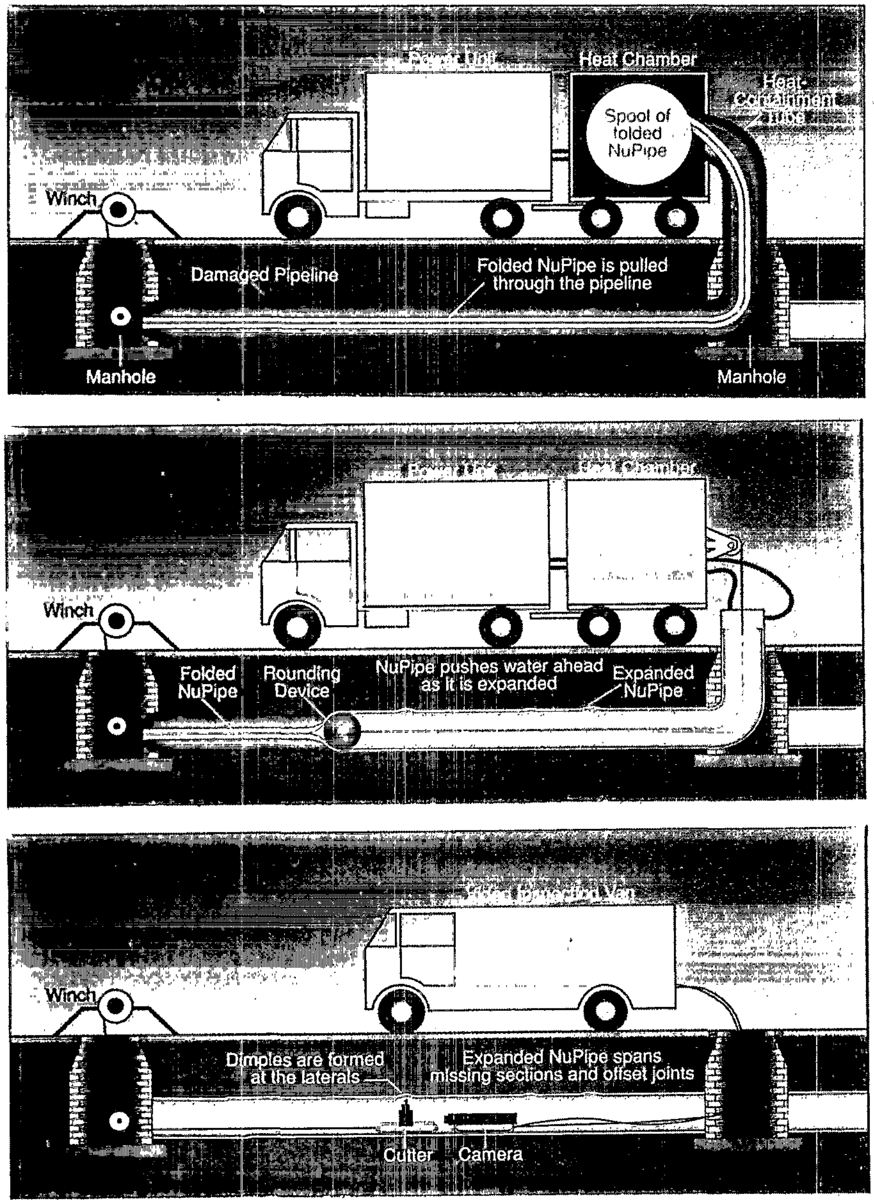


Table 6-10. Advantages and Disadvantages of Specialty Concretes

Advantages	Disadvantages
Cement Mortar	
• Minimal service interruption	• Excavation required for sharp ends or curves
• Improved structural integrity	• Cannot be done in winter if freezing potential exists
• Applicable for wide range of pipe sizes	• Bypass required
	• Extensive surface preparation required (e.g., chipping, sandblasting)
	• Access holes required every 150-210 m (500-700 ft)
	• Concrete shelf life must be tracked for the project duration
	• Transportation cost higher for concrete
	• May not provide adequate corrosion resistance
Shotcrete	
• Minimal excavation required Access is through manholes	• Extensive surface preparation required
• Can restore structural integrity to a pipe that would otherwise require replacement	• Extended downtime period of 3-7 days or longer required for cleaning
• Minimum traffic interruptions	• Some reduction in hydraulic capacity
• Applicable to all shapes of man-entry size pipes	• Limited to man-entry size structures
	• Concrete shelf life to be tracked for project duration
	• Transportation cost high for concrete
	• May not provide adequate corrosion resistance.
Cast Concrete	
• Established procedure	• Cleaning required
• Simple to design	• Bypass required
• Applicable to all shapes of pipes	• Seldom applicable to pipes less than 1.2 m (4 ft) in diameter
	• Concrete shelf life to be tracked for project duration
	• Transportation cost high for concrete
	• May not provide adequate corrosion resistance

Specialty concrete is used to reinforce weakened concrete pipes and structures by applying an acid resistant coating over the original surface. Specialty concretes are unique in that their matrix is not formed by a hydration reaction. Rather, they are the result of the reaction of an acid reagent with an alkaline solution of a ceramic polymer of potassium silicate. Portland cement releases calcium hydroxide during hardening whereas the specialty cements do not release calcium hydroxide. Specialty cements can resist attack by many substances including mineral salts, mild solutions of organic and mineral acids, sugar solutions, fats and oils. Acid reagents used in some cases are also effective bactericides.[1]

Applicability of specialty concrete depends on the degree of corrosion-related deterioration and the structural integrity of the sewer. Thin film specialty concrete is applicable to mildly deteriorated pipes or structure, whereas an elastic membrane concrete system is applicable to all cases. After curing, the specialty concrete bonds firmly to the original surface. The new acid-resistant layer, if applied and cured properly, extends the useful life of the structure. Advantages and disadvantages of specialty concretes are listed in Table 6-10.

6.7.2 Procedures and Equipment

Specialty concretes are available in three types: cement mortar, shotcrete, and cast concrete. Acid resistant mortars have been used in industry as linings in tanks or as mortar bricks. Development of mechanical in-line application methods (centrifugal and mandrel) has established mortar lining as a successful and viable rehabilitation technique for sewer lines, manholes and other structures.

Mortar lining is applied using a centrifugal lining machine. The machine has a revolving, mortar-dispensing head with trowels on the back to smooth the mortar immediately after application. In smaller diameter pipes a variable speed winch pulls the lining machine through a supply hose. Reinforcement can also be added to the mortar with a reinforcing spiral-wound rod. The reinforcing rod is inserted into the fresh mortar and a second coat is applied over it. For man-entry structures the mortar can be applied manually with a trowel.

Shotcrete, sometimes referred to as gunite, is a low-moisture, high-density mixture of fine aggregate (particle size of 19 mm [0.75 in] and smaller), cement and water; solids to liquid mix ratios are typically 5:1. Well placed shotcrete has a high modules of elasticity (greater than 4 million psi) and a coefficient of thermal expansion similar to that of low carbon steel. Bonding with the original surface is usually stronger than the base material itself, with better adhesion occurring with the more deteriorated and irregular existing pipe. Shotcrete is applied to a minimum thickness of 5 cm (2 in). Shotcrete is used in man-entry size sewers (81 cm [32 in] or greater) and manholes. Prior to shotcreting, reinforcing steel is set into place. The shotcrete lining machine is self propelled and controlled by a person riding it. Mortar is supplied to an electrically driven supply cart that conveys mortar from the access hole to the feeder which is attached to the lining machine. The dry specialty cement

Table 6-11. Costs for Rehabilitation Using Specialty Concretes

Item	Repair Cost Severely Corroded Concrete ($/sq ft)	Repair Cost Mildly Corroded Concrete ($/sq ft)	Cost to Apply to New Concrete ($/sq ft)
Cement with Polymer Lining	16 - 18	9 - 11	5 - 6
Cement with acid Proof Concrete	22 - 27	16 - 19	16 - 19
Cement with urethane Membrane	22 - 27	16 - 19	16 - 19

- Mildly Corroded - Less than 19-mm (3/4-in) loss of concrete. No reinforcement attack.
- Severely Corroded - Greater than 19-mm (3/4-in) concrete loss. May require replacement of reinforcement.
- Costs include installation.
- Costs obtained from *Report to Congress: Sulfide Corrosion in Wastewater Collection and Treatment Systems*[1].

and aggregate is mixed with water in a specially designed spray nozzle. Hydration occurs, and the resulting mixture is shot into place under pressure. Curing occurs under moist conditions for the first 24 hours and an additional six days at a temperature above 4°C (40°F).

Cast concretes are potassium silicate bonded, poured or cast in place structural concretes. They typically have half the in-place density or strength value of shotcrete. Solids to liquid mix ratios are generally 2:1, similar to cement mortar.

Cast concrete is poured over prefabricated or hand built interior pipe forms that can be removed and reused section by section. Reinforcing steel is added between the original surface and the form, setting within the cured thickness.

Each of the three application techniques requires prior cleaning to remove oils, greases, foreign objects, and loose materials, as well as wastewater bypass during application and initial curing.

6.7.3 Costs

Table 6-11 provides typical costs for the three types of specialty concrete.[1] The costs in this table were obtained from *Report to Congress: Sulfide Corrosion in Wastewater Collection and Treatment Systems*[1] and were adjusted to current prices through the use of a cost index. Costs were also verified by contacting vendors and contractors.

6.8 Liners[1]

6.8.1 Description

Rehabilitation techniques using liners include the installation of prefabricated panels or flexible sheets on the existing structure usually with anchor bolts or concrete penetrating nails shot into place. The following materials of liners are available for rehabilitation purposes[1]:

- PVC liners
- PE liners
- Segmented, fiberglass reinforced plastic liners
- Segmented, fiberglass reinforced cement liners

PVC liners are manufactured from acid-resistant, rigid unplasticized PVC which has excellent resistance to acids and also is initially conductive to better hydraulics than concrete. The liner is composed of high molecular weight vinyl chloride resins combined with chemical-resistant plasticizers. The completely inert mixture is extruded under pressure and temperature into a liner plate with a minimum thickness of 1.6 mm (0.065 in). The liners are pin-hole free, forming an effective barrier to gaseous penetration.

PE liners are similar to PVC liners but are made of polyethylene resins. These liners are tough, rigid, acid-resistance, smooth and inexpensive.

Fiberglass reinforced plastic liners are manufactured in a range of wall thicknesses and consist of a composite of fiberglass and acid-resistant resin. The resins are specified according to the degree of acid resistance required. The composite has high mechanical and impact strength and good abrasion resistance. These liners can be manufactured to a wide variety of shapes and are applicable to sewers over 107 cm (42 in) in diameter.

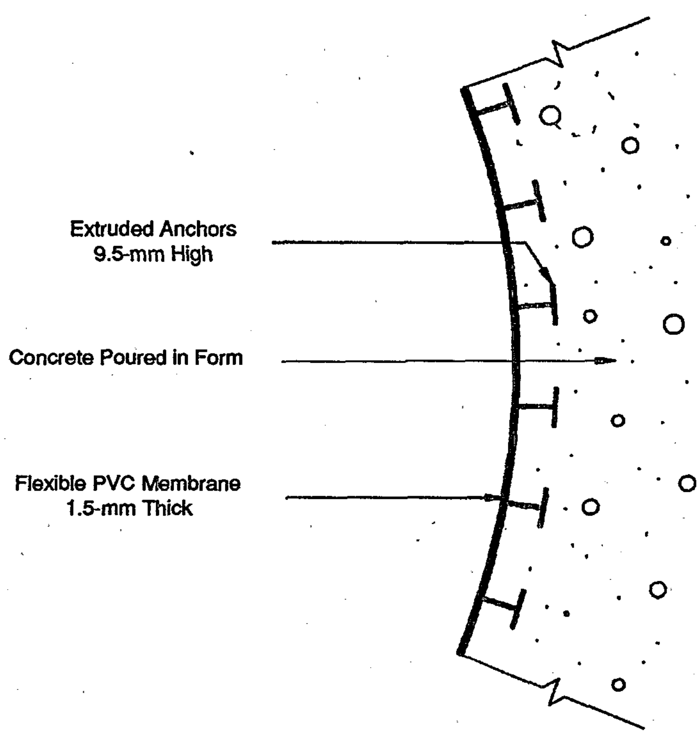
These liners do not provide any structural support but they do provide an adequate corrosive barrier and smooth lining for structurally sound sewers. These liners have little absorption and no apparent permeability.

Fiberglass reinforced cement liners consist of cement and glass fibers. They usually are 9.8 mm (0.385 in) thick and are in thin panel form. They have high mechanical and impact strength and good acid and alkaline resistance. They are also highly resistant to abrasion with negligible absorption and permeability. These liners are not designed to support earth loads and should be used only in structurally sound sewers. The liners can be easily assembled to fit variations in grades, slopes and cross-section. The smooth interior surface improves hydraulic capabilities. These liners can be used in circular, oval, rectangular and other sewer shapes above 107 cm (42 in) in normal size and can be segmented to fit the diameter required.

Table 6-12. Advantages and Disadvantages of Liners

Advantages	Disadvantages
• Material cost inexpensive	• Applicable only to man entry size sewers (i.e., 76 cm [2.5 ft] or greater)
• Liner materials have very good acid resistance	• Susceptible to leakage due to number of joints
• No disruptions to traffic as installation is performed entirely in-line	• Timely to install. Thus total project cost may be uneconomical.
• Smooth surfaces provide good hydraulics	• Prolonged bypass required
	• Surface preparation required
	• PE can crack in areas of turbulent flow

Figure 6-6. Detail of liners with anchors.



Advantages and disadvantages of liners as a sewer rehabilitation technique are listed in Table 6-12.

6.8.2 Procedures and Equipment

Segmented plastic and fiberglass reinforced cement liners are installed so they overlap at the joints and are then attached to the concrete surface by anchor bolts or nails. Space is left between the existing surface and the liners for grouting purposes. After a thorough line cleaning and dewatering, the segments are installed in 2.4-m (4-ft) lengths which overlap at the joints, and the flanges on the segments may be pre-drilled for filling by screws or impact nail gun. Joints are coated with an adhesive to better connect panels and are sealed with an acid resistant resin. After all the panels are set in place, the entire section is cement pressure grouted in place to prevent sagging and deformation. Some liners are installed in conjunction with the casting of concrete by placing the liners against the inner surface of the form prior to pouring. Anchors become embedded in the concrete during curing, thereby securing the liner in place (see Figure 6-6).[1] Alternate installation procedures for flexible PVC liners or ribbed sheets involve only grouting, without anchor bolts or impact nails for attachment. Installation of another type of liner requires an access pit to fit the special winding machine that joins a male and female PVC strip. This process is applicable to pipes up to 76 cm (2.5 ft) in diameter. The latest liner installation method uses an acid resistant mastic to fasten the sheets directly to the sewer concrete surface. This technique does not require grouting but requires thorough cleaning prior to installation.

Liner failures can occur due to leaking joints that allow H_2S gas or sulfuric acid to penetrate the liner materials and attack the concrete substrate beneath. Liner failures have also been reported in areas of high turbulence where cracks developed. Cracking has been identified in PE pipes and thus PE is not recommended in areas of turbulent flows.

6.8.3 Costs

Table 6-13 gives approximate costs for rehabilitating sewers by lining the pipes with cement mortar or shotcrete and Table 6-14 gives approximate costs for lining with anchor liners. The costs in these tables are based on costs taken from *Utility Infrastructure Rehabilitation*[3] and were adjusted to current prices through the use of a cost index. Costs were also verified by contacting vendors and contractors.

6.9 Coatings

Table 6-13. Rehabilitation Costs for Lining with Cement Mortar and Shotcrete

Pipe Diameter (in)	1984 ENRCCI=4144 ($/LF)	March 1991 ENRCCI=4773 ($/LF)
Cement Mortar Lining		
12	12 - 21	15 - 25
24	13 - 27	15 - 30
36	16 - 34	20 - 40
48	17 - 42	20 - 50
60	22 - 51	25 - 60

- Costs are for cleaning and lining only.
- Valve rehab., bypass installation, pavement removal, etc., are not included.
- Costs are base contractor bids.
- 1983 costs are from Reference 3; 1991 costs based on 1983 costs.

Pipe Diameter (in)	1984 ENRCCI=4144 ($/LF)	March 1991 ENRCCI=4773 ($/LF)
Reinforced Shotcrete Unit Costs		
48	100-125	115 - 145
54	115 - 150	135 - 175
60	125 - 175	145 - 205
66	135 - 185	160 - 215
72	150 - 220	175 - 255
84	176 - 250	205 - 290
96	200 - 285	230 - 330
108	225 - 315	260 - 365

- Based on minimum project size of 300 m (1,000 LF).
- 1983 costs are from Reference 3; 1991 costs based on adjusted 1983 costs.
- Costs apply to circular and non-circular pipe.
- Lower rates for existing pipe with good pipe alignment, no need for spot repair, and no significant groundwater.
- Higher costs for existing pipe with poor pipe alignment and some need for groundwater dewatering.
- Costs include cleaning of existing line; material, labor and equipment for reinforced shotcrete placement; bypassing of wastewater; restoration of up to 20 services; contractor mobilization and demobilization; bonds and insurance.

Table 6-14. Rehabilitation Costs for Lining with Anchors

Unit Costs for PVC T-Lock Liners

Item	April 1989 ENRCCI=4577 ($)	March 1991 ENRCCI=4773 ($)
Black: 4 x 8 ft sheet	60.80/each	65/each
White: 4 x 8 ft sheet	60.80/each	65/each
Anchor liner 4-ft W x 20-ft L	1.90/sq ft	2/sq ft
Anchor 25-ft W x 20-ft L	2.25/sq ft	2.35/sq ft
1/16-in thick - 48 x 50 in	220/roll	230/roll
3/32-in thick - 48 x 50 in	300/roll	320/roll
1/8-in thick - 48 x 50 in	400/roll	420/roll
3/16-in thick - 48 x 25 in	325/roll	340/roll

- Prices do not include primer and installation.
- Prices do not include any site work.
- 1991 costs based on adjusted 1989 costs.

Table 6-15. Advantages and Disadvantages of Coatings

Advantages	Disadvantages
• Economical	• Applicable only to man-entry sewers and manholes
• No disruption to traffic or other utilities	• Surface imperfections-pinholes, blowholes
• Most are fast curing, some cure in less than one hour	• Poor bonding to vertical or overhead surfaces
• Quick to apply	• Bypass required
• Can be applied to uneven surfaces	• Surface preparation required
	• Few contractor inexperience with products
	• Surface repairs often required prior to application
	• Still a developing technology

6.9.1 *Description*

Coatings include a myriad of proprietary materials including coal tar epoxy, concrete sealers, epoxy, polyester, silicone, urethane, and vinylester that can be applied by spray machines or brushed onto a concrete surface. They are intended to form an acid resistant layer that protects the substrate concrete from corrosion. Coatings have been applied to sewer pipes and manholes since the 1960's, with mixed success. The lack of success is largely due to the specification of coating materials on the basis of manufacturer claims without actual field testing[1]. As a result of these findings, rehabilitation engineers are recommending standard field testing of new products prior to their use. Some of the advantages and disadvantages involved with the use of coatings are listed in Table 6-15.

6.9.2 *Procedures and Equipment*

Application of coatings usually includes the following procedures:

- bypass of wastewater
- prepare/clean concrete surface
- allow concrete surface to dry
- apply coating by brush or spray (more than one coat is usually necessary)
- allow coating to cure
- remove bypass.

Table 6-16. Costs for Rehabilitation Using Coatings

Item	April 1989 ENRCCI=4577 ($/sq ft)	March 1991 ENRCCI=4773 ($/sq ft)
Agatapoxy (Epoxy)	9-19	9-20
Agatapoxy Gel (Epoxy)	7	7.50
Plasite (Epoxy)	5	5.50
Sancon (Urethane)	9	9.50

- Costs obtained from *Report to Congress: Sulfide Corrosion in Wastewater Collection and Treatment Systems*[1].
- 1991 costs based on adjusted 1989 costs.

Most coatings can be brush or spray applied. Spray application requires 3,000 psi, which is double the pressure used for conventional airless spraying.

Spraying is excellent for coating uneven surfaces and is much faster than brush application methods for some products.

6.9.3 *Costs*

Approximate costs for various types of coatings are shown in Table 6-16.

6.10 All Techniques for Manholes

6.10.1 *Description of Materials, Equipment and Products*

Sewer manholes require rehabilitation to prevent surface water inflow and groundwater infiltration, to repair structural damage and to protect surfaces from damage by corrosive substances. When rehabilitation methods will not solve the problems cost-effectively, manhole replacement should be considered. Selection of a particular rehabilitation method should consider the type of problems, physical characteristics of the structure, location, condition, age and type of original construction.[4] Extent of successful manhole rehabilitation experiences and cost should also be considered.

Manhole rehabilitation methods are directed at either: (1) the frame and cover, or (2) the sidewall and base. The following is a summary of manhole and base rehabilitation methods.[4,5] Advantages and disadvantages for these rehabilitation methods are presented in Table 6-17.

6.10.2 *Description of Procedures*

Manhole rehabilitation methods are directed at either: (1) the frame and cover, or (2) the sidewall and base. Manhole frame and cover rehabilitation prevents surface water (storm water runoff) from flowing into the manholes.

Table 6-17. Advantages and Disadvantages of Manhole and Sump Rehabilitation Methods[4,5]

Method	Advantages	Disadvantages
FRAME AND COVER		
Stainless steel, and neoprene washers or corks in holes in covers.	Simple to install	Restricts natural venting
Prefabricated lid insert	When installed properly it prevents surface water, sand and grit from entering manhole through or around cover.	Requires perfect fit for success.
Joint sealing tape	Simple to install	Short service life.
Hydraulic cement	Provides strong waterproof seal to stop infiltration	Labor-intensive; freeze thaw cycle may reduce patch life.
Raise frame above grade	Minimizes inflow through cover and frame.	Limited to areas outside of street right-of-way.
SIDEWALL AND BASE		
Epoxy or polyurethane coatings on interior infiltration	Protects interior walls against corrosion and	Requires structurally sound and dry manhole surface walls must be very clean prior to application; short service life.
Chemical grout	Can be very inexpensive method for stopping infiltration.	Short service life; cannot predict amount of grout required to eliminate infiltration.
Structural liner	Provides structural restoration; manholes requires less disruption of traffic and utilities than replacement; longer service life than coatings.	Complex and costly installation
Hydraulic cement	Seals manhole frame in place. Prevents infiltration between frame and cone section.	
Raise frame	Prevents surface water inflow through manhole cover.	
SIDEWALL AND BASE		
Epoxy or polyurethane coatings on interior walls	Protects wall from corrosion and infiltration on structurally sound manholes.	

Surface water from storm runoff, etc., can often flow into the manholes through the holes in the cover lid, through the annular space around the lid and the framed cover and under the frame if it is improperly sealed. Manhole frames and covers can be rehabilitated by the following techniques:

- By installing stainless steel bolts with caulking compound and neoprene washers or corks to plug holes in the cover.
- By installing a prefabricated lid insert between the frame and the cover. These plastic lids are resistant to corrosion and damage by sulfuric acid or road oils. The lids come with gas relief and vacuum relief valves to allow gas escape. They prevent water, sand, and grit from entering the manhole. The lids are easy to install, can fit any manhole, and require periodic maintenance to function properly.
- By installing a resin based joint sealing tape between metal frame and cover. The sealing tape provides flexibility to seal imperfectly fitting surfaces and to move with ground shifting. These sealing tapes can be used for all types of manholes.
- Cracks and openings on the existing manhole/frame seals are applied with hydraulic cement and waterproofing epoxy.
- By raising the manhole frames to minimize flows through the frame covers.

Manhole sidewall and base rehabilitation is primarily done to prevent infiltration of groundwater. Casting or patching can be used to rehabilitate structurally sound sidewalls. Complete replacement should be carried out for severely deteriorated manholes and bases. Manhole steps also deteriorate frequently and they should be replaced. Manhole sidewall and base rehabilitation can be carried out by the following procedures:

- By applying epoxy, acrylic or polyurethane based coatings to the interior wall of the manhole. These waterproof and corrosion resistant coatings can be applied to brick, block and precast concrete manholes and bases. The coatings are applied by towel brush or sprayer. Prior to coating application, the surfaces of the manhole walls should be cleaned and all leaks are plugged using patching or grouting materials.
- By applying chemical grout from interior walls to exterior walls to stop infiltration through cracks and holes.
- By inserting structural liners inside existing manholes. These liners are typically fiberglass of the reinforced polyester mortar type.

6.10.3 Costs

Manhole rehabilitation costs are provided in Table 6-18.

Table 6-18. Rehabilitation Costs - Manhole Techniques

Item	March 1991 ENRCCI=4773 ($)
Chemical grouting*	540 - 835/manhole
Seal frames to corbels*	395 - 415/manhole
Chemically seal and plaster walls*	395 - 430/manhole
Raise manhole to grade*	645 - 1,095/manhole
Replace frame*	415 - 645/manhole
Insert structural liner*	4,610 - 13,825/each
Manhole replacement**	1,200 - 2,395/each
Manhole repair**	120 - 1,200/each
Raise manhole frame and cover**	240 - 360/each
Manhole cover replacement**	120 - 240/each

* Costs based on Reference 3, Dec. 1984 (ENRCCI=4144) adjusted to March 1991 (ENRCCI=4773).

** Costs based on Reference 2, Mid. 1974 (ENRCCI=1991) adjusted to March 1991 (ENRCCI=4773).

6.11 Service Lateral Techniques

6.11.1 Description

Service laterals are the pipes that connect building sewers to the public sewer main. The service laterals usually range in size from 7.5 to 15 cm (3-6 in) and are often laid at a uniform slope from the building to the immediate vicinity of the main sewer. They can enter the sewer at angles of 0-90 degrees from horizontal. For many years the effect of leaking service connections were considered insignificant because it was assumed that most service connections were above the water table and therefore subject to leakage only during periods of excessive rainfall or high groundwater levels. Recent studies indicate that a significant percent of infiltration in any collection system is the result of service connection defects such as cracked, broken or open-jointed pipes. Service connections may also transport water from inflow sources such as roof drains, cellar and foundation drains, basement or subcellar sump pumps, and storm water flows from commercial and industrial properties. In a national survey carried out by state and local agencies, it was found that the estimated percentage of total system infiltration from service laterals ranges from 30 to as high as high as 95 percent in some cases.

6.11.2 Procedures and Equipment

Following are the procedures and equipment used for rehabilitating service laterals:

Chemical Grouting: The following chemical grouting methods are utilized:

Table 6-19. Service Lateral Rehabilitation Costs

Method	Unit Cost ($/lateral)
Sealing (test and seal by joint)	1,980
Sliplining	1,730
Add two way clean out	450
Air test	
Partial or entire lateral	75
Lateral connection to main	200
Exfiltration test	
Partial or entire lateral	75
TV inspection	200
Seal with chemical grout	
Lateral connection to main	650
Remaining lateral	590
Replacement	2,880
Chemical Grouting	460 - 1,155

• Costs based on Reference 3, December 1984 (ENRCCI=4144) adjusted to March 1991 (ENRCCI=4773).

Pump Full Method: Chemical grout is injected through a conventional sealing packer from a sewer main into the service connection to be grouted. The forced grout surrounds the pipe and a seal is formed after the gel has set. Excessive grout is augured from the building sewer and the sewer is returned to service after the sealing has been accomplished.

Sewer Sausage Method: This method is similar to the pump full method except that a tube is inverted into the service connection before sealing to reduce the quantity of grout to be used and to minimize the amount of cleaning required after the sealing has been completed.

Camera-Packer Method: This method utilizes a miniature TV camera and a specialized sealing packer which is pulled out while it is simultaneously repairing faults that are seen through the TV camera. The equipment is

Table 6-20. Miscellaneous Additional Rehabilitation Costs

Item	March 1991 ENRCCI=4773 ($)
House service pipe replacement	1,440 - 2,875 each
House service pipe repair	480 - 960 each
Roof leader drain disconnection	120 - 180 each
Foundation drain disconnection	720 - 2,875 each
Cellar drain disconnection	120 - 840 each
Area drain disconnection	120 - 840 each
Cross connection plugging	240 - 1,200 each
Drain from springs plugging	1,200 - 5,990

• Costs based on Reference 2, Mid. 1974 (ENRCCI=1993) adjusted to March 1991 (ENRCCI=4773).

Table 6-21. Sewer System Evaluation Survey Costs

	March 1991 ENRCCI=4773 ($/ft)
Physical Survey Costs	0.35 - 0.60
Rainfall Simulation	
Smoke testing	0.35 - 0.75
Dyed water testing	0.60 - 1.20
Water flooding	0.60 - 1.20
Preparatory Cleaning (Pipe Diameter, in)	
6	0.75 - 2.65
8	0.60 - 2.15
10	0.75 - 3.15
12	0.85 - 4.10
15	0.95 - 5.05
18	1.20 - 5.40
21	1.70 - 8.40
24	1.95 - 10.20
30	2.75 - 13.20
36	3.50 - 16.30
Internal Inspection (Pipe Diameter, in)	
6	1.10 - 3.00
8	0.85 - 2.90
10	0.75 - 2.75
12	0.75 - 2.90
15	0.75 - 3.15
18	0.85 - 3.35
21	0.95 - 3.75
24	1.20 - 4.20
30	1.35 - 4.80
36	1.80 - 5.30

• Costs based on Reference 2, Mid. 1974 (ENRCCI=1991) adjusted to March 1991 (ENRCCI=4773).

Table 6-22. Sewer Pipe Problems with Applicable Rehabilitation Methods

Problem	Rehabilitation Method
1. Poor structural integrity	a. Excavation and replacement b. Insertion c. Some specialty concretes
2. Significantly misaligned pipe	a. Excavation and replacement
3. Additional sewer capacity needed	a. Excavation and replacement
4. Most rehabilitation methods would reduce sewer capacity to unacceptable levels	a. Excavation and replacement
5. Pipe is seriously damaged	a. Excavation and replacement
6. Excessive infiltration in non-pressure pipes	a. Chemical grouting sliplining CIPL, etc.
7. Leaking pipe joints which are not badly offset or misaligned	a. Chemical grouting, CIPL
8. Circumferential cracks	a. Chemical grouting
9. Small holes	a. Chemical grouting
10. Small radial cracks	a. Chemical grouting
11. Serious root problems	a. Sliplining, CIPL
12. Severe corrosion	a. Sliplining, CIPL b. Cured-in-place inversion lining, sliplining
13. Damaged pipes under structures, large trees, or busy streets	a. Cured-in-place inversion lining, sliplining, coatings
14. Problems in non-circular pipes	a. Cured-in-place inversion lining
15. Mildly deteriorated structure	a. Cured-in-place inversion lining
16. Corrosion; structurally sound; diameters of 76 cm (2.5 ft) or greater	a. Liners, CIPL b. Coatings
17. Corrosive or acidic wastes	a. Sliplining b. Specialty concretes c. Liners d. Coatings e. Cured-in-place inversion lining
18. Pipes with misalignment or bends	a. Cured-in-place inversion lining

removed and the service connection returned to service after the repairs are completed.

Inversion Lining: This technique is similar to the sewer main installation in that it involves the insertion of a resin-impregnated flexible polyester felt liner into the service line. No annular space is created between the liner and the pipe that might result in infiltration migration. No prior excavations are required to correct slight offsets. An access point is always needed on the upstream side of the service connection line. A variation from the sewer main installation is the use of a special pressure chamber to provide the needed pressure to invert the fabric materials through the service pipeline. After the completion of the curing process, the downstream end of the liner is cut manually or via a remotely controlled cutting device placed in the sewer main. The upstream end is trimmed at the access point, restoring the sewer service.

6.11.3 Costs

Costs for rehabilitating service laterals are presented in Table 6-19.

6.12 Miscellaneous Costs

6.12.1 Rehabilitation

There are miscellaneous rehabilitation costs which were not covered by the other sections in this chapter. These costs are based on costs taken from the *Handbook for Sewer System Evaluation and Rehabilitation*[4] and are presented in Table 6-20.

6.12.2 Costs for Preliminary and I/I Analysis and SSES

Approximate costs involved in preliminary analyses, I/I analyses, and SSES's are given in Table 6-21.

6.13 Matrix of Problems and Applicable Corrective Measures

Table 6-22 lists common problems in sewer pipes with applicable rehabilitation method(s) for each.

6.14 References

When an NTIS number is cited in a reference, that reference is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

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Glossary

U.S. EPA	United States Environmental Protection Agency
SRF	State Revolving Funds
CDBG	Community Development Block Grant
CG85	Construction Grants 1985
PL-92-500	Public Law 92-500
NASSCO	National Association of Sewer Service Companies
ENRCCI	*Engineering News Record* Construction Cost Index
ASCE	American Society of Civil Engineers
WPCF	Water Pollution Control Federation
RII	Rainfall Induced Infiltration
LF	Linear foot
PVC	Polyvinylchloride
CFR	Code of Federal Regulations
SSES	Sewer System Evaluation Survey
CWA	Clean Water Act
H_2S	Hydrogen Sulfide
O&M	Operation and Maintenance
NOAA	National Oceanic and Atmospheric Association
WSSC	Washington Suburban Sanitary Commission
BOD	Biological Oxygen Demand
SO_2	Sulfur Dioxide
DO	Dissolved Oxygen
NIOSH	National Institute of Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
Service	LineSewer pipes that connect building sewers to public sewers
PE	Polyethylene
ASTM	American Standards for Testing of Materials
FRP	Fiberglass Reinforced Polyester
RTR	Reinforced Thermosetting Resins
T-Lock	Trade name for Ameron Liners
Infiltration	The water entering a sewer system and service connections from the ground, through such means as, but not limited to, defective pipes, pipe joints, connections, or manhole walls. Infiltration does not include, and is distinguished from inflow.
Inflow	The water discharged into a sewer system, including service connections, from such sources, as but not limited to, roof leaders, cellar, yard and area drains, foundation drains, cooling water discharges, drains from springs and swampy areas, manhole covers, cross connections from storm sewers and combined sewers, catch basins, storm sewers, surface run-off, street wash waters, or drainage. Inflow does not include, and is distinguished from, infiltration.
I/I	The total quantity of water from both infiltration and inflow without distinguishing the source.

I/I Analysis	An engineering and if appropriate, an economic analysis demonstrating possible excessive or non-excessive I/I.
Excessive I/I	The quantities of I/I which can be economically eliminated from a sewer system by rehabilitation, as determined by cost-effectiveness analysis that compares the costs for correcting the I/I condition with the total cost for transportation and treatment of the I/I.
Combined Sewer	A sewer intended to serve as a sanitary sewer and a storm sewer, or as an industrial sewer and storm sewer.
SSES	A systematic examination of the tributary sewer systems or subsections of the tributary sewer systems that have demonstrated possibly excessive I/I. The examination will determine the location, flow rate and cost of correction for each definable element of the total I/I problem.
Storm Sewer	A sewer intended to carry only storm waters, surface run-off, street wash waters, and drainage.
Sanitary Sewer	A sewer intended to carry only sanitary and industrial wastewaters from residences, commercial buildings, industrial plants and institutions.
Rehabilitation	Repair work on sewer lines, manhole and other sewer system appurtenances that have been determined to contain excessive I/I. The repair work may involve grouting of sewer pipe joints or defects, sewer pipe relining, inversion an desliping, sewer pipe replacement and various repairs or replacement of other sewer system appurtenances.
Preparatory Cleaning	An activity of the sewer system evaluation survey. This activity involves adequate cleaning of sewer lines prior to inspection. These sewers were previously identified as potential sections of excessive I/I.
Internal Inspection	An activity of thesewer system evaluation survey. This activity involves inspecting sewer lines that have previously been cleaned. Inspection may be accomplished by physical, photographic and/or TV methods.
Physical Survey	An activity of the sewer system evaluation survey. This activity involves determining specific flow characteristics, groundwater levels and physical condition of the sewer system that had previously been determined to certain possibly excessive I/I.
Rainfall Simulation	The activity of the sewer system evaluation survey. This activity involves determining the impact of rainfall and/or run-off on the sewer system. Rainfall simulation may include dyed water or water flooding of storm sewer sections, ponding areas, stream sections and ditches. In addition, other techniques such as smoke testing and water sprinkling may be utilized.

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