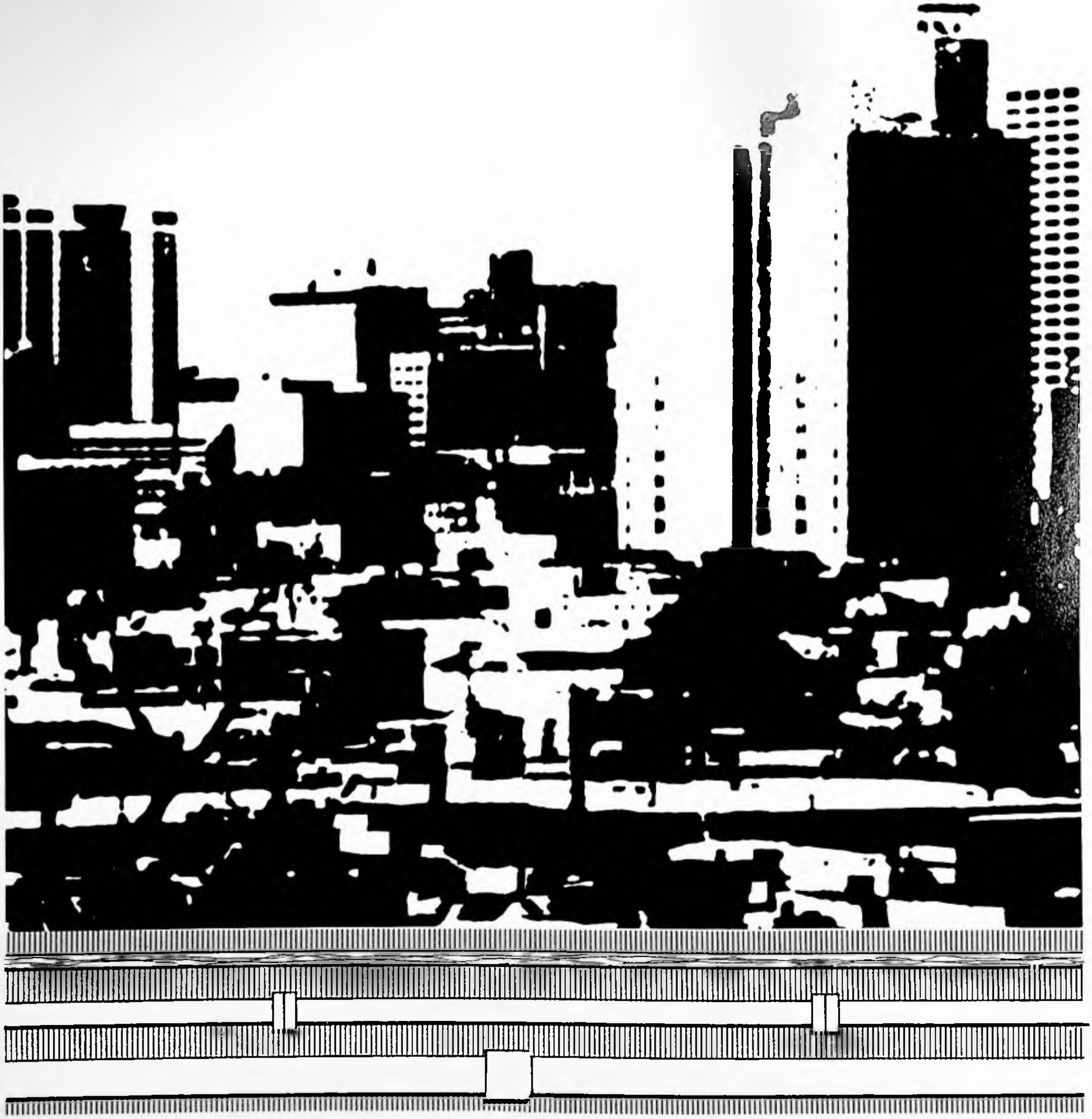
U.S. Department of Housing and Urban Development
Office of Policy Development and Research

Utility Infrastructure Rehabilitation



DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
WASHINGTON, D.C. 20410

ASSISTANT SECRETARY FOR
POLICY DEVELOPMENT AND RESEARCH

IN REPLY REFER TO:

Communities all across the country are bringing new life and economic vitality to their older commercial and residential areas through various redevelopment programs. A key element in any redevelopment effort is the availability of adequate utility services; commercial, industrial, and even residential investors demand such services as a condition for making these investments. But the fact is that many of these systems in our older cities are 50 to 100 years old, or older, and no longer can be depended upon to support the businesses and residents of the city.

The cost of replacing these old, worn-out systems is high, beyond the resources of many communities. Replacement, however, is not the only choice; many of these systems can be rehabilitated at 30 to 70 percent of the cost of replacement. The problem for many communities has been to learn about the new techniques and materials available for utility infrastructure rehabilitation.

This manual has been developed by HUD's Office of Policy Development and Research to provide this information. The manual is based on surveys of a number of city programs, interviews with national experts in the field, and information from major manufacturers of utility system components. It presents a comprehensive compendium of information on utility rehabilitation techniques for use by community officials faced with a choice between replacement, repair, or resignation to continuing deterioration.

I urge the leaders of every community concerned about deteriorating underground utility systems to review the information in this manual. I believe you will find it useful, and its use can save significant tax dollars.

Sincerely,

June Q. Koch, Ph.D.

Utility Infrastructure Rehabilitation

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For:

U.S. Department of Housing and Urban Development
Office of Policy Development and Research
Building Technology Division

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DISCLAIMER

CHAPTER 1

Public agencies planning the redevelopment of existing urban areas must consider the condition of existing public and private utility services provided to these areas. These services frequently utilize seriously deteriorated facilities which are inadequate to support the redeveloped area.

This manual provides information on a number of new techniques for rehabilitating underground utility systems or improving the management of private utility services. It is intended to assist public works officials to plan rehabilitation projects, to develop realistic project budgets, and to suggest alternative technical approaches for consideration in the design process.

It is not a complete design manual; public works officials and design engineers will need to obtain additional information from individual manufacturers or system promoters in order to develop specific designs for rehabilitation projects. But the information in this manual will assist in deciding whether to rehabilitate a system, to repair it as is, or to replace it, based on the probable costs of the work and the consequences of future system failure.

The principal emphasis is on inspection, evaluation, and rehabilitation or replacement of underground piping systems for water supply and for sanitary and stormwater sewerage, since these are most commonly the direct responsibility of the public official. However, since the public official must also be concerned with utility services often provided by private organizations, such as natural gas, electricity, and solid waste collection, these systems are also discussed in the manual.

BACKGROUND

In a number of our oldest cities, water distribution and sewage collection systems date back over 100 years. Some of the original brick sewers built in the 19th century are still in service. Systems of clay pipes with open joints which were constructed at the turn of the century are often still being used.

All structures wear out in time; pipelines are no exception. Because pipelines are underground, signs of wear are not readily apparent until there is a failure. Failures start with cracking, lateral deflection, crown sag, offset joints, deteriorated mortar, and exposed reinforcing. Most of the community sees only the inevitable results of prolonged neglect, such as cracked pavement, collapsed streets, backed-up sewers, local flooding, or low water pressure. Figures 1-1 and 1-2 are examples of the consequences of a failed sewer pipe and a water pipe clogged with scale.

The poor physical condition or limited capacity of the existing utility infrastructure in areas subject to redevelopment can discourage private investment. To encourage redevelopment by private enterprise, the redevelopment agency must offer adequate utility service.

Replacement of underground utilities is very expensive. On the other hand, available pipeline rehabilitation techniques can restore capacity and structural reliability for 30 to 70 percent of the replacement costs.

The situation with electrical utilities is somewhat different, since these systems are frequently commercial for-profit companies or—if municipally owned—managed as separate for-profit organizations. In either case, they usually approach rehabilitation of an aging system with frequent power outages from an economic investment standpoint, balancing effective maintenance with a planned replacement program.

SCOPE

Utility infrastructure elements covered in this manual include:

- Water distribution piping and equipment.
- Sanitary sewers.
- Pumping stations.
- Storm drains.
- Gas distribution piping.
- Electric distribution systems.
- Solid waste collection and processing.

Rehabilitation of water and wastewater treatment plants, bridges, and roads are not included.

ORGANIZATION

The manual is organized to assist those planning to implement rehabilitation programs. Chapters 1 through 4, relate to deciding what to do, while Chapters 5 through 7 describe the techniques available and their costs. The contents and orientation of each chapter are as follows:

Figure 1-1 Newspaper Carrier's car lies in 30-foot-deep hole caused by leaking sewer. Courtesy Associated Press World Wide Photo

Chapter 1 outlines the purpose and scope of the manual.

Figure 1-2 Scale Forming in Water Pipes Reduces Capacity

Chapter 2 summarizes the evaluation process and the structure of a rehabilitation program.

Chapter 3 presents techniques to evaluate the physical condition of each utility system type. These include leak detection methods for water pipelines, inspection methods for sewers, and methods to analyze gas system leaks, electrical system reliability, and adequacy of solid waste handling.

Chapter 4 involves deciding whether rehabilitation or replacement is the best course of action. Issues discussed include life cycle costing, the consequences of failure, financing methods, and techniques to evaluate the effectiveness of the rehabilitation program over time.

Chapter 5 covers pipeline system rehabilitation methods applicable to water, gas, sanitary sewers, and storm drains. Included are excavation and replacement, chemical grouting, cement mortar lining, reinforced shotcrete, pipe insertion (slip lining), resin-impregnated fabric, other pipeline methods, house laterals, manholes, and pumping stations.

Chapter 6 provides city engineers and consultants basic information on electrical system rehabilitation. Topics covered include: present power distribution practices, factors relating to the decision for underground distribution lines, and considerations in transmission line routing and substation upgrading.

Chapter 7 describes methods to improve solid waste management activity, including better storage and collection, improved litter control, and modified institutional arrangements.

Appendix A is a sewer pipeline rehabilitation cost estimating example.

This chapter describes the utility rehabilitation process and provides detailed suggestions on how to organize a rehabilitation program.

OVERVIEW OF THE UTILITY REHABILITATION PROCESS

The process of rehabilitating a utility system logically falls into four phases as shown on Figure 2-1.

- Phase I - Organize the Program
- Phase II - Assess Physical and Capacity Conditions
- Phase III - Develop the Plan
- Phase IV - Implement the Plan

Phase I--Organize the Program

Rehabilitation programs are large undertakings. Program goals and resources must be determined, based on future demands on the utility due to redevelopment or new growth and on failure history data.

Phase II--Assess Physical and Capacity Conditions

This is perhaps the most important and time-consuming step. It involves deciding what needs to be done now and what can be scheduled for a later date. It is the subject of Chapter 3.

Physical surveys are used to indicate the need for a rehabilitation/replacement project before a crisis develops. Techniques include sophisticated leak detection equipment, field pipe flow tests and television or walk-through inspections.

Capacity evaluation techniques are readily available. Because utilities usually function as a system, mathematical computer models of distribution/collection systems can assist in defining the need for increased capacity. Decisions about rehabilitation must be based upon cost, the probable reliability of future service, and the risks and hazards introduced by the continuing use of existing facilities.

Results of the physical survey can be used to determine the seriousness of the problem. Utility segments in danger of imminent failure, and where failure will have serious consequences, can be given a high priority, whereas those with lesser problems can be given a low priority.

Phase III--Develop the Plan

Depending on the situation, there are, at most, four alternatives:

1. No new action required (capacity, physical condition, and reliability are adequate). Continue to maintain and repair as necessary.
2. Rehabilitate (by one of the various applicable techniques).
3. Replace (possibly with a different capacity pipeline, larger or smaller).
4. Parallel (to increase capacity and reliability).

Which of these will apply depends upon future capacity needs and the physical condition of the existing systems.

The plan must focus on taking care of the most serious problems first.

Life-cycle cost analysis is the preferred method to identify the least costly alternative. This accounts for reduced or increased maintenance costs, as well as the capital cost and useful life of different solutions. Chapter 4 addresses these issues.

Phase IV--Implement the Plan

The availability of capital funds for financing will control what gets done and when. Alternative, adequate financing methods, such as privatization, may help encourage more rehabilitation.

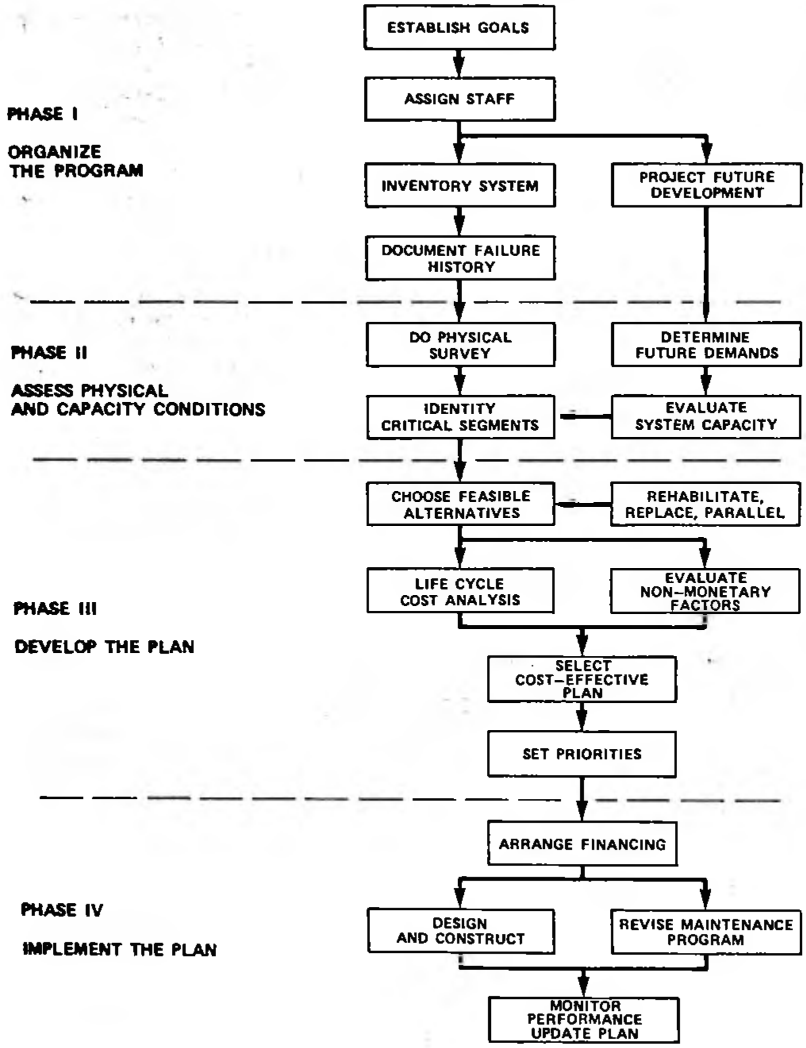
Once a rehabilitation program is set up and the first few projects completed, simplification to the procedure outlined on Figure 2-1 may be readily apparent. Specific guidance is offered on these topics in Chapter 4.

ORGANIZING FOR UTILITY REHABILITATION

The process of getting organized is shown on Figure 2-2. The utility owner must deal with the issues of:

- Program goals.
- Appropriate in-house staffing.
- Appropriate use of consultants.
- Adequate inventory of the system.
- Documented failure history.

Figure 2-1 . Rehabilitation Decision-Making Process



- Systematic design of the rehabilitation program.
- Adequate system maintenance.
- Planned future development or redevelopment.
- The proper roles, relationships, and responsibilities of agencies such as the Public Utilities Commission, the utility owner, and other public agencies.

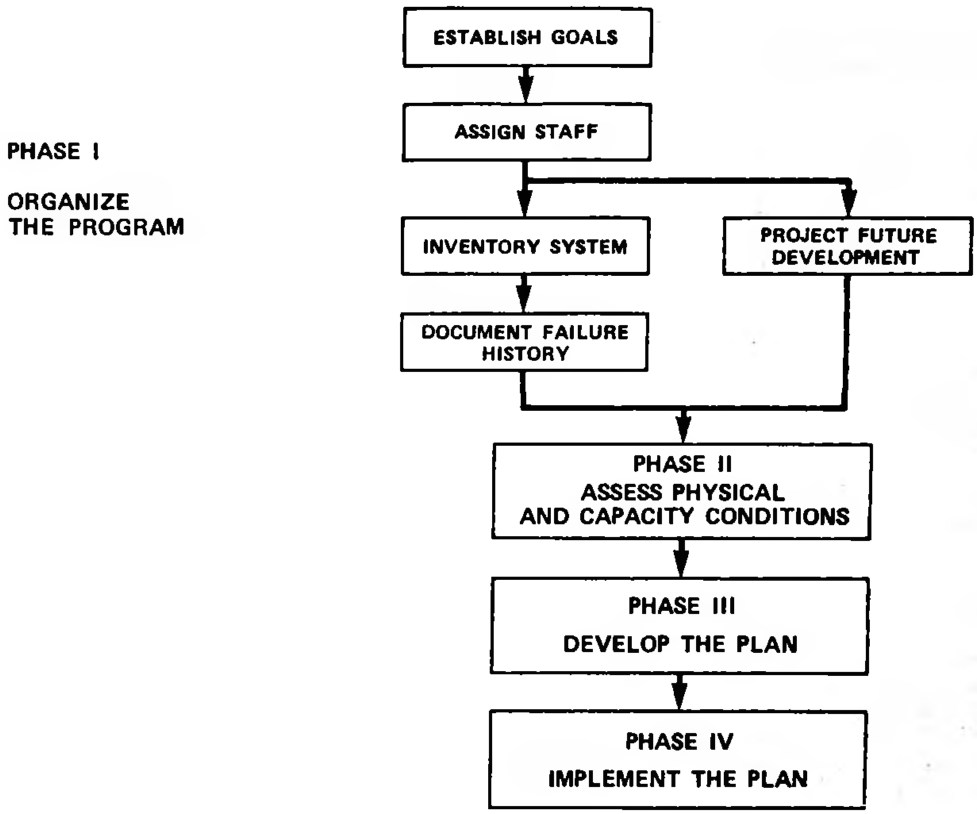
The first five of these issues are matters to be resolved in-house by the utility owner. The last two issues must be resolved cooperatively by the utility owner and other public agencies.

Program Goals

Goals should be initially established to get the program moving and then refined after more is learned about the physical condition and costs for rehabilitation. Typical goals to get started might be:

- Meet fire flow requirements everywhere in the water system.
- Reduce frequency of pipe breaks.
- Reduce sewer system infiltration/inflow.
- Reduce customer complaints (sewer back-ups, low water pressure).
- Reduce gas system losses.
- Reduce power outages.
- Reduce litter.

Figure 2-2 Phase I of the Rehabilitation Process



The reductions should be specified as a percent relative to existing conditions.

In-House Staffing

An effective rehabilitation program requires a technically-competent core staff of management, design, construction, and maintenance personnel. Since the governing board of the community may consist primarily of lay persons who have little direct technical knowledge, it is incumbent upon the senior management official of the utility department to clearly communicate the benefits, needs, costs, and other factors involved in carrying out a rehabilitation program. This must include consideration of qualified personnel to direct the program.

Effective Use of Consultants

Consultants may be used to fill gaps in in-house expertise and/or provide a work force needed to perform one-of-a-kind and occasional project work which cannot efficiently or effectively be staffed in-house.

Inventory of Existing System

An adequate inventory of the existing system is essential to an organized rehabilitation program. The inventory information should include:

- As-built drawings and construction inspection reports.
- Current maps of the system.
- Complete inspection, maintenance, and repair records.
- Complete records of service complaints.
- Interview with key maintenance and operations personnel.

As-Built Drawings and Construction Inspection Reports. As-built drawings of the system can provide useful information on depths, invert slopes, and conduit sizes, shapes, and junctions. However, many system changes may have occurred since the original construction, therefore, as-built drawings must be field-checked.

Written records of construction inspection also can provide valuable insights to the reasons for, and mechanisms of, structural failure.

System Maps. Most utility agencies have some form of system mapping. Adequate mapping includes:

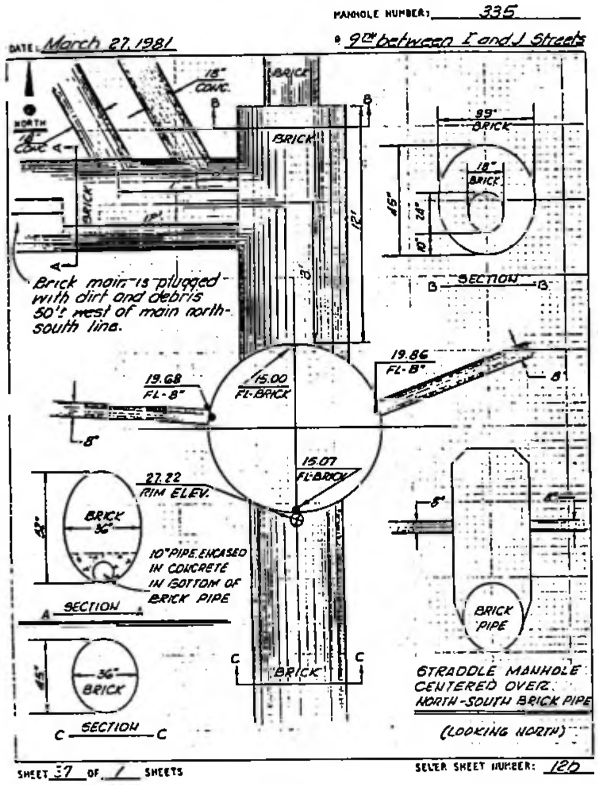
- Alignment positions referenced to curb lines or other reasonably permanent features;
- Ground surface elevations at key points;
- Conduit diameter and elevations (both invert and crown in gravity pipes) which have been verified by field surveys referenced to a recognized and permanent datum;
- Connection locations and size;
- Conduit shapes where pipes are of noncircular cross section (include key dimensions from field measurements).

The above information can be presented in a combination of surface maps and junction diagrams. An example of the junction diagrams prepared in recent pipeline rehabilitation planning by the City of Sacramento, California, is shown on Figure 2-3.

Document Failure History. Inspection, maintenance, repair, and complaint records are valuable in pinpointing trouble areas in the system. They are used in rehabilitation program planning to prioritize the detailed field investigations by subareas of the total service area (Phase II).

- Maintenance records should show the location and dates of all maintenance activities together with a summary of actions which were performed and costs incurred.

Figure 2-3 Example of Junction Diagrams Prepared in Rehabilitation Studies of Sacramento, California



- Inspection records should show the location and dates of inspections, together with the reasons for the inspection and a summary of the inspection findings. The records should also include any recommended further action. Photographic or video-tape documentation of inspections is desirable and should be preserved for future reference.
- Complaint records should document the locations and dates of complaints and show what action was taken or recommended. These records are typically keyed to inspection records.

- Repair records should provide complete information on the date, location, nature, and origin of the repair problem and the means by which repair was accomplished. The records should include an accurate accounting of all labor and materials costs. Frequency of repairs is useful in identifying utility segments that need rehabilitation.

Organizing the Inventory Information: A number of techniques exist for organizing system inventory information. The selection of a particular method will depend on a number of factors, including resources available. Decisions to be made include setting standard sizes for drawings, standard scales for various drawing elements, the number and size of service zones, and the method filing and organizing these details.

Historically, this type of information has been organized and filed manually in card files, drawing files, and ledgers. More recently, the advent of the small "personal" computer work station and computer-aided design (CAD) methods has let to much more efficient storage, retrieval, and data handling methods. A full discussion of CAD and computerized data base management systems is beyond the scope of this manual.

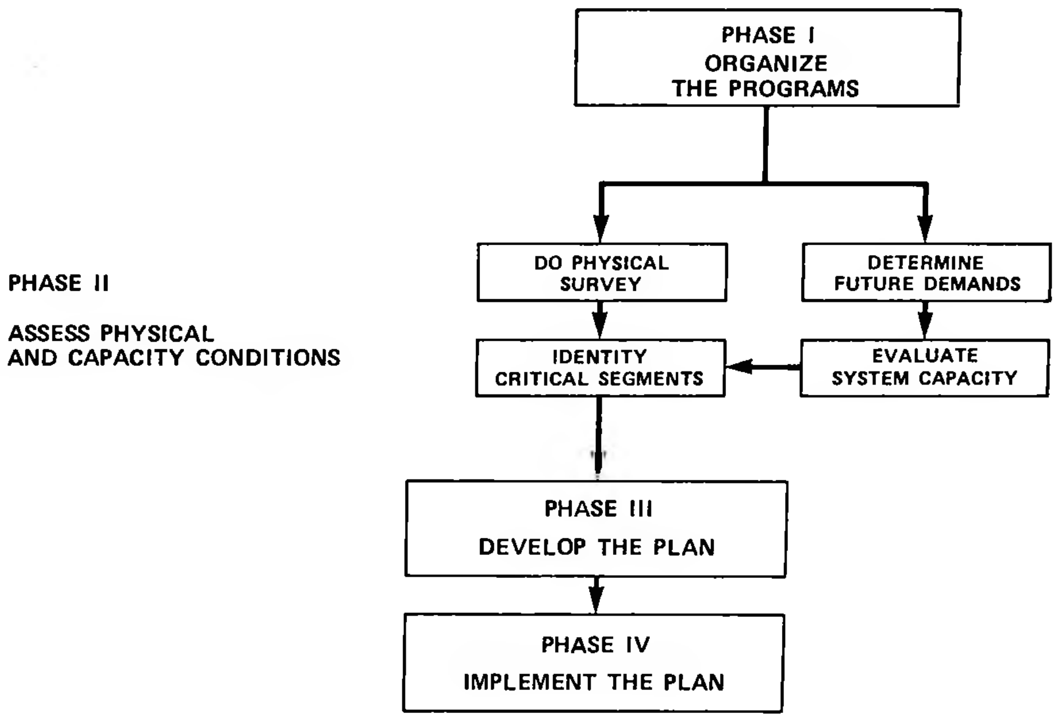
Project Future Conditions

The local planning and redevelopment agencies can provide demographic and land use projections. Chapter 3 discusses how these can be used to determine future loads/demands to be placed on the utility system. In planning utility rehabilitation, at least a 20-year time horizon is needed. In some cases, it may be appropriate to use ultimate development conditions. The format and detail of the projections are dependent on the capacity evaluation technique selected. Chapter 3 summarizes the available techniques.

CHAPTER 3

Phase II of the utility rehabilitation process, illustrated on Figure 3-1, involves the use of methods described in this chapter to indicate the physical and capacity condition of utility systems and provide information needed to decide when to rehabilitate or replace a system component.

Figure 3-1 Phase II of the Rehabilitation Process



1. Physical Conditions Assessment
   a. Plan the inspection program.
   b. Conduct facility inspections.
   c. Use the inspection results to evaluate structural conditions and relative severity of problems.
   d. Identify system reaches needing rehabilitation.
2. Capacity Assessment
   a. Assemble system model to be used in capacity evaluations (Note: complex systems nearly always warrant mathematical modeling. Capacities of simple systems can be hand calculated.)
   b. Verify the system model against field conditions.
   c. Use the verified model to assess capacity performance under various service assumptions (i.e., existing and projected demands, design storm conditions, sanitary sewage flows, etc.).
   d. Identify locations and causes of capacity deficiencies and surpluses.

WATER PIPELINES

Water pipelines fail because they eventually leak, break, or become heavily tuberculated so that flow is greatly restricted. Various hydrant tests can be made to check hydraulic performance. The frequency of main breaks and the amount of leakage are also measures of the condition of the distribution system. Leak detection surveys and spot repairs are a common method to reduce water loss. Cleaning and lining (see Chapter 5) are among the techniques used to rehabilitate tuberculated pipes.

District heating with hot water or steam is handled in this document as a special category of water pipelines. Techniques to inspect and evaluate hot water pipes are much the same as for cold water pipes. Hot water district heating is not commonplace in this country. Applications are usually limited to college campuses and military bases. Steam distribution systems are more prevalent. Thermographic surveys using infrared video cameras have been perfected and a number of companies offer this service. A description of this technique is given at the end of the water pipeline section.

Loss of Hydraulic Capacity

New pipes are generally smooth inside, but they become rougher over time because layers of scale or corrosion products form in them. New pipes often have a high hydraulic capacity but, as pipes age, this can drop to one-half of its original value or less, requiring more pumping to deliver the same amount of water. Without increased pumping, low pressures in the distribution system result, especially during high-use periods. This is a sign that the pipes may need to be cleaned and lined. Tests can be made to identify which pipe sections to do first. These same tests are useful in calibrating water distribution system models.

Hydrant Flow Test. To measure the discharge from a fire hydrant, a pitot gage is inserted into the flow. The pitot gage measures velocity head in pounds per square inch (psi) which can be converted to discharge using:

$$Q_T = 29.83\ cd^2\ (P)^{0.5} \qquad (3\text{-}1)$$

where

Q_T = hydrant discharge, gallons per minute (gpm)

c = discharge coefficient

d = outlet diameter, inches

P = pressure reading from pitot gage, psi

c is usually 0.90 for standard 2.5-inch-diameter hydrant outlets. The constant 29.83 applies only when English units are used.

Fire Flow Tests. Fire flow tests are conducted to determine the adequacy of water distribution systems for fire fighting.[1,2] The results are used for establishing fire insurance ratings and can also be used to assist in calibration of water distribution system models. A typical test is begun by attaching a pressure gage to a hydrant (called the residual hydrant) and recording the pressure (called the static pressure, P_S) One or more nearby hydrants are then opened, and the total flow (Q_T) is recorded while the pressure (P_T) at the residual hydrant is again recorded (once the initial pressure fluctuations due to hydraulic transient effects are damped out). The flow (Q_R) that can be delivered at a given pressure (P_R), usually taken at 20 psi, can be estimated:

$$Q_R = Q_T \left\{ \frac{P_S - P_R}{P_S - P_T} \right\}^{0.54} \qquad (3\text{-}2)$$

where

Q_R = flow delivered at pressure P_R, gpm

Q_T = total flow during test, gpm

P_S = pressure at static condition, psi

P_R = pressure during fire condition, psi

P_T = pressure during test, psi

Determine C-Factor. Head losses in mains are usually calculated by either the Hazen-Williams or Darcy-Weisbach equation. For the more commonly used Hazen-Williams equation, it is necessary to know the Hazen-Williams C-factor. Values of these factors for new pipe can be found in the literature. C-factors often decline with age and are an indication of the condition of the pipe. The lower it is, the more corroded or tuberculated the pipe. Figure 3-2 is an example of a tuberculated pipe with a low C-factor. The procedure to determine the C-factor of an existing pipe, given velocity and head loss data, is described below.[3]

Average velocity can be determined accurately by inserting a pitot static gage into the pipe and converting the pressure difference into velocity. This requires excavating the top of the pipe and installing a corporation stop. A somewhat simpler, but less accurate, technique is to open a hydrant at the end of the pipe, determine the flow rate, and then calculate velocity. If a calibrated meter is located at either end of the pipe, the flow can be determined.

The hydraulic gradient at the the beginning and end of the pipe can be calculated from measured pressures. Given the average velocity and hydraulic gradient, the C-factor can be calculated from:

$$C = \frac{8.71\ V}{D^{0.63} S^{0.54}} \qquad (3\text{-}3)$$

where

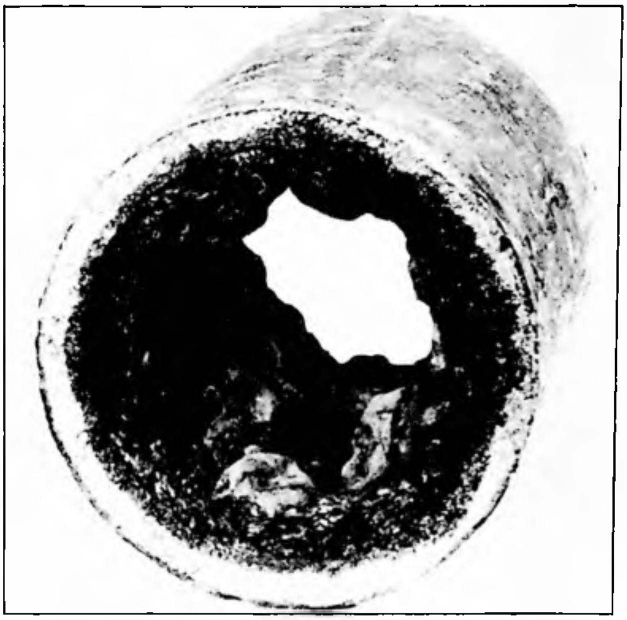
C = Hazen-Williams C-factor

V = average velocity, ft/sec

D = pipe diameter, in.

S = hydraulic gradient, ft/ft

Figure 3-2 Tuberculated Water Pipe With Low C-Factor. Courtesy Rodding-Cleaning Services Inc.



Distribution System Losses

The parameter used by most water systems to quantify distribution system operating efficiency is the percentage of unaccounted-for water (UAW). UAW is the difference between the amount of water produced or purchased and the amount of water sold to customers. This amount divided by water produced multiplied by 100 is the percentage of UAW.

Some sources of UAW are authorized by the utility as being beneficial and necessary.

These include:

1. Street cleaning
2. Sewer and water main flushing
3. Park watering
4. Firefighting
5. Construction water
6. Public building use (unmetered)

Unauthorized UAW is all other sources including:

1. Transmission and distribution system leakage
2. Reservoir overflow, leakage, or evaporation
3. Meter error

Figure 3-3 shows a water leak on a service lateral and Figure 3-4 shows the leak repaired.

Figure 3-3 Service Lateral Leak With Sump. Courtesy California Department of Water Resources.

<u>National Averages</u>. The UAW sources listed above commonly occur in most cities. Therefore, all water utilities have some UAW. The 1981 American Water Works Association (AWWA) Water Utility Operating Data Report[4] contains estimates of total UAW for 1,400 water utilities serving 104 million people in the total United States. These statistics are useful to a utility that wants to compare itself to national or regional averages. The total U.S. UAW is reported to be 11.4 percent. States with mostly new water distribution systems, and presumably less leakage, such as Arizona, reported 6.3 percent UAW; whereas New Jersey, a state with older systems, reported 14.9 percent. California reported 9.5 percent.

Figure 3-4 Repair of Service Lateral Leak. Courtesy California Department of Water Resources.

Authorized UAW is often found to be 3 to 5 percent. Unauthorized UAW varies considerably from city to city. Rarely is it below 2 to 3 percent. In a few cities, it is an order of magnitude higher.

Quantifying UAW. If a preliminary estimate of total UAW indicates that it is high, then the following steps can be taken to quantify UAW and to reduce it:

1. Check water supply master meters for accuracy. Verify that they are installed according to manufacturer's recommendation. These large meters need to be periodically calibrated.

2. Check larger industrial or commercial water meters, preferably every year or two.

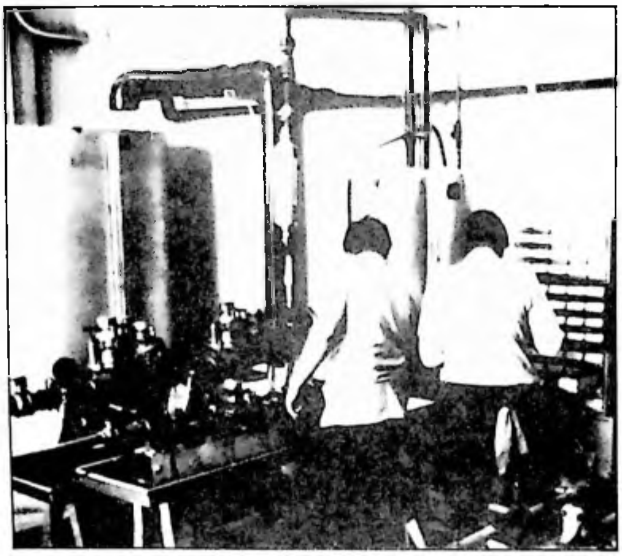
3. If domestic meters have been in service more than 8 to 10 years they should be routinely inspected. Stopped meters can be detected by a computerized billing system. A random sample of older meters can be replaced and the old ones checked for accuracy. Older meters start to fail by under-registering low flows. The AWWA publishes standards for meter accuracy. Larger cities often have their own meter testing and repair shop (see Figure 3-5). Smaller cities can use commercial shops.

4. Construction water and water used for street cleaning can be metered.

5. Public buildings, parks, schools, etc., can be metered or their use estimated.

6. If distribution system leakage is isolated from other sources and found to be high, then the cost-effectiveness analysis of a leak detection survey and repair program should be determined. This is discussed in the next section.

Figure 3-5 Meter Testing and Repair Shop. Courtesy California Department of Water Resources.



Leak Detection and Repair

All water distribution systems leak. Some leak more than others. Many leaks are easy to find because water appears on the surface. Water agencies usually become quickly aware of these types of leaks and repair them rapidly. A large number of leaks do not surface. Instead they soak into the ground, flow into streams, enter sewer drains, or otherwise disappear. This section discusses techniques for detecting this type of leakage so that it can be repaired.

Leak-Detection Methods. Before starting a leak-detection program, the water agency should conduct a water audit. The audit will determine the extent of leakage and, in some cases, which part of the system has the most leaks.

A leak-detection and repair program can range from a one-time effort, concentrating on known problem areas, to a continuous program conducted by full-time staff. Conducting a cost benefit analysis, described later in this section, will help decide the appropriate level of effort.

Leak-detection equipment is used for two different purposes:

- Surveys to detect possible leaks and approximate locations.
- Pinpointing leaks to establish precise locations so field maintenance crews can make the necessary repairs.

Available equipment for surveys and pinpointing is discussed in the next section.

Available Equipment. Equipment currently used by water agencies for leak-detection surveys is predominantly the sonic type (made by Health Son-i-Kit, Fisher XLT-20, and others). This type consists of an accoustical pickup and an electronic amplifier with an intensity meter and controls for volume, frequency range, and filtering. Listening is done through headphones; various accessories are available for surface monitoring above the pipe and for direct contact with meters, valves, hydrants, and the pipe itself. Figure 3-6 shows this type of equipment in use.

Leak detectors that use tracer gases require dewatering of pipelines and are considered impractical for most water system leak detection. All significant leaks with flows ranging from a fraction of a gallon per minute or more can be found with sonic equipment. The cost of sonic equipment varies from less than $500 to about $2,600.

Highly sophisticated leak-locating equipment is also available (Detect-a-Leak/Locate-a-Leak by Fluid Conservation Systems, Leak Noise Correlator by Palmer EaE, and others). The equipment varies but generally includes combinations of oscilloscopes, microprocessors, and high-quality accelerometers and amplifiers to detect and pinpoint leaks. The equipment is usually mounted in a van. This type of equipment has superior accuracy in locating leaks. Agencies like East Bay Municipal Utility District in Oakland, California, use this equipment only for pinpointing after a leak in the vicinity has been detected by sonic equipment. They have found this method to be faster than using the sophisticated equipment for both surveying and pinpointing. The more sophisticated equipment is comparatively expensive. A complete installation, including the van, costs between $25,000 and $45,000. Figures 3-7 and 3-8 shows this type of equipment in use.

Figure 3-6 Sonic Leak Detection Equipment in Use. Courtesy of East Bay Municipal Utility District

Staffing. Leak-detection crews need to be well trained. Some agencies prefer to train existing staff members to perform the leak-detection service so that they will have crews available as they are needed. Crews need to have excellent hearing and to be able to recognize the noise made by a leak, as differentiated from other street noise.

Some agencies prefer to contract for leak-detection services, because of specialized equipment and personnel required, and then make their own repairs. A number of consultants and leak-detector manufacturers offer leak-detection services. Hiring a consulting firm offers the advantage of not having to invest in equipment, training, etc., and the cost may be reasonable compared to establishing a full program. Large agencies often have their own crew(s) and small agencies usually decide to use consultants.

Figure 3-7 Van-Mounted Leak Pinpointing Unit. Courtesy of California Department of Water Resources

Figure 3-8 Electronic Leak Pinpointing Equipment in Use. Courtesy of East Bay Municipal Utility District

Examples of Successful Programs. There are a number of agencies with ongoing leak-detection programs, including:

- East Bay Municipal Utility District, Oakland, California.
- Los Angeles Department of Water and Power, Los Angeles, California.
- Denver Water Department, Denver, Colorado.
- New York City Water Department, New York, New York.
- Philadelphia Water Department.

Costs. As stated above, leak-detection equipment costs currently range from $500 to $45,000. The approximate cost for a full-time, two-person survey crew and truck is $250 per day. Leak repair cost varies depending upon the type and location of the leak. Small, easily accessible leaks, such as those at meter boxes, cost the utility about $20 to $50 each to repair when a number are done at one time by utility forces. Larger leaks involving excavation and pavement replacement cost an average $500 to $600 on smaller mains (4 inches or less) and up to several thousands of dollars on large pipelines.[5]

Evaluating Benefits and Costs. Leak detection and repair is often a very cost-effective element for water system maintenance and rehabilitation. If small leaks are allowed to go unrepaired and a water main breaks, then the sections of the water main may have to be replaced at a higher cost. In addition, substantial secondary damage can result from a large leak.

The decision to start a leak-detection and repair program is usually based upon the ratio of benefits to costs (B/C ratio). If the B/C ratio is greater than 1.0, the decision should be to proceed. If it is less than 1.0, but the water agency needs to conserve water for whatever reason, then it may still be appropriate to go ahead.

An example calculation sheet developed by the Los Angeles Department of Water and Power is shown on Figure 3-9. Guidelines on estimating benefits and costs are given in a paper by Kingston.[6]

Analysis of Pipe Breaks

Pipe breaks are defined herein to be major pipe ruptures as opposed to joint leaks or service leaks. Pipe breaks usually result from external causes such as contact with other structures, improper bedding during installation, expansive or corrosive soils, frost loads, brittle failure, live loads, and accidents. The rate of breakage often, but not always, increases with the age of the pipe.

Typical Frequency of Pipe Breaks. A report prepared by the U.S. Army Engineer District, New York, on the water distribution system (underground facilities) in Manhattan contains an excellent general discussion on causes and types of main breaks in cast iron pipes.[7] The report contains a table taken from an earlier study of breaks in New York that showed the wide variation in break rates between cities. The rates varied from 1.29 breaks per mile per year in Houston, Texas, to 0.012 breaks per mile per year in

Seattle, Washington.[8] In Binghamton, New York, a rate of 0.111 breaks per mile per year over the last decade was found.[9] The Manhattan report study team found that the mains were not wearing out with age. The age of the pipe was only a minor consideration in the main replacement program developed in the report. Location and prior leakage, which eroded the bedding, were the primary break-causing factors.

Figure 3-9 Example Leak Detection Program Benefit - Cost Calculation Fill-In Sheet

Benefits	
Value of water saved—system	$_____/year
Value of water saved—customer	_____
Value of deferred construction of new supply works	_____
Value of property damage prevention	_____
Value of reduced legal fees and court costs	_____
Value of improved meter reading	_____
Value of improved public relations	_____
Value of savings in leak repair crew time	_____
Value of reduction in time-of-day power charges	_____
Grand Total Benefits (A)	$_____/year
Costs	
Labor and equipment costs	$_____/year
Leak repair costs	_____
Grand Total Costs (B)	$_____/year
Benefit-Cost Ratio A/B =	$_____

Comparison of local pipe break histories with these rates, along with an analysis of why the breaks are occurring, will help assess the physical condition of the distribution system.

Chapter 4 contains information on how to interpret pipe break data to determine whether it is economical to replace the pipe or to continue to repair it when it breaks.

Assessing System Capacity Using Water Distribution System Models

Water systems, and portions thereof, function as a network and are analyzed using mathematical models. Models are used to plan system enlargements, test existing systems under unusual conditions, evaluate system operation, and more recently, evaluate system performance after rehabilitation. Almost every large water distribution system has had some type of model developed for it. There are many models available and the choice is usually made on model features and convenience of use. Thus, the real effort in modeling is not developing the computer program but rather, developing the data and existing program needs and calibrating it so that it simulates the "real world".

The following is needed to use a model:

1. Accurate map of existing system;

2. Survey of present physical condition;

3. Projection of future demands—size and location;

4. Adequate time and budget to use the model;

5. Experienced staff or consultants to do the work;

The following discussion highlights the capability of some of the commonly available models and provides general guidelines on their use. Further information on applications and how to run the model can be found in technical papers and users' manuals.

Selecting the Right Model. The first step in modeling the system is to define the project objectives and then to select a model(s). Generally, the objectives are to either simulate the system under design (fire flow) conditions (steady-state solution desired), or during real-time operation (unsteady-state solution desired). Selection is usually based upon model features, ease of use, speed, and cost.

Table 3-1 lists some models currently widely used by water agencies and their consultants. The models have been adapted to a variety of computers. Storage requirements can be relatively large for complex systems with many nodes or pipes. The steady-state models solve for water pressure at pipe junctions and pipe flows under design flow conditions. Design flows are usually specified as fire flows plus average or maximum day demands. For example, it may be desired to simulate water system pressures if a fire, requiring a flow of 2,500 gallons per minute (gpm), occurs on the maximum day in a certain area. Programs such as UKNETWRK can also simulate reservoir drawdowns over extended periods of time, and effects of booster pumps.

Table 3-1 Some Available Water Distribution System Models

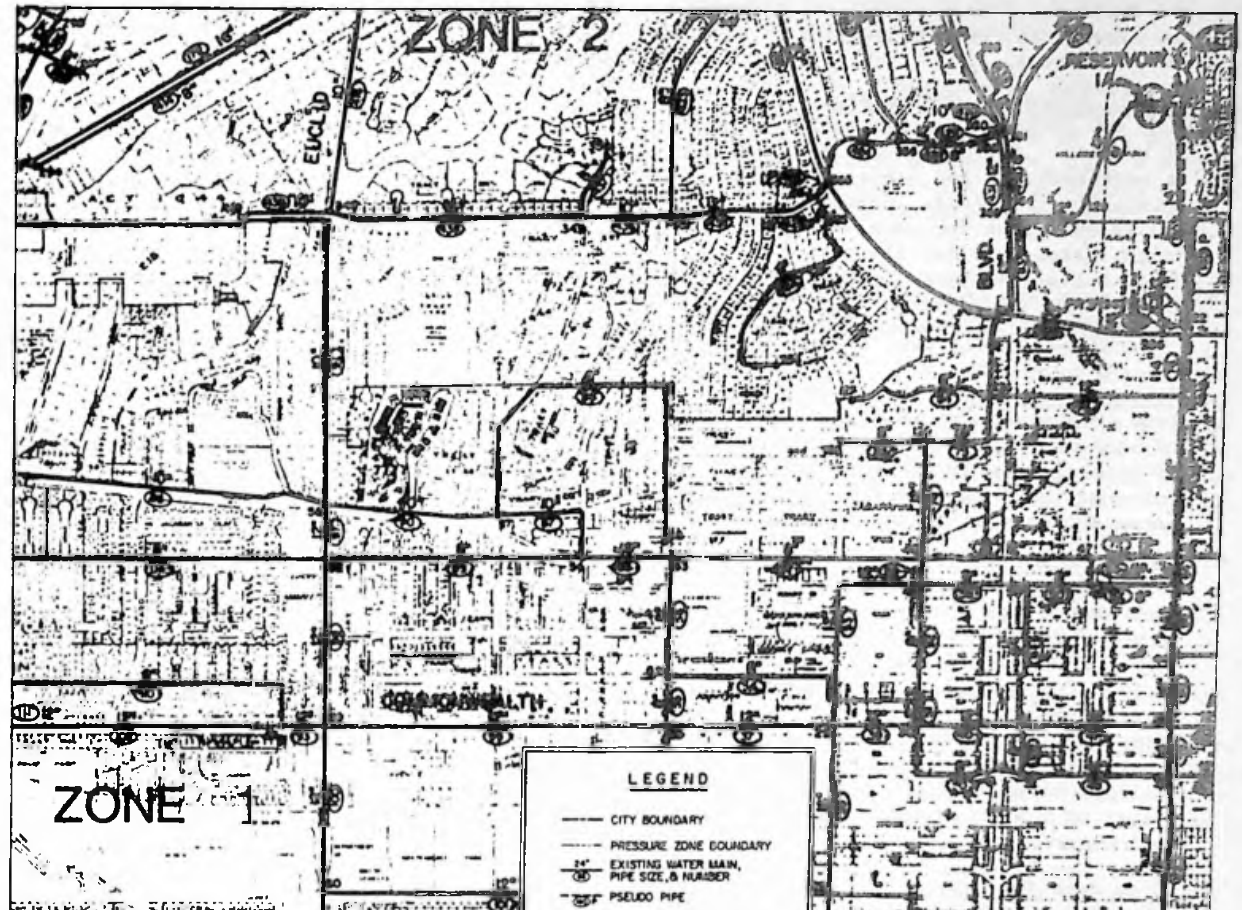
Model name	Requirements	Function	Available from
UKNETWRK	Time-sharing terminal or large computer.	Determine steady-state and extended period flows and pressures at successive time steps.	Don J. Wood Department Civil Engineering University of Kentucky Lexington, Kentucky 40506
MAPS	Access to Corps of Engineers computer system	Determine steady-state flows and pressures at nodes.	Thomas M. Walski U.S. Army Engineers Waterways Experiment Station Post Office Box 631 Vicksburg, Mississippi 39180
FAAST	Time-sharing terminal	Determine steady-state flows and pressures at nodes.	W. R. Vickroy MCAUTO Department K502 Box 516 St. Louis, Missouri 63166
LIQSS	IBM PC with 512K and two disk drives	Determine steady-state flows and pressures at up to 1,000 nodes.	Stoner Associates Post Office Box 86 Carlisle, Pennsylvania 17013
NODES	IBM PC/XT with PC-DOS, 128K and one disk drive	Steady-state analysis of networks up to 600 pipes.	SYSTEK, Inc. Post Office Drawer 6234 Mississippi State, Mississippi 39762
WATER	IBM PC or compatible w/MS-DOS (PC-DOS) and 256K	Steady-state analysis of looping and non-looping networks up to 150 nodes.	CIVILSOFT 290 S. Anaheim Blvd, Suite 100 Anaheim, CA 92805
SOFTNET	Apple II/IIe, III, and 48K with one disk drive	Steady-state analysis of networks up to 150 nodes.	Data Systems Engineering Inc. 401 West Mt. Vernon Drive Plantation, Florida 33325
TRSFLOW	IBM-PC, TRS-80, or CP/M systems with 64K	Steady-state analysis of networks with 150 nodes.	First Principles Software Post Office Box 4236 Santa Rosa, California 95402
PRESSURE-FLOW	Apple II with 64K or IBM PC with 256K and two disks drives	Interactive for computer-aided design of pressure pipes.	Advanced Engineering Software 17782 Skypark Blvd. Irvine, California 92714

There are now a number of these models that run on personal computers, some of which are listed in Table 3-1. These programs are sold at prices ranging from $50 to $1,000. Software companies advertise in technical magazines such as Civil Engineering, published by the American Society of Civil Engineers. Programs for personal computers vary considerably in ease of use, capability, type of output, speed, and other important characteristics. The potential user would be well-advised to obtain a demonstration disk (available for a small fee) and try the program before purchasing it.

Preparing Input Data. A large amount of time will be spent preparing the data in the form usable by the model. Figure 3-10 shows a distribution system with pertinent data. Note that a relatively small number of water pipes are shown but all reservoirs, pumping stations, pressure-reducing valves, and water supply inputs are shown. The following data preparation steps are suggested:

1. Prepare System Map. Using plans and as-built drawings prepare a map of the water system on one sheet at a suitable

Figure 3-10 Portion of Water Distribution System Map. Fullerton, California



scale. A 1:10,000 scale map is suggested. Show all pipe locations and diameters. Show water tank volume and elevations, pump capacities, and regulators.

2. Develop Schematic System Map. Start with the larger pipes (greater than 12 inches). Add pipes down to 8 inches, as necessary, to get desired level of detail for the model. Substitute equivalent pipes for paralled pipes. Select color code for the map to differentiate between diameter, nodes (pipe junction points) elevations, pump and tank data, water use, valves etc.

3. Estimate C-Factors. Select C-factors from literature values based upon type of pipe and age. Start with low values if pipes in system are known to be tuberculated. They will be adjusted later in the calibration stage.

4. Assign Water Use to Nodes. Aggregate water use in each area served by a node and assign an average water use. Start with known large water uses (industries,schools, golf courses, etc). Then aggregate residential water use on a per-household basis and remaining commercial/industrial on a gpm/acre-times-acre/node or some other uniform basis. Assign unaccounted-for water on a similar basis. Check that all water use is included.

5. Code Data for Model. Putting data into the proper form for input to the model is straightforward but cross-checking is recommended.

6. Collect Calibration Data. Unless the water agency has very complete records of fire flow tests, it will be necessary to collect some data to calibrate the model. The data to be collected includes: (1) fire flow tests at important locations, especially near the perimeter of the system; (2) static pressure readings at hydrants throughout the system; (3) elevation of water in tanks and pressure at pumps taken at the same time as pressure readings described in (1) and (2) are made; (4) pressure readings at pressure reducing valves; and (5) flow through meters of mains. The only equipment required to obtain the data described are a pitot gage and a hydrant pressure gage. Test procedures are described in this chapter.

Calibrate the Model. Usually either the C-factors or water use can be modified to achieve calibration. If the user has only one set of pressure data, then it is not possible to know which parameter to adjust; for example, instead of increasing a C-factor, the user may incorrectly decrease water use. The model will then appear to be calibrated, but would be incorrect. To overcome this problem, the user should attempt to simulate both average use and fire flows, corresponding to actual flow tests, at several locations. If the model is more accurate for the average use condition, then the hydraulic parameters are the source of most of the error and the C-factor should be adjusted or valves should be checked to see if the model and the system are in agreement. If the model is more accurate for the fire flow conditions (i.e., when the effects of nonfire users are diminished), then the source of most of the error is the water use data. Calibrating a model for several operating conditions virtually eliminates the possibility of compensating errors as is possible if the model is calibrated for only one operating condition.

Models should be able to be calibrated to predict pressures within ±5 psi. However, a model calibrated over a range of operations to ±10 psi is usually more desirable than one calibrated at ±5 psi for only one use rate.

Run the Model. Once the model of the existing system is calibrated, the user is ready to begin making simulation runs of interest to him. Before making the production runs, the user should outline the runs to be made and establish a numbering system or naming scheme for each run. Notes should be made on the printouts as to the adequacy of the system change simulated. The following is a suggested list of investigations:

1. Changes in system pressures after pipe rehabilitation program to increase C-factors.

2. Performance of new pipes, tanks, pumps, etc., to serve new growth areas. Determine proper size of new facilities.

3. Improvement in system pressures in existing built-up area when new pipes are inserted into the network.

4. Possible staging plans to keep pace with growth over the planning period.

Thermographic Surveys of Steam Distribution Piping

Infrared imaging is a proven form of non-destructive testing, and can be employed in an inspection program wherever a surface temperature differential is indicative of an abnormal condition. Underground steam lines provide numerous applications for a thermographic survey; such as steam leaks, poor insulation, bad steam traps, and steam return to the boiler. All of these items are characterized by an increase in ground temperature. Since there is no physical contact with the system, the survey can be completed prior to excavation work and while the system is fully loaded.

Surveys are performed with the use of a high resolution video thermographic camera such as Inframetric's Model 525. The Model 525 is a small, light-weight field instrument that produces a video output signal of the thermal patterns in the scanner's field of view. Two low-inertia mirrors scan the screen for all naturally emitted infrared radiation. This is converted to an electrical signal by a liquid nitrogen cooled detector. The signal is processed into a TV picture of temperature patterns in the scene. Surveys are usually recorded on a 1/2-inch VHS video tape. This equipment is capable of measuring temperature differences between 2/10 of 1 degree and 1500 degrees centigrade (C) and recording the data for future reference.

Thermographic surveys are normally done from the ground or by helicopter, and occasionally by boats. Scanning the system with this camera reveals hot spots where high surface temperatures on the piping indicate some deficiency. A steam pipeline without corrosion and with adequate insulation should have a relatively low and uniform temperature profile. A temperature differential less than 10 degrees C indicates a possible minor insulation deficiency. A 10 to 20 degree C differential likely is due to damaged insulation and/or casing. A differential larger than 20 degrees C probably is caused by leaking steam. The identification of these deficiencies in exposed aboveground piping is immediate.

The results of the thermographic surveys are particularly valuable in locating suspected problem areas in the underground steam piping. Subsequent field investigations are required to describe the problem. Often times, some of these hot spots are caused by hot condensate in piping trenches and by the different heat radiation properties of the pipe backfill and trench cover materials (e.g., soil, asphalt pavement, concrete pavement, and metal coverplate). High ground surface temperatures can also be caused by lack of sufficient cover over the buried steam piping.

Results of thermographic surveys are documented on video tape, usually with a voice recorder to add descriptions of the conditions noted by the camera operator, plus a written inspection report. The tapes should be saved for comparing with future thermographic surveys.

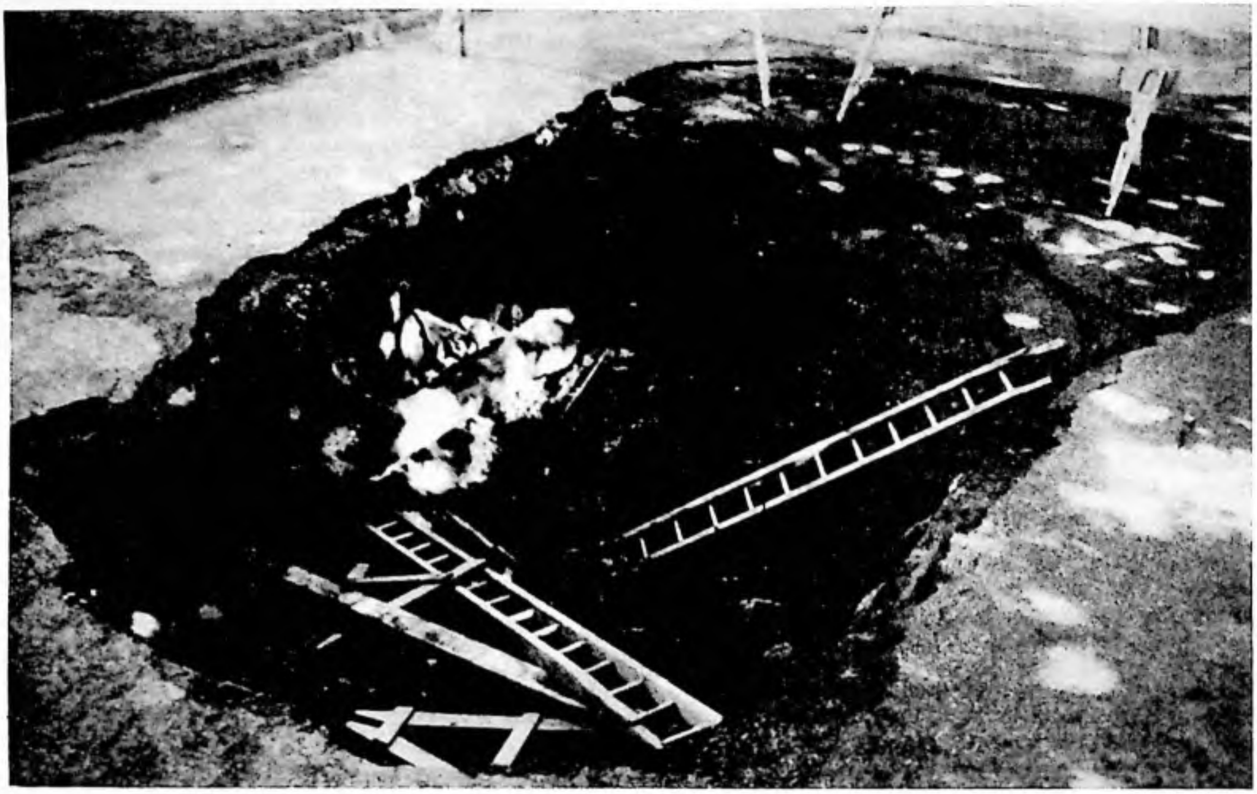
Costs of this service are approximately $3,000 per day, including equipment, one camera operator, and helicopter rental. A survey in 1984 of 40,000 feet of steam lines on a naval shipyard took 5 days and cost $15,000. Purveyors of this service include Infrared Technologies, Inc., Duggan Road, Bethel, New York, 12720, En Tech Engineering Consultants, 400 Mansion House Center 2010, St. Louis, Missouri, 63102, and Thermotest, Inc., 156 Fourth Avenue, Bayshore, New York, 11706.

SEWER PIPELINES AND MANHOLES

Sewer pipelines and manholes can fail either structurally or by allowing excessive infiltration/inflow (I/I) to enter. Infiltration results from groundwater entering through porous walls, cracks, or leaky joints. Inflow comes from storm drains illegally connected to the sanitary sewer system and from sources such as poorly sealed manhole covers. With the passage of PL 92-500 in 1972, far more emphasis has been placed upon eliminating excessive I/I to reduce the hydraulic loads on the sewer systems and wastewater treatment plants. The pollution impacts of bypassed and undertreated wastewater flows on receiving waters caused by excessive I/I have been serious in many urban areas. Sometimes, the presence of excessive I/I is an early warning signal that the sewer system is progressing towards structural failure. When structural failure occurs, i.e., a pipe collapses, it can no longer be rehabilitated at low cost, and it must be replaced on an emergency basis which can be very expensive (see Figure 3-11).

This section emphasizes identifying structural deterioration and excessive infiltration. Collection system subareas with high I/I can be identified by flow monitoring. Structural deterioration can be observed by videotaping or man-entry inspection (cracks, root penetration, leaking joints, sagging crown or invert, etc.). This information is needed to set rehabilitation priorities.

Figure 3-11 A Prioritized Rehabilitation Replacement Program Can Prevent Costly Sewer Failures



Mechanisms of Sewer Failure

An understanding of the mechanisms of sewer structural failure is essential to selection of effective rehabilitation techniques. There are several factors that can cause failure, including:

1. Corrosive soils and/or groundwater.
2. Voiding of bedding and backfill as infiltration enters a failing pipe (see Figure 3-12).
3. Undermining due to earth movement.
4. Sulfide formation in the wastewater flow.
5. Corrosive and erosive industrial wastes.
6. Root intrusion at deteriorated joints (see Figure 3-13).
7. Differential settlement of soil adjacent to the pipe.
8. Loss of bricks in brick sewers.
9. Loading in excess of design limits.
10. Improper installation in the original construction.
11. Repeated sewer rodding.

I/I Analysis

Periodic flow monitoring at key points in the collection system provides information which allows for efficient scheduling of preventive maintenance activities. Continuous flow data can be evaluated to determine what portions of the system permit unacceptably high quantities of infiltration and/or inflow. Problem areas can then be identified, and the maintenance schedule for testing, inspection, and rehabilitation of an area can provide information about the effectiveness of specific repair methods.

Flow Monitoring Equipment. The normal hydraulic regime of sanitary sewers is classified as steady-state, uniform, open channel flow. When the sewer is not flowing full (i.e., not surcharged), flow rate can be determined under these circumstances by

Figure 3-12 Infiltration Entering Sewer Through a Failed Joint

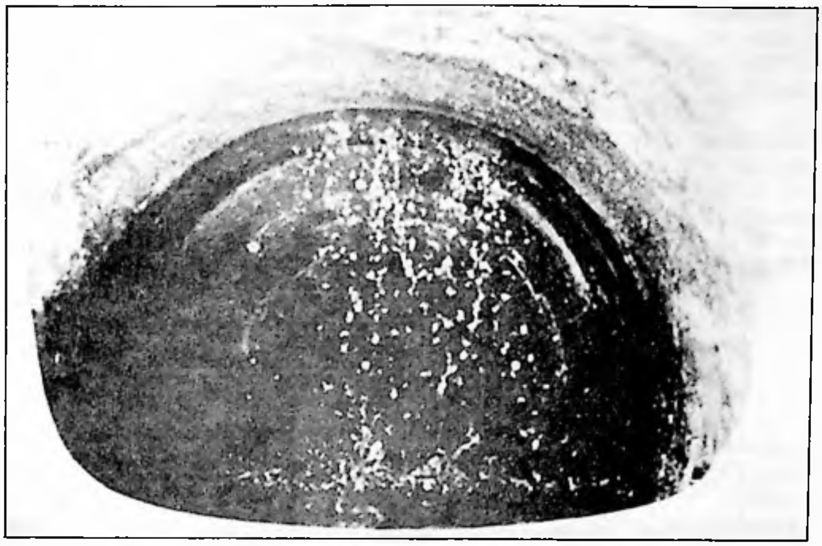


Figure 3-13 Serious Root Intrusion. Courtesy Rodding-Cleaning Services, Inc.

two methods. One method requires that the velocity and flow depth be measured. Then the continuity equation is used to calculate discharge from the product of average velocity and cross-sectional flow area. For a pipe of known shape (typically circular), the flow area can be calculated from the flow depth.

The other method uses the Manning equation to calculate discharge. This only requires a measurement of flow depth and is easier to do but not as accurate. The Manning equation is an empirical formula usually written as follows:

$$Q = \frac{1.486}{n} r^{2/3} s^{1/2} A \qquad (3\text{-}4)$$

In this equation, discharge (Q) is expressed in cubic feet per second (cfs), s is the pipe slope foot/foot. A is the cross-sectional flow area in square feet, r is the hydraulic radius in feet (a function of flow depth and pipe diameter), and n is the pipe roughness coefficient. The pipe slope is obtained from the difference in pipe invert elevations. Typically, in sewers, n is assumed to be 0.013, but can be as low as 0.011.

Several types of recording flow monitors are available. Careful consideration of the following factors will assist in the appropriate selection of equipment:

- The monitor selected should have demonstrated accuracy and reliability over the anticipated flow range under similar environmental conditions.
- A pair of flow depth meters are required for surcharged flow conditions. Velocity is computed from the difference in the energy grade line between the location of the two flow meters (usually two manholes).
- Equipment intended for use in sewers should have few moving parts, with no moving parts that contact the flow.
- It is desirable that the data collected by the monitor be stored on an electronic chip rather than on a strip chart, circular chart, or tape cassette. Chip storage results in less data loss due to mechanical failure and provides for more accurate data storage.

Equipment available for measuring depth and velocity of flow and their costs, reliability, and accuracy is tabulated in Table 3-2. The Manning dipper, often used in conjunction with a V-notch weir built in a manhole to increase accuracy, is made by the Manning Corporation. ISCO makes a bubbler tube device (as do others) and a pressure transducer. The latter device also made by American Digital Systems (ADS) is the most commonly used device today. Ultrasonic devices are made by ADS, ISCO, Manning, Movitek, Fischer & Porter, and others. Controlotron manufactures a velocity-measuring device that uses the doppler effect. ADS manufactures a fluid shear sensor as does Marsh-McBirney for measuring velocity.

Identification of I/I Components. The results of flow monitoring data can be analyzed to isolate the extent and sources of infiltration and inflow from normal dry-weather wastewater flow. Subareas in the collection system with high infiltration are candidates for more detailed inspection (television, etc.) and then possibly for rehabilitation. Infiltration comes from defective mainline sewers and/or laterals.[10] Subareas with high inflow also may be causing downstream problems (such as overloaded treatment plants or overflows), but the mainline sewer may not require rehabilitation, only the disconnection of inflow sources. Much can be learned from the shape of the flow hydrograph following a rainfall event. Shown on Figure 3-14 is a hydrograph with typical components or their subcomponents defined as follows:

- Dry-weather base flow is determined from dry-weather flow monitoring data and winter water use. Dry-weather flow data should be close to winter water use in residential areas except where considerable landscape irrigation occurs and then it will be higher.
- Groundwater infiltration (GWI) is defined as groundwater entering the wastewater collection system and building sewers through defective pipes, pipe joints, and manhole walls. The magnitude depends on the depth of the groundwater above the defects as well as the percentage of the collection system submerged. The variation in groundwater levels and subsequent groundwater infiltration is seasonal and may affect the calculation of dry-weather flow. Manhole or well-type groundwater gages are good methods for measuring the shallow groundwater table level.

Table 3-2 Sewer Flow Monitoring Equipment Summary

Sensor type	Cost, dollars[a]		Operation and maintenance cost	Application	Reliability	Accuracy and repeatability
	Equipment	Installation				
Depth measurement						
Manning dipper	2,500[b]	500	High	Temporary	Low	Low
Bubbler tube	4,000[b]	500	Moderate	Temporary	Moderate	Low
Pressure transducer	2,250[b]	500	Low	Temporary	High	Moderate
Ultrasonic						
Pulse-time difference	7,000[c]	1,000	Low	Temporary	Moderate	Moderate
Quadra Scan	15,000[c]	5,500	Moderate	Permanent	High	High
Velocity measurement						
Doppler effect	7,000[c]	1,000	Low	Temporary	Moderate	Moderate
Fluid shear	-	-	-	Temporary	-	-

[a]Cost basis, October 1982.
[b]Cost includes basic equipment package including probe, memory recorder, etc.
[c]Cost includes equipment package including probe, sensor, memory, display, totalizer, etc.

Source: The Eastshore Consultants, Sewer System Preventive Maintenance Program.

- Rainfall-dependent I/I (RDI/I) is that portion of total I/I directly influenced by the intensity and duration of a storm event. This component of I/I may be further subdivided into stormwater inflow and rainfall-dependent infiltration.

- Stormwater inflow (SWI) is defined as water discharged into the collection system, including private sewer laterals, from such sources as downspouts, yard and area drains, manhole covers, cross connections from storm drains, or catch basins.

- Rainfall-dependent infiltration (RDI) is the component of I/I that enters the system through pipe defects similar to GWI, but due to the rapid response, the RDI impacts the collection system by contributing to peak flows comparable to SWI. Stormwater can reach defective sewers either by penetrating through the soil above a defective sewer or via the pipe trench in which the sewer is constructed, particularly if the pipe is placed in impermeable soil and bedded and backfilled with a granular material.

Figure 3-15 illustrates the effects of the groundwater table on the infiltration components. The groundwater table elevations will indicate the areas which are submerged and are therefore susceptible to GWI only. Those areas within the collection system located above the groundwater table will have no GWI component. From the long-term monitoring data and the groundwater data, a relationship may be developed between the rate of GWI and the groundwater level.

The following procedure can be used for each event monitored.

1. Subtract dry-weather base flow and GWI from total flow and produce new hydrograph of RDI/I versus time.
2. RDI equals the flow after the rainfall has stopped and inflow ceases, usually about 1 hour.
3. SWI equals all flow above RDI.

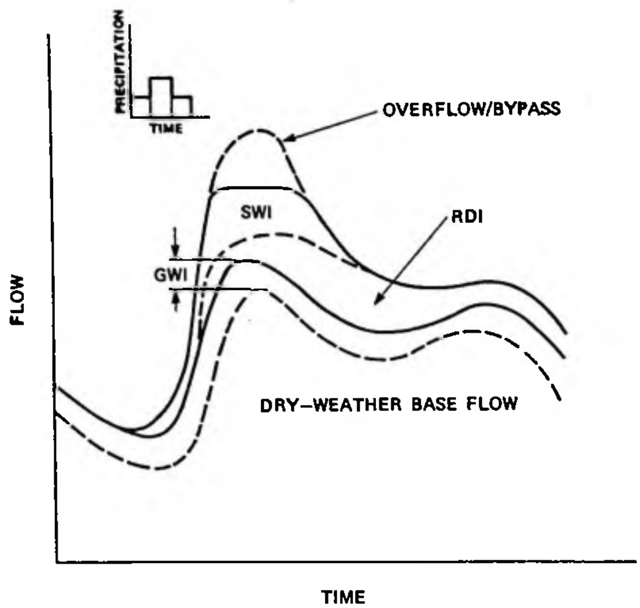
RDI and SWI data will assist in deciding whether the rehabilitation solution is to disconnect inflow sources or repair leaking pipes to stop infiltration. Keeping track of total RDI over a number of years is another measure of changes in the physical condition of the sewer system.

Sewer System Inspection Methods

The methods which can be used to evaluate the system with respect to structural condition or locating I/I sources are:

- Smoke testing
- Rainfall simulation (dye testing and flooding)
- Manhole inspection and lamping
- Building plumbing inspection
- Flow isolation
- Television inspection
- Man-entry inspection
- Infrared thermography
- Lateral testing

Figure 3-14 Typical Sewer Hydrograph Showing Infiltration/Inflow Components



The six inspection methods--manhole inspection, lamping, building plumbing inspection, television inspection, man-entry and infrared thermography--can be used to evaluate system structural condition, and all of the above testing and inspection methods are applicable for I/I source detection and evaluation.

The methods are all labor intensive and some, such as television inspection and infrared thermography require expensive equipment. Initially, it is prudent to perform flow monitoring during expected high I/I periods to indicate possible presence of high I/I and to prioritize areas to be inspected. Suggested criteria for applying each method are listed in Table 3-3. Infrared thermography, used to detect voids above sewer pipes that might cause a cave-in, is still new and developmental and is not included in the table. Using this technique to make an initial survey of an area served by old brick sewers with a history of cave-ins appears worthwhile. Criteria should be tailored to each location depending upon the problem, history, results of previous inspections and budget available. Excessive I/I should be determined by a cost-effectiveness analysis comparing costs of transport and treatment of I/I versus identification followed by rehabilitation.

Recommended testing and inspection frequencies shown in Table 3-3 are for a well-maintained system after a rehabilitation program has been completed. Frequencies should be tailored to each city after review of the problem history, corrective action and rehabilitation taken, available budget, and/or staff and equipment, etc. Flow isolation and lateral testing is normally only done in the investigative stages of a rehabilitation program.

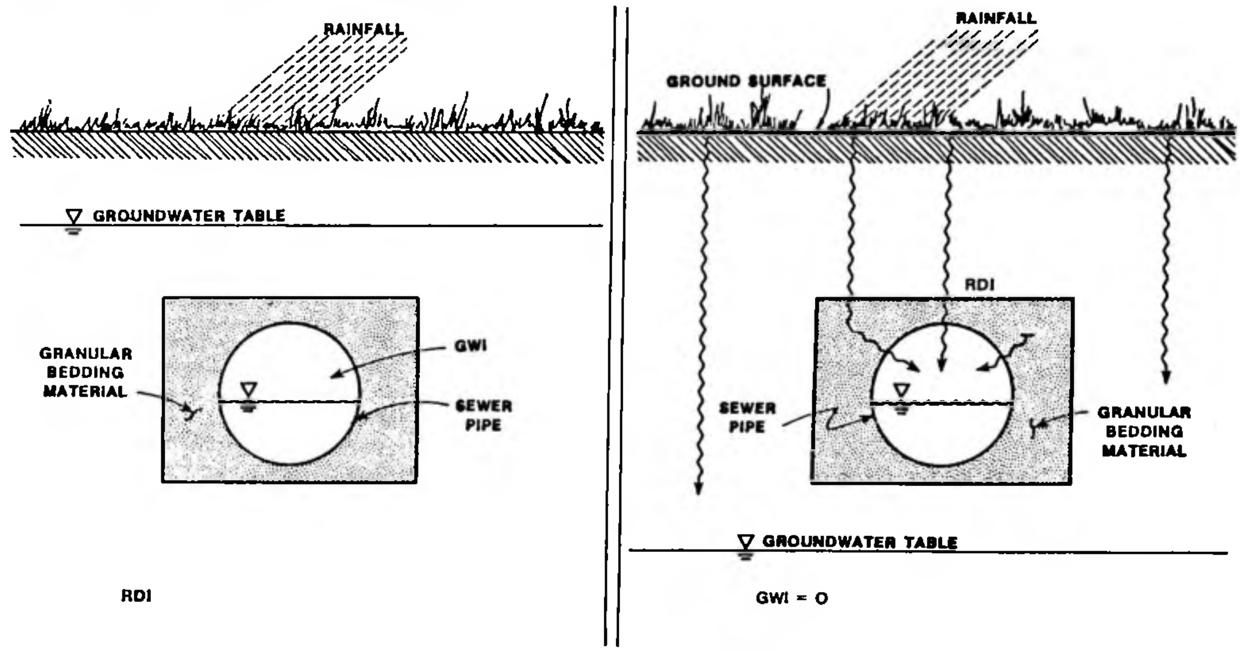
Relative unit costs for the first six inspection methods are presented in Table 3-4. They were developed for the Oakland, California, area in 1984. Each technique is briefly described below. Further information to tailor these costs to a local area can be obtained from equipment vendors and cities with active programs.

Smoke Testing. This is a technique for detecting stormwater inflow sources and infiltration sources located near the ground surface. Specific sources readily detected include downspout connections, yard and area drain connections, catch basins, and broken laterals.

A nontoxic, nonstaining "smoke" (actually a zinc chloride mist) is forced through a section of a sewer pipe using an air blower set up at manholes at approximately 600-foot intervals. The smoke surfaces through sewer pipe connections and defects. The effectiveness of smoke testing is dependent upon thorough documentation of findings including a description of each smoke leak, numbered photographs, and maps showing location of the leaks. A typical smoke test between two manholes takes approximately 10 to 30 minutes, varying with the number of smoke returns. An efficient field crew can usually average 8,000 to 10,000 linear feet per day.[11] However, reduced efficiency (in terms of total footage of pipe tested per day) can be expected in difficult areas, such as major streets and along easement sewers and portions of the community with special problems of access or visibility. The public and fire department for the involved area should always be notified in advance when a smoke test is planned to avoid false alarms. Other authorities should be notified, as appropriate, to avoid undue panic or concern. Figure 3-16 shows a smoke test in progress.

or sources of RDI indirectly contributing through the soil and pipe cracks. The nearest manhole is observed for dye appearance which confirms the suspected connection. Concurrent television inspection may provide the exact location of the connection or point of infiltration entry for later rehabilitation work. During dye flooding, a section of a storm drain is isolated by plugging at a selected downstream manhole, and the storm drain and catch basin are flooded with dyed water. Appropriate sanitary sewer manholes are observed for dyed water infiltration from the storm to the sanitary pipelines. The flow increase in the sanitary sewer resulting from dyed water transfer may be measured. Alternative uses for dye flooding include checking laterals, low-lying manholes, and areas where the sanitary sewers cross below a creek. Concurrent television inspection allows actual location of the infiltration sources for future rehabilitation.

Figure 3-15 Infiltration Components



Rainfall Simulation. This involves two techniques: (1) dye tracing to confirm or eliminate possible I/I sources and/or (2) dye flooding to determine the existence and quantity of I/I contributed by suspected sources. Dye tracing is the introduction of dyed water into possible sources of inflow, such as area drains, downspouts, or catch basins suspected of being connected to the sewer lines

Manhole Inspection and Sewer Lamping. Manhole inspection is observation of the physical characteristics of the manhole including dimensions, construction material, quantity of debris, and the condition of the lid, frame, walls, and benches. Evidence of present or previous I/I is noted with an estimate of the flow rate, if possible. Manhole inspections may be conducted from

Table 3-3 Sewer System Testing and Inspection Methods

Method	Application/criteria	Recommended frequency, years
Smoke testing	Routine source detection to identify inflow sources and evaluate infiltration (as evidenced by defective laterals).	10
	Source detection after previous lining or replacement.	20
	Routing long-term monitoring indicates I/I exceeding cost-effective limits and temporary monitoring not desired.	Immediate
	Temporary flow monitoring indicates high inflow.	Immediate
Rainfall simulation (dye flooding and tracing)	As needed after smoke testing to confirm suspected storm drainage connections.	N/A
Building plumbing inspection	As needed after smoke testing to confirm suspected inflow sources.	N/A
Manhole inspection/lamping	Routine source detection to evaluate I/I sources and structural condition.	10
	Inspection performed incidental to other investigation procedures.	N/A
Flow isolation	Follow-up source detection after sealing.	N/A
	Flow monitoring indicates high infiltration in large area.	Immediate
	Routine smoke testing indicates potentially major infiltration sources.	
Television inspection	Routine inspection for pipes 50 years old or older.	5
	Routine inspection for pipes 50 years or younger.	10
	Previous history of emergency repairs or maintenance problems since last testing and inspection.	Immediate
	Routine inspection for pipes rehabilitated by sealing if interim detection does not reveal I/I sources.	10
	Previously grouted pipes.	5
	Smoke testing, flow isolation or temporary flow monitoring indicates excessive I/I.	Immediate

Source: The Eastshore Consultants, Sewer System Preventative Maintenance Program.

Table 3-3 Sewer System Testing and Inspection Methods (continued)

Method	Application/criteria	Recommended frequency, years
Lateral testing	Smoke testing indicates major defects.	Immediate
	Building inspection indicates major defects.	Immediate
	Main sewer to be rehabilitated or replaced and concurrent selective lateral rehabilitation desired.	Immediate

Source: The Eastshore Consultants, Sewer System Preventative Maintenance Program.

the street, but surface inspection generally yields more complete information and also permits concurrent lamping and inspection of the inlet and outlet sewers to the manhole. Lamping can reveal cracks, offset joints, root intrusion, and infiltration for a distance of about 10 feet up each pipe. Documentation of manhole inspection and lamping includes manhole numbers, location, dimensions, evidence of surcharge, and any requirement for cleaning. Photographs are an essential part of the documentation.

Building Plumbing Inspection. A building plumbing inspection consists of an inspection of the building and the surrounding area for evidence of illegal connections to the sewer system (downspouts, area or foundation drains, basement sump pumps, etc.), open plumbing or rat holes, or evidence of sewer backups or overflows that might represent a potential public health hazard, and evidence of defects in buried pipes (e.g., sink holes, settlement of the soil directly over the pipe, etc.). This requires entry to the property and so is normally done when a building inspection for another purpose is being conducted.

Dye Dilution and Flow Isolation. Dye dilution is used to measure flow in a trunk sewer. This type of measurement gives an instantaneous flow value. It is normally done during low-flow periods (1 a.m. to 6 a.m.) to get a direct measurement of GWI or GWI + RDI if it has recently rained. A dye (Rhodamine WT) or a lithium chloride solution of known concentration is fed continuously at the upper end of a basin or subbasin. Lithium chloride may be used instead of dye, where the dye may adsorb to organic sewage solids. A lithium chloride tracer is fed into the line and sampled downstream in a similar manner. Grab samples are taken at predetermined locations along the trunk sewer and analyzed for fluorescence. The results are compared to a standard curve to determine dilution. The flow at each sampling site can be calculated from the dilution and, by subtraction, incremental flows can be determined.

During flow isolation, flows are measured in the sewer at key manholes. Incremental flows may be calculated by subtracting the measured upstream flow. Plugs may be required for isolation of pipe sections for accurate flow readings. Techniques which may be used for flow measurement are:

Hand-held weirs
Depth/velocity measurement
Bucket and stop watch
Time and dye addition
Estimate

Dye dilution and flow isolation are recommended for use by skilled crews only. It is not a routine testing method and is only used in special cases.

Television Inspection. The purpose of television inspection is observation and documentation of the following conditions of the pipelines:

- Structural integrity
- Root intrusion (see Figure 3-17)
- Infiltration from the main and/or laterals (see Figure 3-18)
- Protruding laterals (see Figure 3-19) Defective lateral connections
- Offset joints
- Dips in pipeline

As necessary, minor rehabilitation by grout sealing can be performed concurrently with television inspection with a combined television-and-grout packer unit. Assuming it is cost-effective to remove I/I, then cost savings can be realized with this procedure by avoiding a second television inspection which is usually done immediately prior to rehabilitation work.

Television inspection using normal procedures is possible on pipelines between 6 and 36 inches in diameter. In larger pipes (greater than 24-inch diameter), it is difficult to see the crown of the pipe because of distortion from the camera angle. Large pipes are best inspected by man-entry.

Table 3-4 Relative Unit Costs for Source Detection (ENR 4400)

Technique	Unit cost,[a] dollars per unit or item
Smoke testing	0.20/linear foot
Rainfall simulation	
Dye tracing	150/site
Dye flooding	600/site
Manhole inspection	
Detailed	48/manhole
Surface	20/manhole
Building plumbing inspection	50/building
Dye dilution	1,400/run
Flow isolation	48/manhole
Television inspection[b]	
Television inspection alone	2.12/linear foot
Television inspection with minor rehabilitation[c]	19.00/linear foot

[a]Unit costs include field work, office coordination and limited data review and evaluation.

[b]Costs assume outside contractor does the work. Will be less if city does it with own forces.

[c]Minor rehabilitation includes air testing all joints and sealing approximately 75 percent. The unit cost is based on the present worth of resealing every 5-years during a 20-year period at 7-3/8 percent interest.

ENR = Engineering News-Record Construction Cost Index.

Source: East Bay Municipal Utility District, Manual for Cost-Effectiveness Analysis.

Sewer pipelines must be clean prior to inspection. Afterwards, a closed-circuit television camera is pulled through the pipeline, and the images are recorded on videotape for permanent records. Figure 3-20 shows how the equipment works. During the inspection, locations of structural defects, root intrusion, lateral connections, and points of infiltration are documented on the television log form or made directly on the videotape using a microphone. For detection of I/I sources, television inspection is best performed during rainfall and/or periods of high groundwater. Color television produces more useful images, but the cameras are more sensitive to breakage. Figure 3-21 shows a television camera and Figure 3-22 the monitor.

Purchase of a fully equipped rig costs approximately $90,000 for television inspection only, and $145,000 for one with inspection and sealing capabilities. Television inspection requires a three-person crew. Work force requirements are approximately 16 man-hours per 1,000 linear feet of sewer inspected plus an additional 1 to 1 1/2 man-hours per 1,000 linear feet for data review and input.

Man-Entry. This type of inspection is used in large sewers (30-inch diameter and larger) where it is safe to enter. Air packs should be worn. Inspections are done during low-flow periods. A log is maintained of lateral corrections, overall condition of the sewer, and any special problems or conditions. Photographs are taken of areas with missing bricks, poor joints, offset joints, sagging crowns, etc.

could scan 300 feet up and down the street. The equipment is sensitive to temperature differences on the pavement in one-tenth of a degree increments. The surface temperatures are dependent on subsurface configurations. Voids change the energy flow more than soil or rock surrounding the pipe and produce a different image on the scanner. The air acts

Figure 3-16 Field Engineer Prepares Smoke Test Blower Set-Up

Infrared Thermography. Research on locating voids around sewers has shown that infrared themography is a promising technqiue.[14] As described in the Water Pipeline section, this technique has been used for steam pipeline leak surveys. An infrared scanner measures temperature differences in the pavement above the sewer. In a recent test in St. Louis the scanner was mounted in a cherry picker 50 feet above the street so that it

to insulate energy sources such as a warm sewer. In one 500-foot section of a street in 4.5-foot-diameter brick sewer. The thermograms were computer analyzed to intrepret the temperature variations. The location of the voids was confirmed by drilling borings. The cost of the thermography project was $29,000. A sewer repair program was developed that cost one-half of what emergency repairs would have cost, had the sewer collapsed before it was

Figure 3-17 Root Intrusion From Failed Neoprene Gasket

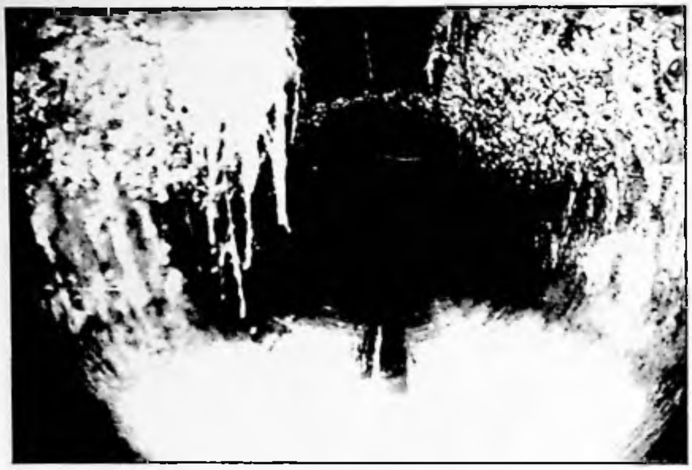


Figure 3-18 Severe Infiltration. Courtesy Rodding-Cleaning Services, Inc.

Figure 3-19 Protruding Sewer Lateral. Courtesy Rodding-Cleaning Services Inc.

Figure 3-20 Video Inspection Identifies Trouble Spots Where Leakage into Sewers Occurs

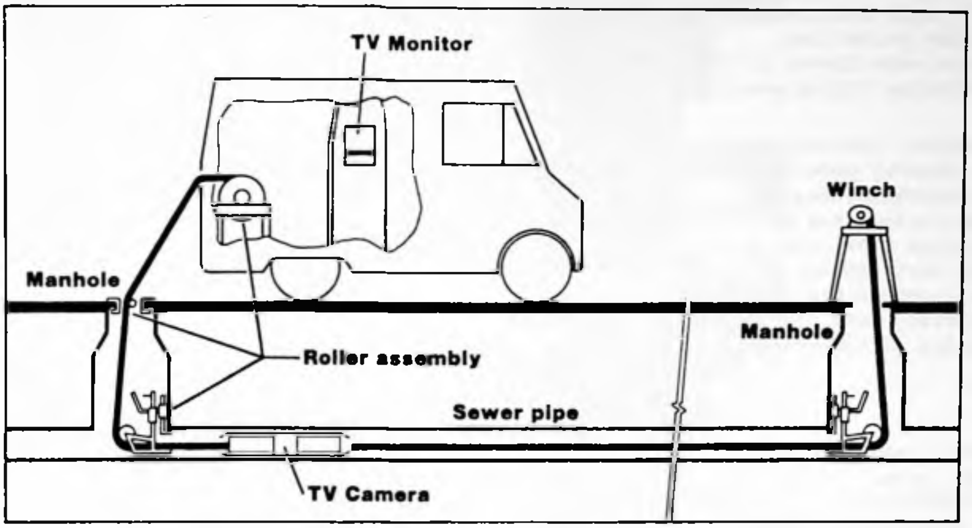


Figure 3-21 Television Camera Being Lowered into Manhole. Courtesy Rodding-Cleaning Services, Inc.

Figure 3-22 Van-Mounted Television Monitor. Courtesy Rodding-Cleaning Services, Inc.

rehabilitated. This technique could be effective in averting many sewer collapses if used on a systematic basis and the results used to set rehabilitation priorities. Purveyors of this service were listed at the end of the Steam Distribution Piping section.

Lateral Testing. Lateral testing is conducted in order to identify specific problem laterals to be rehabilitated. Lateral testing methods include the air pressure test, exfiltration test, and television inspection. The test methods selected depend upon the specific conditions present, e.g., pipe age and material, soil and groundwater conditions, location of cleanouts, etc.

Sewer Cleaning

The objective of a sewer cleaning program is to remove the grease, scum, grit, and other materials which accumulate in the system. This process restores the sewer to its maximum flow capacity, controls sources of corrosion, odors, and toxic gases decreases the possibility of stoppages, and allows subsequent inspection by lamping or television.

Sewer cleaning frequency is dependent on the characteristics of the individual system, specifically the type of area served, the slope of the pipes, and the history of the area. A cleaning frequency of 5 years is commonly used but this will vary from one area to the next. An example of a situation which might change this frequency is if a sewer serves restaurants, meat processing plants, or other facilities which could introduce a large amount of grease into the system. A proper and routine inspection of building grease traps will minimize grease deposits in the sewer. Pipes serving these establishments should be cleaned more often than for those in a residential neighborhood. If the slope of the pipes is flat, one can expect much more settlement of sand and grit than where the slope of the pipes is steep. If the area has grease traps but a history of grease accumulation and/or root intrusion, the area pipes should be cleaned more often than if the area has no such history.

Various devices for sewer cleaning are available including hydraulic methods such as high-velocity cleaners (see Figure 3-23), balls, scooters, kites, bags, and poly pigs (see Figure 3-24). Mechanical methods are also available such as power and hand rodders, and bucket machines (see Figure 3-25). Chemicals are also used for cleaning purposes.

Each of the cleaning methods has been used successfully in maintenance programs. However, the effectiveness of each method varies, depending on the specific problem it is used to relieve. Table 3-5 categorizes the effectiveness of the different methods. High-velocity cleaners are the most versatile of all methods, but also the most expensive. Balling, on the other hand, is very inexpensive but has limited effectiveness. It causes a temporary sewer backup that may flood low-lying basements. Rodding should not be used in pipes which have been sliplined or inversion-lined because the cutting tip is highly abrasive to the liner. Production rates and unit costs vary with sewer diameter. Further information is given in Chapter 5 under "Grouting Preparation Costs." Each sewer agency should evaluate its needs and determine the best equipment for its use.

Root Control

Roots grow toward the best available source of water and nutrients. Often this is the sewer. Roots enter sewer pipes through broken sections, cracks, and pipe joints. Street plantings should be controlled and property owners informed of lateral alignment to minimize chances of roots being near a sewer lateral. Laterals must be inspected during construction to verify that they have solid joints and no cracks. Figure 3-26 is an example of roots removed from a sewer lateral. Root intrusion is detected by inspecting the pipes using lamping or television, knowing an area has a history of periodic root problems, or, in the extreme case, by stoppages in the pipe. Root control is a temporary rehabilitation technique.

The best way to remove roots is to apply chemicals. The most advanced chemicals prevent further root intrusion for 2 to 7 years. Chemicals are applied either by flooding or foaming.

Chemical application requires a crew of two or three operators, depending on whether manhole entry is necessary. Productivity varies depending on manufacturer's recommendations for length of chemical contact, assessibility of manholes, and pipe size but is usually between 1,000 and 2,500 feet per day. Cost and application rates of chemicals vary greatly between manufacturers and depend on the product composition. Products which include herbicides cost about 60 percent more than products with toxins only.

Figure 3-23 High Velocity Water Cleaner. Courtesy Rodding-Cleaning Services, Inc.

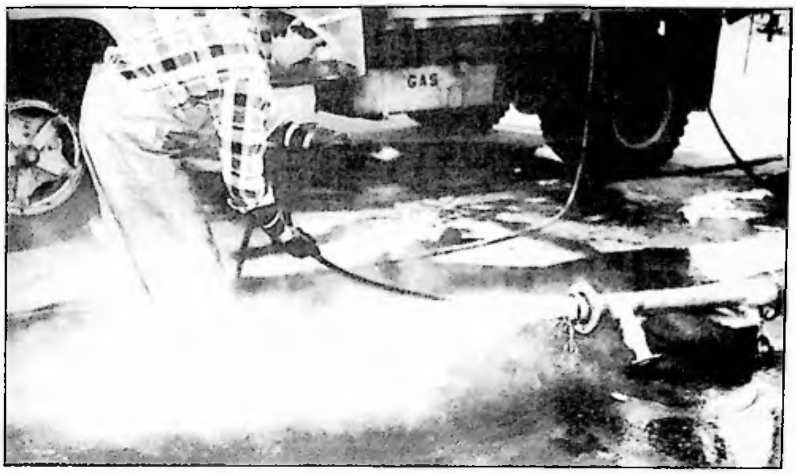


Figure 3-24 Cleaning Pig Being Inserted in Sewer Foremain. Courtesy Rodding-Cleaning Services, Inc.

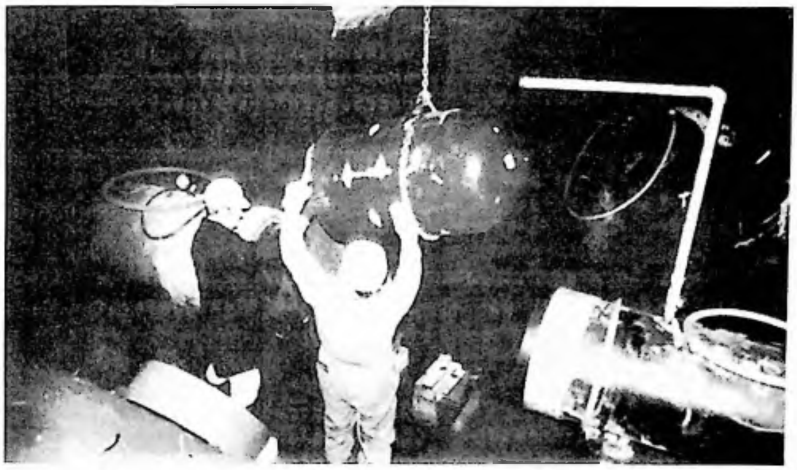


Figure 3-25 Bucket Machine Removes Loose Grit in Sewer. Courtesy Rodding-Cleaning Services, Inc.

Table 3-5 Cleaning Method Effectiveness

Cleaning method	Problem				
	Emergency stoppage	Grease	Grit, debris	Hydrogen sulfide, odors	Roots
High-velocity cleaner	Fair	Good	Good	Fair	N.A[a]
Balling and other hydraulic methods	N.A.	Fair	Fair	Fair	N.A.
Bucket machines	N.A.	N.A.	Fair[b]	N.A.	N.A.
Hand rodders	Good	Poor	N.A.	N.A.	Fair
Power rodders	Good	Poor	N.A.	N.A.	Fair
Chemicals[c]	N.A.	Poor	N.A.	Poor	Good

[a]Method not applicable.
[b]Excellent for grit in large lines.
[c]Effectiveness depends on type of chemical.

Source: California State University, Operation and Maintenance of Wastewater Collection Systems, A Field Study Training Program.

Evaluation of Sewer Structural Conditions

The sewer condition evaluation presented in this chapter leads to setting of priorities for rehabilitation or replacement of sewers. Inputs to the setting of priorities are:

1. The structural condition of each of the sewers and their relative states of deterioration.

2. The consequences of failure of each of the sewers and the relative impact of failure.

3. The opportunity to improve system hydraulic performance and eliminate flooding trouble spots.

The first item is addressed in this section and the other two items and a decision making process are described in Chapter 4.

To evaluate and compare the structural condition of brick sewers, some assumptions must be made regarding the characteristics that indicate potential structural failure. Generally, brick sewers fail suddenly and completely without prior warning. A brick sewer which appears to be in better overall condition than another may collapse while the other remains in service. This is due to the nature of brick construction and the high degree of local variability in the condition of the sewers. A concrete or clay sewer, on the other hand, is less likely to fail completely without some prior indication of severe structural damage.

Brick Sewers. Nearly all old brick sewers have problems. The useful life remaining can be determined from a physical inspection. Man-entry is the best technique to view the subtle differences in condition. For example, soft mortar or loose bricks can only be observed by using a probe, such as a pick. This would not show up in a television inspection. Infrared thermography is the best way to find voids in the soil outside the pipe that might mean a collapse is imminent, if the voids are large enough. The purpose of the evaluation method described herein is to quantify these subtle changes in condition as a brick sewer moves closer to failure.

The first deterioration that occurs in the brick sewers is a general mortar loss by erosion or deterioration. Nevertheless, many of these sewers will maintain their original cross-sectional shape and, as long as the deteriorated mortar remains in place, the sewer structure will support the earth and live loads on it. The structural danger is that the softened mortar may be eroded by high flows in the sewer or by groundwater infiltration. The soft mortar also offers little resistance to root intrusion and infiltration which can accelerate mortar loss, produce structural deformation, and obstruct flow.

Once the sewer loses a significant portion of the mortar between bricks, it begins to deform under the earth loads. The lower the depth of cover over the pipe, the higher are the street traffic loads and vibration. The vibration helps dislodge the mortar and then the bricks. Complete loss of the mortar results in loosened and, eventually, missing bricks, allowing severe deflections. Figure 3-27 shows a sewer with a considerable number of missing bricks. The sewer may also deform vertically by developing longitudinal cracks on the crown, either before or after the mortar is severely degraded (see Figure 3-28). Large deformations or extensive cracking are apparently the final prefailure warning in brick sewers.

Figure 3-26 Roots Removed From a Sewer Lateral. Courtesy Rodding-Cleaning Services, Inc.

In high groundwater areas, leakage through brick mortar joints may transport backfill material into the pipe, eventually creating cavities or zones of poorly consolidated material around the sides and over the sewer. Sudden collapse of the soil arch or redistribution of overlying loads may cause collapse of the pipeline or result in severe structural damage. Subsurface conditions of the type described above can only be determined by exploration (drilling) after candidate areas have been selected as a result of infrared thermography and/or an in-pipe inspection program.

Recommended brick sewer structural condition evaluation criteria are presented in Table 3-6. The relative importance of the criteria are indicated by the weighting factors which are highest for those conditions indicating greatest structural deterioration. In other words, a factor equal to 4 indicates the sewer is close to failure, whereas a factor equal to 1 indicates the process is just starting. Note the subtle differences in condition that would only be apparent from a man-entry inspection.

To quantitatively compare the conditions of brick sewers, a structural condition matrix can be used. The matrix numerically rates the severity (slight, moderate, and severe) of the various observed conditions and the extent to which they occur in the sewer. Thus, the larger the number of damaged areas in the sewer section being rated the more severe the problems. Sewer sections evaluated should be approximately the same length. Typically, one block is used. Table 3-7 is an example of the use of the structural condition matrix. In this case, the sewer section was found to have a moderate problem with vertical deflection and a score of 8 was entered in the table and so forth. Vertical deflection is normally associated with other problems as well and sections with this condition should receive the highest grand total scores. The example shown has a considerable number of moderate and severe problems. Professional judgment is used to rate the severity of the problem noted in the inspection reports.

The use of the structural condition matrices for the brick sewers results in a single numerical value (Structural Condition Index) representing the condition of the sewers. Because sewer conditions vary locally, the matrix analysis is on a block-by-block basis for each sewer. The use of this index allows a structural condition comparison of the various sewer reaches and prioritization as to relative need for rehabilitation or replacement based on degree of structural deterioration. Sewers in Priority Group 1 are in the most serious condition. In this approach, the higher Structural Condition Indices denote the worst structural conditions. Table 3-8 gives the range of Structural Indices represented by each of four Structural Condition Priority Groups. The relation between the sewer Structural Condition Indices and Priority Groups will vary from one city to the next, depending on the range of the scores. For example, if all scores range from 20 to 30, then use of Table 3-8 would only result in sewers being assigned to groups 1 or 2 and clearly a finer breakdown would be needed. In some cases, it may be desireable to have more than four priority groups. In other words, the evaluation needs to be tailored to each city's needs.

Figure 3-27 Sewer With Missing Bricks

Figure 3-28 Sewer With Temporary Prop to Support Sagging Crown

Concrete and Clay Sewers. The criteria for the structural condition evaluation of concrete and clay sewers are less complex than those for brick sewer evaluation. These criteria are, in numerical order of importance:

1. Structural cracking with deflection (see Figure 3-29).
2. Corrosion.
3. Structural cracking without deflection.
4. Open joints due to sagging.

Table 3-6 Brick Sewer Structural Condition Evaluation Criteria

Condition	Importance weighting factor
Vertical deflection/cracks	4
Missing bricks	3
Lateral deflection	3
Root intrusion	2
Missing mortar	2
Loose bricks	2
Soft mortar	1
Depth of cover	1

These criteria could be assigned importance weighting factors of 4 for item 1, 3 for item 2, 2 for item 3, and 1 for item 4. Then the same matrix format as shown for brick sewers could be used for evaluation.

sewer system being analyzed, the type of computer available, ease of use, and cost. Table 3-9 lists some commonly available sewer models and their applications. Some require a time-sharing terminal or large computer and others are available on personal computers. The former can handle larger networks. Prices for the personal computer programs range from $50 to $300. Software companies advertise in magazines such as Civil Engineering.

The Storm Water Management Model (SWMM) has undergone years of development and testing and has been applied to many combined sewer systems in the United States. In the past it has required a large computer. It is expensive and difficult to use but provides very useful results, especially when the sewer system functions as a network and is surcharged. Software companies are in the process of making this program available for personal computers.

Table 3-7 Structural Condition Matrix Example - Location: 20th Street to L Street

Structural condition	Importance weighting factor	Extent of condition[a]			Subtotal extent of condition
		Slight (Score 1)	Moderate (Score 2)	Severe (Score 3)	
1. Vertical deflection/cracks	4		8		8
2. Missing bricks	3[b]				
3. Lateral deflection	3		6		6
4. Root intrusion	2			6	6
5. Missing mortar	2[b]		4		4
6. Loose bricks	2[b]				3
7. Soft mortar	1[b]			3	
8. Depth of cover	1	1			1
Grand total (Structural Condition Index)					28

[a]The scores in the matrix are the products of the "Importance Weighting Factors" and the "Extent of Condition" column heading numbers.

[b]These factors are reduced by 25 percent when sewer is multiple-course brick.

Source: Brown and Caldwell, Sacramento Central City Sewer System Study.

Using Sewer System Models

For small projects, computer models are not needed and simple hydraulic calculations are made for each pipe section. For separate sewer systems with minimal infiltration/inflow, a steady-state model is adequate. Model selection is based mostly upon the type of sanitary

Steady-State Models. Steady-state models can analyze or design existing and proposed sewer systems. It is normally used for sanitary sewers but can be used for storm sewers provided peak design flows are specified. The following information is provided for analysis of an existing or proposed system:

- Sewer system geometry, pipe lengths, sizes, shapes;
- Friction factors and invert elevations;
- Sanitary plus storm water inflows at node points;

Table 3-8 Example Brick Sewer Structural Condition Priority Group

Structural condition index	Structural condition priority group[a]
0 - 14	4
15 - 19	3
20 - 24	2
25 - 30	1

[a]Priority Group 1 sewers are the most deteriorated; Priority Group 2 sewers are the least deteriorated.

Source: Brown and Caldwell, Sacramento Central City Sewer System Study.

An example of dividing a sewered area into subareas for analysis of major trunk lines is shown on Figure 3-30. For design of a new system, the pipe sizes and shapes and invert elevations are not specified. The model is provided with the following additional information:

- Ground surface elevations and minimum/maximum cover;
- Minimum/maximum velocities;

Output from these programs is:

- Pipe diameters, lengths, slopes, inverts (design only).
- Design flows and velocities.
- Elevation of hydraulic and energy grade lines.

These models are relatively easy to use and user manuals give specific instructions. Their purpose in a rehabilitation project study would be to determine whether a smaller pipe or pipe with a lower friction factor (due to rehabilitation) will adequately carry the flow. If more pipe capacity is needed, the model can be used to size the new interceptor.

Unsteady-State Models. The SWMM model is the most commonly used model for separate sewers with high infiltration/inflow rates and combined sewers. The model consists of two functional blocks:

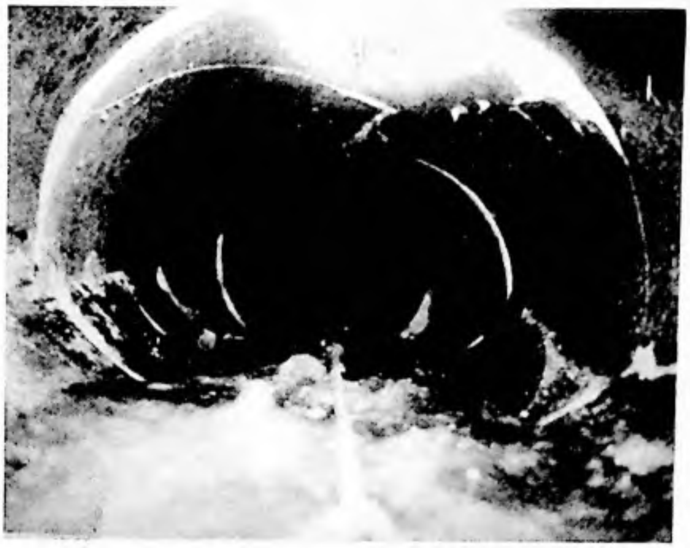
- Runoff block which uses the rainfall hyetograph and watershed characteristics to compute a runoff hydrograph entering each node point in sewer system;
- Transport block which uses sewer network geometry data to compute flows and hydraulic gradeline on a hourly basis. Hydrographs at each node point are generated. The pipe lengths, diameters, inverts, elevation of manhole rims (where local flooding might occur), interconnections of pipes, pumping station characteristics, storage, and treatment facility details must be specified.

The model must be calibrated to data from monitored storm events. For a particular storm, rainfall data and depth of water at key manholes (node points) must be measured every 15 to 45 minutes, depending upon how rapid the depth changes. Several watersheds are usually isolated to calibrate the Runoff block. Other manholes are monitored during the storm to gather data to calibrate the Transport block.

Figure 3-31 shows the results from a typical calibration of the Runoff block. Flow data in cfs can be adjusted by varying the surface detention storage and infiltration rate (variables in the model input). Figure 3-32 shows the comparison of model output for the Transport block (water surface elevation) with the measured field data.

A design storm, with usually a 2-year, 5-year, or 10-year return frequency is selected for evaluating proposed improvements to the sewer system. The SWMM model output gives the volume of flow lost at node points. This indicates the relative severity of local flooding at node points. Alternatives are developed to relieve the flooding and the model rerun to evaluate the improvement. Water elevations in pipe sections combined with a physical inspection (see Chapter 3) and other information can be used to design a rehabilitation program. For example, a low-water surface elevation means that a pipe capacity is more than adequate could be rehabilitated by inserting a pipe of smaller diameter. If the pipe is flowing full or surcharged then the pipe may need to be replaced with a larger diameter pipe or a parallel pipe unless changes can be made downstream to improve the hydraulics, lowering the backwater curve, or upstream such as storage provided to lower peak flow rates. Thus, the SWMM model is useful in evaluating rehabilitation projects will eliminate local flooding problems.

Figure 3-29 Concrete Sewer With Severe Cracking and Deflection



GAS PIPELINES

Unaccounted-for gas, as a percent of total sales, is an important parameter in establishing the condition of the distribution system. Gas losses are of significant economic value and represent a public hazard. Therefore, gas utilities monitor this very closely. Changes in unaccounted-for gas can be used to indicate the need for rehabilitation and to monitor the success of the improvements.

Most old gas pipelines were made of cast iron and were wrapped to prevent corrosion. These were low-pressure systems generally operating at 0.25 psi. Modern gas systems operate at higher pressures today, about 3 to 40 psi, where the distribution system has been upgraded to handle this pressure. Corrosion generally occurs from the outside where the wrapping has decayed. This can eventually cause a gas leak. Corrosion is intensified when the soil is corrosive or stray electrical currents are present. Gas leaks can also occur at pipe joints and other fittings such as gas meters. Because of the explosion hazard with a gas leak, gas utilities do periodic leak detection surveys using procedures and equipment described below. When a leak is found, pipe rehabilitation is often the method used to repair the leak.

Leak Detection Procedures

Gas leaks are detected by sensitive electronic instruments. The instruments are portable and can be handled by one person. Gas leaking from a buried pipe tends to accumulate in soil voids and then to escape through cracks or joints in the pavement. It can also follow the gas pipe along the trench or even another pipe trench if it crosses the leaking gas pipe trench. Therefore, the procedure is to walk or carefully drive the pipeline route and to check all gas services. A leak detection specialist's rate of travel is governed by the accessibility of services. For on-foot inspection, the average is:

- 250 to 300 services per day when gas meter is in front yard.
- 60 to 80 or less services per day when gas meter is in backyard or in locked enclosure (older areas).

Frequency of leak detection is set locally by the gas utility and/or the public utilities commission. Typically, it may be once every 5 years in low-density residential areas to once or twice a year in areas where people congregate (shopping centers, churches, etc.)

Gas leaks are serious in the modern higher pressure gas systems being built today because gas leakage is proportional to the gas pressure. Gas companies have perfected equipment to isolate small sections of the gas distribution system so that repairs can be made. This is to avoid the high cost of relighting pilot lights.

Leak Detection Equipment

Two types of equipment are used:

- Wheatstone bridge apparatus.
- Flame-ionization unit.

The Wheatstone bridge apparatus functions by drawing a sample of air manually with an aspirator bulb over a sensor. The sensor is a platinum-wire filament coil which is connected to one arm of a balanced Wheatstone bridge operated at a controlled temperature. Any

Table 3-9 Some Available Sewer Models

Model name	Requirements	Function[a]	Available from
SEWER	Time-sharing terminal	Design, analyze, compute steady-state flow versus capacities	Mr. W. R. Vickroy MCAUTO Department K502 Post Office Box 516 St. Louis, Missouri 63166
POLYSEWR	Time-sharing terminal	Design and steady state analysis of sanitary and storm sewers (4 programs)	Control Data Corporation CYBERNET Services HQW05H Post Office Box 0 Minneapolis, Minnesota 55440
SWMM	Time-sharing terminal or large computer	Unsteady-state (real time) flow routing of runoff	Mr. W. R. Vickroy MCAUTO Department K040 Post Office Box 516 St. Louis, Missouri 63166 or U.S. Environmental Protection Agency or Software Companies who are in the process of converting SWMM to run on personal computers.
PRESSURE SEWER ANALYSIS	IBM PC/XT,128K and one disk drive	Analysis and design of tree-structured system of up to 200 pipes	SYSTEK, Inc. P.O. Drawer 6234 Miss. State, Mississippi 39762
SEWER	PC with 256K MS-DOS(PC-DOS)	Analysis and design of sewer network up to 800 reaches and 500 manholes	CIVIL SOFT Suite 100, 290 S. Anaheim Blvd., Anaheim, California 92805
HYDRAU	IBM PC	Hydraulic analysis of full pipe wing manning formula	First Principles Software Post Office Box 4236 Santa Rosa, California 95402
ISSAD	IBM PC, 128K, two disk drives	Interactive analysis of storm drainage networks	Engineering Services 901 Douglas Ave., Suite 206 Altamonta Springs, FL 32714
BLPSSAD I	PC with 48K, one disk drive	Separate programs for analysis of existing sewer systems and design of new systems.	Hilbern Engineering Software 8892 Isleworth Court Orlando, Florida 32819

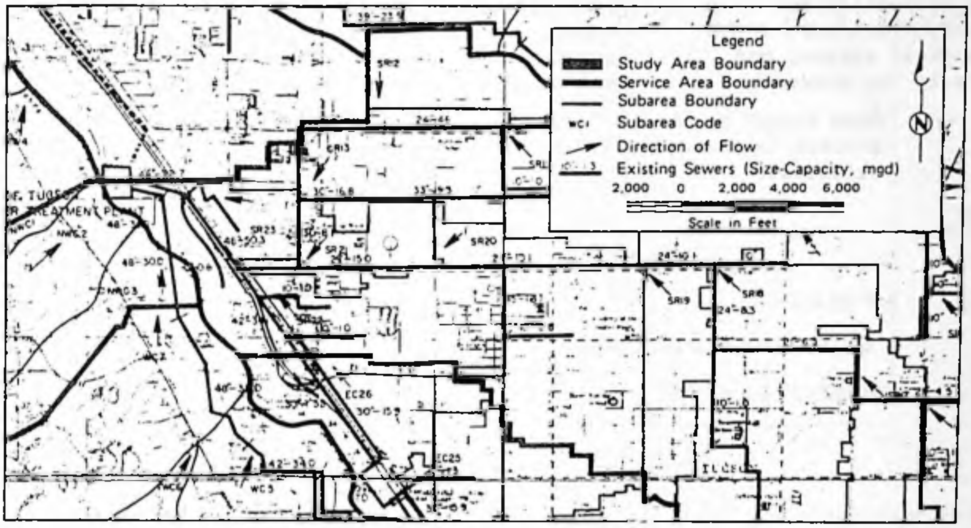
[a]Steady-state analysis unless otherwise noted.

combustible gas present is burned and raises the coil temperature, changing its electrical resistance and generating a voltage, which in turn creates a signal output that is proportional to the gas concentration. Figure 3-33 shows one of these portable units in use. The cost for the basic unit is about $400. This equipment is used by gas servicemen and gas crews but generally not for routine leak detection surveys.

Using Gas Distribution System Models

Gas distribution system models are applied in a similar manner to water distribution system models. The principal difference is that a compressible fluid, natural gas, is being modeled. A potential user must go through the same steps of determining his objectives, selecting a model, preparing the input data, calibrating and then applying the model to his problem.

Figure 3-30 An Example of Dividing a Planning Area into Sewerage Service Subareas--Metropolitan Tucson, Arizona



The flame-ionization unit is more sensitive and can be used by a person on foot or can be mounted on the front of a vehicle. Figure 3-34 shows both installations. The unit works by releasing a controlled amount of fuel gas to detector cell, along with an air sample drawn by a small electrically operated fan. The fuel and sample are consumed within the chamber, and ionization occurs when combustible hydrocarbons are present. The rate of ionization is electrically measured and converted to a visual indicator. These units cost $3,500 to $4,000 and are typically used for required leak detection surveys.

Pressure Regulation

Although not a rehabilitation method per se, careful pressure regulation is another technique gas companies use to minimize leakage. By only distributing the gas pressure needed, leakage rates can be reduced to a minimum. For example, much higher pressure is needed in the winter time than in the summer because of higher heating demand. By changing the pressure to match demand losses are reduced. This may obviate the need to do rehabilitation.

Table 3-10 describes capabilities of three commonly used models, one for steady-state analysis and the other for transient effects. Both are available from Stoner Associates, P.O. Box 86, Carlisle, PA 17103. GASSS, a computer program, has been in use since 1971 and by 1982 over 60 United States natural gas companies were using the program. Similar models are available from Control Data Corporation and others. Software companies advertise in technical gas journals. The potential user should review the water distribution system modeling section of this chapter for general guidance and then obtain users' manuals for computer programs that meet his needs and follow the calibration procedure described in those manuals.

ELECTRIC DISTRIBUTION SYSTEMS

In planning for redevelopment, the physical condition of electric distribution systems should be evaluated to determine whether improvements are needed to adequately serve the anticipated demands for the area. Unless the utility is city-owned, the serving utility is primarily responsible for the system's physical condition. Planning should be coordinated to assure that the system is reliable, meets aesthetic values considered important, and has the needed capacity. Key steps for making this evaluation are outlined below.

Reliability

To evaluate the reliability of electric power for a redevelopment area, obtain and review the outage records for the past 5 years. Most serving electric utilities detect and record the nature, frequency, and duration of outages on their system, and these records are available to the interested public.

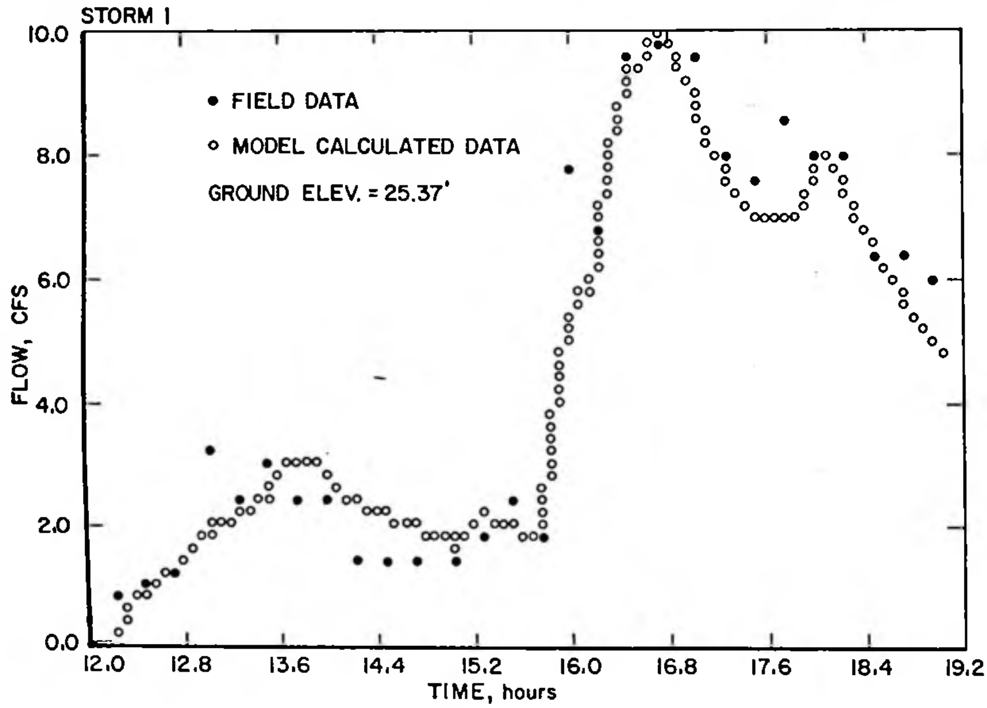
Project the outage history for the first 5 years of completed redevelopment and evaluate the consequences of similar outages for the new occupants. List the prospective occupants and their degree of need for uninterrupted power. Occupancies such as hospitals and manufacturing and certain commercial establishments may have a critical need, but most businesses and residences would not.

Aesthetics

Visit the redevelopment site and drive through the streets. Identify the visible components of the electrical system, such as transmission lines, substations, vaults, distribution lines, poles, transformers, and service drops. Take photographs or make notes of each item, listing each observer's reactions and comments.

Ask questions of the design team and other interested parties about their reactions toward the visual effect of the existing facilities. If they have concerns, ask how they might like to see them resolved. Coordinate with the electric utility to integrate upgrading these facilities with the redesign plan.

Figure 3-31 SWMM Runoff Block Calibration Model Run, Broadway Street Between 1st Avenue and U Street, Sacramento, California

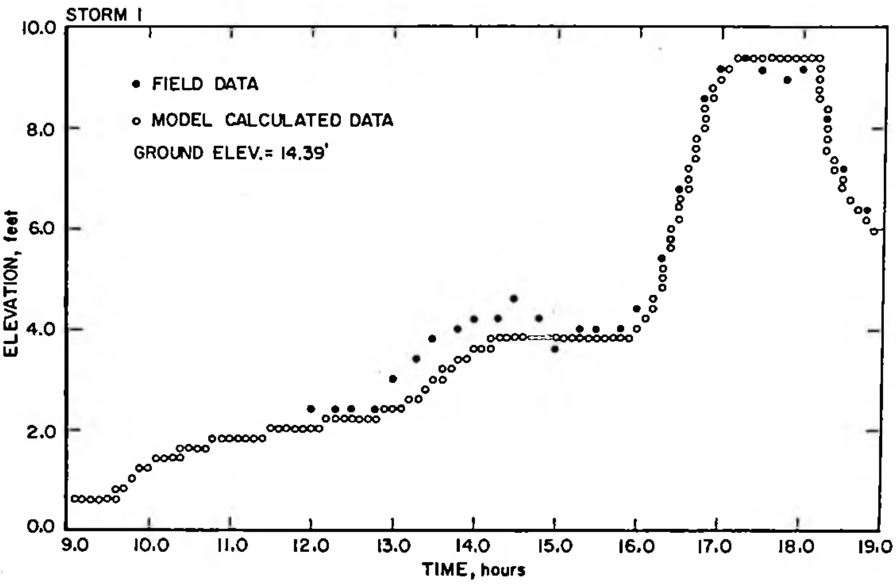


Capacity

One major consideration in evaluating the existing electrical distribution system is the adequacy of those facilities to serve the existing load and their ability to meet the future load needs. Since that information can be determined only by the serving electric utility, it will be necessary to request a report from them which summarizes the function of the major components and feeders as a minimum effort. To ensure that a formal response is prepared by the utility, it is recommended that this request be issued to them in writing. This request may also include other items of concern, such as the utility's plans in the redevelopment area, if any. See Chapter 6, Information Needed by Utility.

In urban redevelopment areas, storage and collection are the primary solid waste management concerns. Transport to an intermediate storage facility, called a transfer station, can be involved if the transfer station is located near the redevelopment area. Normally, solid waste disposal

Figure 3-32 SWMM Transport Block Calibration Model Run 5th and U Streets, Sacramento, California



(e.g., in a sanitary landfill located in a less developed area) is not an issue related to urban redevelopment. Therefore, this section focuses on evaluating the solid waste and collection system with some information on transfer stations and recycling. These topics are discussed generally, followed by specific discussions of litter control and institutional arrangements. Although this discussion is limited to nonhazardous waste management, there may be a need for cities, redevelopment agencies, and owners to address toxic and hazardous waste management. Land to be used for redevelopment may have been used as a dumping site for toxic or hazardous wastes, or industries may have stored, used, and/or manufactured toxic or hazardous materials on or near the area. If it appears possible that soil or groundwater is contaminated, qualified technical specialists must perform an investigation. If conditions cause a health hazard, the site must be cleaned up and made safe prior to any redevelopment.

Electric Distribution System Models

The Electric Power Research Institute (EPRI) in Palo Alto, California, is a good source of information on electric distribution system models. They have one, DLFTM, that can be used for distribution system load forecasting for areas approximately 160 acres in size. They have another PRAM/HISRAM for risk and reliability. PRAM calculates reliabililty indexes for each bus in a radial distribution system. It requires statistics of component reliability. HISRAM is used to analyze distribution system outage data.

SOLID WASTE MANAGEMENT

Solid wastes are materials that are discarded as useless or unwanted, commonly referred to as garbage or refuse.[16] Solid waste management is the task of assuring proper storage, collection, transport, and disposal of the solid wastes. Major concerns in solid waste management are protection of the environment, public health and safety, economics, recycling, and aesthetics.

Figure 3-33 Portable Gas Leak Detection Unit (Wheatstone Bridge Apparatus), Photo Courtesy Bacharach Instrument Company

Figure 3-34 Portable and Mobile Flame Ionization Units. Courtesy Heath Consultants

Assessing Solid Waste Management System Capacity

As discussed above, it is usually not practical or necessary to make significant changes in the type of solid waste management system for an urban redevelopment area. However, system capacity must be assessed to ensure its adequacy. Primarily, system capacity is capacity of the collection system, although container capacity and perhaps transfer station capacity also affect system capacity. Changes in waste quantities generated in a redevelopment area will occur if area population or land use change significantly.

A way to estimate future waste quantity is to estimate unit waste production expected from the new development. This could be in units such as pounds or cubic yards per capita per day, per housing unit per day, or per business per day. The most common unit is pounds per capita per day (lb/cap/day) which is applied to an overall population. An average overall generation rate for mixed residential and commercial wastes is 3.3 lb/cap/day, and for mixed residential, commercial, and industrial wastes is 5.2 lb/cap/day.[16] Each city's per capita rate is different and can be estimated by dividing the total waste disposed at a disposal facility by the population the facility serves. However, this unit generation rate may not apply to a redevelopment area that is all residential or all commercial. In this case, it may be better to estimate waste quantities generated in similar areas of the city and use that information to assess the adequacy of the collection trucks that serve the redevelopment area.

Table 3-10 Three Commonly Used Gas Distribution Models

Model name	Purpose	Capabilities	Application
GASSS	Determines balanced steady-state pressure flow	Gas variable components include: Panhandle A, Panhandle B, Weymouth, Spitzglass, fundamental equation, theoretical horsepower equation, centrifugal compressor equation, 4th degree polynomial HP/million curve, Fisher, Grove, reliance regulators, storage field equation	Natural gas production systems Gas transmission systems Gas distribution systems Municipal steam systems High pressure air supply systems Ventilation systems Btu-specific-gravity balancing
GASVARS	Performs variable state balances of pressure-flow relationships under time-varying conditions	Similar to GASSS but does extended time simulation making consecutive balances on steady-state analyses	In addition to GASSS applications, can also determine compressor fuel usage, evaluates storage field performance
GASUS	Models unsteady flows in gas network systems	Transient effects of: system failure, compressor failure, line pack swings, flaring problem, control equipment shut down	Compressor fuel optimization Dispatcher training Detecting system component malfunction Missing data interpolation On-line modeling Major leak detection Line pack estimation Detecting instrument inaccuracies

- Ninety-gallon plastic cans on wheels can be used for single or double residences and small businesses.

- Most multiple-family dwellings and commercial establishments use bins. Bin volumes typically range between 1 and 10 cubic yards (cu yd). Solid waste can be stored loose or compacted in these bins. Large, open-top bins called roll-off bins or drop boxes can also be used. These range in size from 12 to 50 cu yd.

- Containers must be easily accessible for collection, easily accessible to the users, and compatible with the collection equipment. Collection is discussed in more detail in a later section.

- Property owners are responsible for providing adequate storage and for maintaining cans and bins that remain

Storage

Solid waste storage refers to how wastes are stored at the point of generation prior to collection. Typically, this refers to outdoor storage rather than inside a home or a business.

Storage in Urban Areas. In urban areas, storage containers are typically garbage cans or bins. The containers must be compatible with the collection systems.

- Thirty- to 33-gallon garbage cans (metal or plastic) are used for single residences or small offices.

at the site. If the collector hauls the bins to the disposal site and replaces them with clean ones, the collector is responsible for maintaining them.

- Government agencies are typically responsible for providing adequate storage containers in public areas such as parks and streets.

Assessing Adequacy of Storage. The primary concerns in adequacy of storage are:

1. Sufficient storage volume.
2. Adequate measures for keeping the waste from being scattered by the wind or animals.
3. Easy access to the containers by the users.
4. Easy access to the containers for collection.
5. Aesthetically acceptable (primarily visual).

Assessing litter control in a redevelopment area is discussed in detail in a later section.

Solid waste storage for buildings is primarily the responsibility of the owners as enforced by the city. Adequacy of current storage practices at existing buildings can be assessed based on the four primary criteria listed above. The third and fourth criteria are of direct interest in assessing adequacy of current practices for the overall redevelopment area plans.

Collection

In urban areas, solid wastes are collected by either a city or a private collection company. The collection service (type of equipment, number of crew members per vehicle, and collection frequency) vary. Types of collection services are described below, followed by criteria for assessing the current collection system.

Types of Collection Service. Types and quantities of wastes, street layout, traffic patterns and volumes, and politics (e.g., labor unions) determine the type of collection service provided.

- Normally, residential waste is collected once or twice per week. Commercial wastes may be collected more frequently. Restaurant wastes are usually collected daily.
- Trucks with built-in compactors are used for collecting wastes from noncompactor bins and cans. These trucks can be either manually or mechanically loaded. The three most common types of compactor trucks are rear loaders, side loaders, and front loaders. Front loaders are always mechanically loaded and are used to load waste from bins. Rear and side loaders can be either manually or mechanically loaded.
- Very large open-top bins, 12 to 50 cu yd volume, are picked up by special trucks and hauled to the landfill to be dumped and returned to the site. This type of system is more commonly used at industrial facilities or construction sites than in residential or downtown commercial areas.
- Smaller "satellite" vehicles can be used for collecting wastes from 30- to 33-gallon cans. The wastes are then mechanically dumped into the larger trucks.
- The number of crew members per truck depends largely on the type of collection truck, the size and accessibility of storage containers, and union contracts.

Assessing Adequacy of Collection System. Criteria that can be used to assess the adequacy of the existing collection system for a redevelopment area include:

- Sufficient collection frequency to avoid litter, health, and odor problems.
- Compatibility of equipment with storage containers.
- Ability of collection vehicles to pass through alleys and streets.
- Collection activities scheduled for minimal disruption by traffic congestion.
- Appropriate collection equipment available for planned land use in redeveloped area.

Transfer Stations

Transfer stations are intermediate facilities where wastes from collection trucks are transferred to larger trucks for more economical hauling to disposal sites. A transfer station is built when the hauling time to the disposal site is too great for economical hauling in collection trucks. Unless a transfer station is located in, or very near a redevelopment area, its existence will not affect storage and collection practices in that area. If it is in, or near the area, traffic patterns and congestion and visual aesthetics, noise, and odor must be considered for the redevelopment projects and for the transfer station design and operation.

Recycling

Curbside collection, neighborhood drop-off centers, or recycling centers for recyclable materials (e.g., newspaper, aluminum cans, and glass) and special collection of office and computer paper may be part of the existing solid waste management system. These services may be provided by the city, a private recycling company (profit or nonprofit), the waste generators themselves, or a combination.

To assess the adequacy of recycling operations, some useful criteria are:

- Materials must be properly contained when placed outside for collection and when stored at neighborhood recycling centers. Proper containers prevent litter problems and inadvertant contamination of recycled goods. Proper containers, such as cans or strong bags or boxes, also ease collection in a curbside program.
- Collection of recyclables in a curbside program must be reliable and frequent enough to prevent litter problems.
- Neighborhood drop-off centers and recycling centers must be built and operated to prevent litter problems and to meet aesthetic standards, especially noise and visual. Fences should surround recycling centers and should be high enough to contain windblown paper. Containers at neighborhood drop-off centers should be visually aesthetic, must contain the materials, and must be emptied by the operator frequently enough to prevent overflow. Drop-off centers should also be fenced if windblown paper or visual aesthetics are problems. Traffic and equipment noise must be considered for recycling and drop-off centers.
- Traffic congestion in and around recycling and drop-off centers must be considered.

Litter

Litter is a major problem in urban areas. It is caused by solid waste blowing out of storage containers, storage containers overflowing, and people dumping wastes on streets, sidewalks, alleys, and vacant lots. The usual means for controlling litter are:

- Street sweeping.
- Adding more or larger storage containers at buildings, in parks, and on streets.
- Using containers with secure covers.
- Collecting wastes more frequently.
- Conducting public awareness compaigns.

Frequency of street sweeping is probably the biggest factor in controlling urban area litter.[17,18,19]

Assessing Adequacy of Litter Control. Visual inspection of the area for quantities, types, and locations of litter is the only way to identify the presence or absence of a litter control problem.[20] However, to truly assess the adequacy of litter control, the following steps are useful:

1. Compare the litter problem to similar areas of the city and to similar cities.
2. Identify all agency(ies) responsible for litter control, their budgets, and their political support. (Agencies typically include the department of public works and possibly special task forces and community groups.)
3. Identify the current litter control programs including street sweeping, manual cleanup, publicity campaigns, and education. Compare these to similar cities.
4. Identify litter ordinances, especially regarding requirements and enforcement.

When assessing the adequacy of litter control for the redeveloped area, the most important consideration is the expected land use. Special attention should be focused on open space areas, either underdeveloped areas or parks, since these areas are major sites of litter problems.[21] Frequency of street sweeping and manual cleanup and emphasis on enforcement of ordinances are the primary litter control measures to consider in this assessment.

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Chapter 3 discussed methods to assess the physical and capacity condition of utility systems. Rehabilitation can restore capacity by providing an upgraded, satisfactory performing system. Requirements for large increases in capacity usually mean the system has to be replaced with a larger system. This chapter presents techniques for using the results of the physical and capacity condition analysis, guidance on assessing the consequences of system failure, how to make a cost-effectiveness analysis, and how to use this information to make a decision. Financing rehabilitation/replacement, often the key to how fast the projects are built, is also discussed. Criteria to evaluate the program, once in place, are presented.

SETTING PRIORITIES

Deciding which utility segments to rehabilitate or replace, in what order, and by what method, or whether to continue to maintain and repair failures, is not easy. Each utility will develop its own way to make decisions. General guidelines are presented here.

Chapter 1 gave an overview of the steps to follow in decision making. Setting priorities involves Phases III and IV shown on Figure 4-1 and described below.

Phase III--Develop the Program Plan

This phase: (1) considers the needs identified in the structural and capacity evaluation phase, (2) establishes priorities for dealing with the problems, (3) assesses potential solutions, and (4) combines the solutions into cost-effective prioritized plans. There are four alternatives that should be considered:

1. Do nothing new. Maintain and repair as necessary.
2. Rehabilitate.
3. Replace.
4. Parallel.

Chapters 5 through 7 provides specific techniques to do rehabilitation or replacement.

Phase IV--Implement the Plan

This phase converts the plan into rehabilitated facilities. The prioritization of problem correction needs which is developed in Phase III allows a systematic approach in which the most serious problems are dealt with first. In many systems, funding limits will result in several years being required for complete correction of problems identified in the initial investigation. During the implementation phase, system conditions must continue to be monitored and priorities revised as necessary to reflect changed conditions.

Decision Making Factors

It is recommended that the following factors be evaluated quantitatively for each utility segment and made available to the decision maker:

1. Structural condition. See the sewer Structural Condition Matrix for example, in Chapter 3 in the section "Evaluation of Sewer Structural Conditons."

2. Consequence of failure. See the Failure Impact Matrix for example in this chapter.

3. Performance. For sewers, evaluate the area prone to flooding; for water and gas pipes, tabulate the present friction factor, energy, usage, low-pressure complaints; for electrical systems, show the outage history; for solid waste systems, rate the litter-removal efficiency. Techniques to do this with field data were presented in Chapter 3.

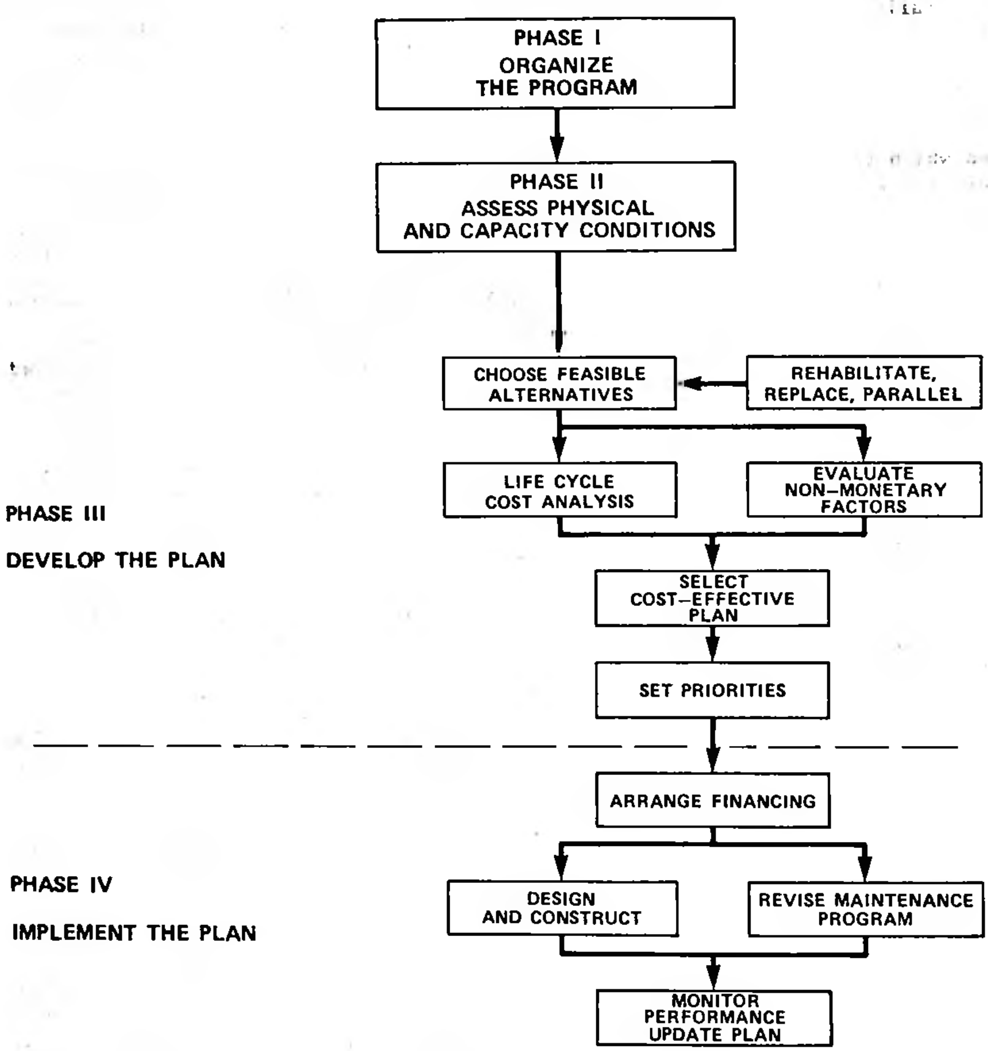
4. Capacity requirement. Tabulate the size or capacity of the replaced segment. If the present size of a pipeline is inadequate, this usually means the segment is a candidate for replacement and not rehabilitation (which usually reduces the size). Models to evaluate capacity requirements were described in Chapter 3.

5. Life-cycle costs. Display the costs for replacement and candidate rehabilitation methods. Project costs can be estimated from Chapters 5 through 7 and life-cycle costs from formulae given in this chapter.

CONSEQUENCES OF FAILURE

The physical condition, existing performance, or costs of operation and maintenance of a utility system element, such as a pipeline, are the major factors in determining which elements need to be rehabilitated or replaced. The order in which projects are done (or nothing is done) is based on other factors including the consequences of failure.

Figure 4-1 Phases III and IV of the Rehabilitation Process



Where a utility system contains problem areas and potential trouble spots too numerous to allow complete immediate correction, priorities need to be identified. Development of a priority order for problem correction which includes the consequences of failure is, of necessity, a subjective process. In this process, value judgments must be made as to the relative importance of service dependability in various areas of a community. The availability of construction money often dictates that failure importance distinctions be made literally on a street-by-street basis. Project priority selection should be based on a logical evaluation and decision process. To be supportable, the process needs to recognize that:

- The service consequences of failure are different depending upon the kind of development that is affected by the failure. Loss of service has varying importance depending on whether the service loss occurs in residential, commercial, or industrial areas or in areas which are blends of two or more of these development types.

- Service failure consequences can extend well outside the immediate area of the failed pipeline or power distribution element. If the failure occurs in a key system component such as an interceptor sewer or distribution main, it may affect a large area of development.

- For utilities such as water or sewer where a pipeline failure can cause failure of a street, the consequences of street failure (disruption of traffic and local access) must also be considered.

- The same forces which can collapse a street in water or sewer pipeline failure can also threaten other utilities, particularly underground power and natural gas distribution. Failures in underground power and gas lines may likewise threaten water and sewer facilities.

Failure Consequences Evaluation Approach

A comparative evaluation which leads to a relative importance ranking of system problems in view of failure consequences can be made using a scoring system. The scoring system can be devised to take into account the several failure consequences considerations identified above. The example which follows illustrates the evaluation approach. There are many possible variations which individual agencies may wish to adopt.

Failure Impact Categories. The failure consequences considerations described earlier can be grouped into failure impact categories and subcategories as follows:

1. Service disruption, consisting of:

   a. Local service impact

   b. Service impact outside the immediate area

2. Associated urban disruption, consisting of:

   a. Traffic disruption

   b. Disruption of utilities

The failure impact evaluation is aided by the use of an evaluation matrix in which each problem is subject to numerical scoring.

Numerical Scoring. A numerical scoring system allows a grading of problem areas to establish their relative importance in regard to failure consequences. The scoring system needs to:

- Give recognition to the relative importance of the various kinds of failure impacts.

- Give recognition to differences in the extent of impacts that will be associated with failure events in individual problem areas and failure instances.

The relative importance of the various kinds of failure impacts are taken into account by assigning importance weighting factors to the various impact subcategories. The differences in the extent of impacts are taken into account by individual scores assigned to the various impact categories for each individual problem area.

Failure Consequences Matrix. A simplified example matrix is shown in Table 4-1. The example matrix is for evaluating the consequences of failure in a combined storm and sanitary sewer system. The matrix is to be completed for each individual problem area in the system.

The example matrix shows two failure impact categories, each with two subcategories. There are three levels of impact for the impact subcategories. These impact levels (slight, moderate, and severe) have impact scores of 1, 2, and 3, respectively.

In our example, the impact ratings for the various impact subcategories are determined as follows:

1. Local service impact is rated assuming a complete failure in the pipeline reach being examined. The rating is selected based on: (1) the time required to restore the failed pipeline to service and (2) the likelihood that physical damage will occur from sewer backups and flooding, etc., in the time between the pipeline's failure and its restoration. The extent of the affected local area is also considered.

2. Tributary area impact is rated based on the tributary area size and the presence or absence of alternative flow paths from the tributary area around the failed pipe section. Restoration time is also considered.

3. Traffic and access impact is rated based on the assumption that the pipeline failure will cause street damage and/or require excavation within the street during repair. The rating is based on the normal traffic volume and the expected duration of traffic disruption while pipeline and street repairs are made.

4. Other utilities impact is rated based on the kind of other subsurface utility (i.e., water, natural gas, and/or power) which might be damaged by earth movement associated with the sewer collapse and the extent of that utility's service area. The rating of "severe" would, for example, be assigned if a major natural gas distribution main were located close to the pipeline. This rating would be based on both the potential safety hazard which would accompany a gasline rupture and the likelihood that a large service area would be impacted by the gas line's loss.

service disruption and both are considered significantly more important than residential service disruption. In this case, we would assign an Importance Weighting Factor of: 1, if tributary service area development is residential; 2, if the development is mixed residential/commercial; 3, if development is commercial; and 4, if development is industrial. The weighting factors selected for the example are for illustration of the concept and should not be taken as applicable to all communities. The utility must assign service area type weighting factors based on its own view of service reliability priorities and relative importance.

Table 4-1 Example Situation Matrix-Location: 20th Street--K Street to L Street

Failure impact category	Importance weighting factor	Extent of impact		
		Slight (Score 1)	Moderate (Score 2)	Severe (Score 3)
1. Service disruption:				
a. Local service	2		4	
b. Tributary area service	2			6
c. Service disruption score	-		10	
2. Other urban disruption:				
a. Traffic and access	2		6	
b. Other utilities	3			9
c. Subtotals	-		6	9
d. Depth of cover/pipe size factor	2	-	-	-
e. Other urban disruption score	2	-	30	-
3. Failure consequences index			40	

Weighting factors assigned to "local service" and "tributary area" impact subcategories allow adjustment of raw scores applied in the "extent of impact" columns to reflect the scorer's judgment as to the relative importance of service disruption in various kinds of developed areas. In this example, three kinds of developed areas (residential, commercial, and industrial) are recognized. The example gives greatest importance to maintaining "local" and "tributary area" service in the industrial areas and least importance to maintaining residential service. In this example, industrial service disruption is viewed as only slightly more important than commercial disruption in various kinds of developed

The importance weighting factor assigned to "traffic and access" impact is the same factor used with the "local service" impact. The importance weighting factor assigned to "other utilities" impact is based on the other utility's service area type. The factors are the same as used for the various sewer tributary area types.

The "Depth of Cover and Pipe Size" weighting factor recognizes the bearing of these parameters on the size of hole that could develop at the site of the pipeline collapse. The following factors are suggested:

Pipe diameter, inches	Depth of cover, ft: Less than 10	10 to 15	More than 15
Less than 18	1	1	1
21 to 27	1	2	2
30 to 36	2	2	3
42 to 54	3	3	4
60 to 72	3	4	4
More than 72	4	4	4

With the weighting factors selected and the extent of impact identified:

1. The extent of impact values (1, 2, or 3) for the "local service" and "tributary area" impacts are multiplied by the weighting factors and the products are entered in the matrix under the headings "slight," "moderate," or "severe."

2. The entries in the matrix are summed to obtain the "Service Disruption Score."

3. The extent of impact values (1, 2, or 3) for the "traffic and access" and "other utilities" impacts are multiplied by the weighting factors and the products are entered in the matrix under the heading "slight," "moderate," or "severe."

4. The matrix entries for Matrix Items 2a and 2b are summed to obtain the subtotals entry for Matrix Item 2c.

5. The subtotals in Matrix Item 2c are multiplied by the "Pipe Size and Depth of Cover" weighting factor and summed to obtain the "Other Urban Disruption" score.

6. The service disruption and other urban disruption scores are summed to obtain the "Failure Consequences Index."

Table 4-1 is an example of this method applied to the following situation:

- 24-inch concrete sewer with 20-feet depth of cover and located in a commercial area.

- Average repair time after failure, some basements would be flooded.

- Sewer tributary area is moderately large.

- Four-lane street would suffer traffic disruption but would not be closed during repair.

- 20-inch gas main located in same street.

The Failure Consequence Index values will be found to vary across a wide range when there are numerous problem areas in a system. Inspection of the whole array of index values will usually disclose groupings of values which can be assigned the same consequences of failure correction priority. Table 4-2 shows the index ranges which produced four correction priority groups in a recent application of a failure impact matrix analysis at Sacramento, California.

Table 4-2 Sewer Failure Impact Priority Groups

Failure consequences index	Priority groups[a]
≤ 30	4
31 - 40	3
41 - 50	2
≥ 50	1

[a]Consequences of failure are the most serious for Priority Group 1 sewers and least serious for Priority Group 4 sewers.

This approach could be adopted to water and gas pipelines by evaluating the consequences of failure in a similar fashion to that used for sewers. Local service area disruption would be of a different nature but could be rated slight, moderate, and severe. Importance weighting factors would probably be the same. The depth of cover and pipe size factor would need to be modified because a hole probably would not develop as in the case of a sewer collapse. The size of hole would be that required for excavation and repair. The excavation would cause traffic disruption and might affect other utilities. With lower other urban disruption likely, the Failure Consequences Index would probably be lower than for sewers. Therefore, the relation to priority groups that was presented in Table 4-2 would need to be modified to display differences and so that some pipelines end up in priority group 1, assuming that is appropriate. The above method could also apply to electrical distribution lines but not to solid waste systems. In summary, this is a useful method for assisting utility engineers but it is no substitute for professional judgment and experience.

LIFE-CYCLE COSTING

Life-cycle costing is a method of calculating the total project cost over the life of the project including the initial cost, annual operation and maintenance cost, and replacement costs. It is an especially good method for comparing costs of projects that have high operation and maintenance costs or high replacement costs. This method can be effectively used for comparing costs of pipeline repair, replacement, and rehabilitation over the planning period. The repair alternative involves high annual costs while rehabilitation or replacement involve initial costs and lower operation and maintenance costs.

Life-cycle costing compares total cost by converting all costs over the planning period to present worth in a common base year or to average annual costs. Only the present worth method is described here. Formulae for calculating present worth and some guidelines for selecting an appropriate interest rate are presented below, followed by a short discussion of cost factors to consider when doing a life-cycle cost analysis.

Present Worth Formulae

The total present worth of a project is the sum of the initial cost and discounted subsequent costs minus the discounted salvage value at the end of the analysis or planning period. Discounting future costs and salvage value accounts for the time value of money. Subsequent costs include operation and maintenance, repair, replacement, and expansion costs.

Three basic formulae are used to calculate present worth of future costs. The symbols used for these formulas are:

- i = interest rate per period.
- n = number of interest periods.
- P = present worth (or present value).
- F = future worth (or future value).
- A = uniform sum of money in each time period.
- e = expected annual rate of inflation.

The formulae are listed and briefly described below. For a more comprehensive discussion, and prior to using this method for decision making, the reader should consult an economics text.

1. $P = F/(1 + i)^n$ where $1/(1 + i)^n$ is called the single payment present worth factor.

   This formula is used to determine the present worth (P) of one future payment or income (F) discounted at interest rate (i) for (n) interest periods.

2. $P = A((1 + i)^n - 1)/i(1 + i)^n$. This formula is used to determine the present worth of uniform payments or income of (A) per interest period discounted at interest rate (i) for (n) interest periods.

3. $P = (A(1 + e)/(1 + i)) + (A(1 + e)^2)/(1 + i)^2) + \ldots + (A(1 + e)^n/(1 + i)^n)$. This formula is used to find the present worth of an annual cost (A) that is expected to increase at a constant rate (e) for (n) interest periods.

To use these formulae directly, the interest periods start from the present. If annual payments are expected to start after the first interest period, calculate the "present worth" for n = number of periods the payment will be made using formula 2, then calculate the true present worth, using the present base year and formula 1 with n = the number of interest periods from the present base year to the first annual payment.

When comparing the present values of projects, a common present base year, planning period, and interest rate must be used.

Interest tables, found in most texts on economic analysis, save a lot of time when calculating present worth. Table 4-3 shows values for $1/(1 + i)^n$ and $((1 + i)^n - 1)/i(1 + i)^n$ for common interest rates and 5-year intervals up to 40 years.[1] Because of the difficulty of projecting costs, 20 years is a frequently used planning period.

Choosing an Interest Rate

There is much controversy over the best way to choose the interest rate for economic analyses. Selecting an interest rate equal to the opportunity cost of money is the proper method from an economist's point of view. This is the "rate of return available on projects with equivalent risks."[2] However, the opportunity cost is difficult to estimate. Therefore, more commonly, an interest rate, equal to the average borrowing rate, is used. Normally, the interest rate is a compound rate that includes both the real rate and the inflation rate.

Table 4-3 Abbreviated Present Worth Factor Tables

Number of periods, n	Interest rate, percent											
	Single payment present with factor $\frac{1}{(1+i)^n}$						Uniform annual serves present worth factor $\frac{(1+i)^n - 1}{i(1+i)^n}$					
	7	8	9	10	11	12	7	8	9	10	11	12
5	0.7130	0.6806	0.6499	0.6209	0.5934	0.5674	4.1002	3.9927	3.8896	3.7908	3.6959	3.6048
10	0.5083	0.4632	0.4224	0.3855	0.3522	0.3220	7.0236	6.7101	6.4176	6.4176	5.8892	5.6502
15	0.3624	0.3152	0.2745	0.2394	0.2090	0.1827	9.1079	8.5595	8.0607	7.6061	7.1909	6.8109
20	0.2584	0.2145	0.1784	0.1486	0.1240	0.1037	10.5940	9.8181	9.1285	8.5136	7.9633	7.4694
25	0.1842	0.1460	0.1160	0.0923	0.0736	0.0588	11.6536	10.6748	9.8226	9.0770	8.4217	7.8431
30	0.1314	0.0994	0.0754	0.0573	0.0437	0.0334	12.4090	11.2578	10.2736	9.4269	8.6938	8.0552
40	0.0668	0.0460	0.0318	0.0221	0.0154	0.1075	13.3317	11.9246	10.7574	9.7791	8.9510	8.2438

On federally funded projects, the federal government sets the interest rate. Individual state and local governments set their own interest rates. Two suggested methods for setting state and local rates are:

1. Use the yield rates on the governmental agency's long-term bonds, increased by 1-1/2 percent to adjust for their tax exempt status. The minimum interest rate should not be less than the average yield rate on long-term United States Bonds over a recent business cycle.[2]

2. Use the highest of (a) the interest rate on borrowed capital, (b) the opportunity cost of capital to the governmental agency, or (c) the opportunity cost of capital to the taxpayers. Typically (c) will be the highest.[3]

The considerations for selecting an appropriate interest rate are too complex for full explanation in this manual. However, it is important to understand that the selected interest rate affects the outcome of an economic analysis. For accurate analysis, care must be taken in making that decision.

<u>Selecting the Project Design Life</u>

When the alternatives of continued operation and maintenance (repair), rehabilitation, or replacement are evaluated, they are likely to have different design lives. The annual operation and maintenance costs, which should be less after rehabilitation, or replacement, are converted to present worth, using the uniform annual series present worth factor. Replacement of a pipeline is usually expected to last 50 to 100 years. If the planning period is only 20 years, then the pipe will have a salvage value that should be considered.

<u>Salvage Value</u>. Normally, straight-line depreciation is used. If a pipe is expected to last 100 years, then at the end of 20 years it still retains 80 percent of its value. The present worth of the project is then reduced by the discounted salvage value. For example, with an interest rate of 10 percent, planning period of 20 years, and design life of 100 years, the fraction of the original project cost that is subtracted from the present worth of a project built in year 1 is (referring to Table 4-3) 0.8 x 0.1486 = 0.12. That is, the present worth of the capital cost is 0.88 times the project cost. The shorter the design life, or longer the planning period, or higher the interest rate, the less the impact of salvage value has on the total present worth.

<u>Rehabilitation Design Life</u>. Experience with rehabilitation has been too recent to select the design life with the same

confidence as for new pipes. Guidelines for pipelines are:

- Grouting of pipeline joints appears to last 5 to 20 years.
- Pipe insertion with materials that are also used for new pipes should last at least as long as the new pipe, perhaps longer because the pipeline has already been stabilized.
- Procedures that coat the pipe, such as cement mortar lining, cannot be expected to last as long as a new pipe design life, depending on the chemistry (corrosivity) of the transported fluid.

Note that the salvage value for the above example (as a fraction of project costs) would have been 0.09 for a design life of 50 years and 0.03 for a design life of 25 years. The change is much more significant when going from 50 to 25 years rather than 100 to 50 years. Therefore, design life importance is related to the importance of salvage value in the analysis and, in general, use of approximate design lives, based upon engineering judgment, is satisfactory.

EXAMPLES OF THE DECISION MAKING PROCESS

It is not possible to provide a universal method for making this decision that would apply to all utilities. A few good examples will help illustrate what others have done.

Water Pipes

Figure 4-2 is the procedure used by the East Bay Municipal Utility District to evaluate whether to replace a water pipe or to continue to repair and maintain the pipe.[4] Cost numbers were deleted as they only apply to this utility. The calculation of benefits is based mostly on engineering judgment and would have to be tailored to each utility's situation. This procedure does not consider rehabilitation but could be modified to do so. A parallel calculation to the annual cost of replacement could be made for each feasible rehabilitation technique using cost data presented in Chapter 5. The Dallas Water Utility also uses a formal procedure to make decisions. Walski has developed a mathematical procedure to decide whether to replace a water pipe or clean and cement-mortar line it.[5] This reference is recommended reading for those utilities facing this decision.

Application to the Water Main Break Problem. Shamir and Howard[7] were first to develop economic replacement criteria incorporating a model of future pipe breaks. Walski and Pelliccia,[8] in conjunction with the U.S. Army Engineers, Baltimore District, applied a modified version of the method to Binghamton, New York.[9] The U.S. Army Engineer District, Buffalo,[10] also applied the formulae developed by Walski and Pellicia to a study for Buffalo, New York. With the approach, it is possible to identify individual pipes which need to be replaced. The AWWA paper by Walski and Pelliccia[8] contains an equation to calculate the critical break rate in breaks per year per mile. When the current break rate exceeds the critical rate, the pipe should be replaced. In this case, it is assumed that the pipe is in too poor a condition to be rehabilitated (cleaned and lined).

Sewer Pipes

Table 4-4 is an example of how much of decision-making information was displayed in a table and used to set priorities for rehabilitating a combined sewer system in Sacramento, California.[6] The structural condition priority was described in Chapter 3, the failure priority group impact was described above. Flooding relief was based upon Stormwater Management Model (SWMM) model output (see Chapter 3) as follows:

- Priority 1--Recommended sewer sizing would reduce the volume of local flooding 20,000 cubic feet or more for the design storm.
- Priority 2--Sewers in this group should be increased in capacity before upstream capacity changes are made.
- Priority 3--Will reduce local flooding less than 10,000 cubic feet.
- Priority 4--No apparent effect on flooding.

Table 4-4 shows composite priorities which are based on two or three factors. This is done by grouping similar priorities together and ranking them in each group. This method may not be applicable to other cities without modification. It is only an example.

FINANCING INFRASTRUCTURE REHABILITATION

This manual focuses on how to cost-effectively do rehabilitation. Municipal funding limitations usually mean that nothing will be done until the problem reaches crisis proportions. At this stage, rehabilitation options are fewer, replacement more likely, and costs are inevitably higher. In most cases, it will take innovative financing to fund a rehabilitation project before a crisis develops. Both traditional and innovative methods should be considered.

Revenue Methods

Table 4-5 lists commonly used utility revenue. Recently there has been a shift away from property tax financing to user fees. User fees are often billed upon metered use of

Figure 4-2 Water Pipe Replacement Education Form Used by East Bay Municipal Utility District

EBMUD

Pipe Replacement ECONOMICS

LOCATION

DATE

ANNUAL COST OF MAINTENANCE

Avg. Cost of Repair $
Current Repair Freq.
Major Repair Factors ☐
ANNUAL COST $

ANNUAL COST OF REPLACEMENT

Cost per foot $
Length
Length Factor
Present Worth $

Capital Recovery Factor
Life of Pipe
Interest Rate
ANNUAL COST $

BENEFIT/COST RATIO

BENEFITS: $

(Ratio of all benefits to be gained by replacement to the cost of the replacement.)

Reduced Maintenance
Reduced Damage Claims
Improved Public Relations
Improved Fire Protection
Improved Operational Flexibility
Added Capacity
Water Quality Improvements

TOTAL BENEFITS $

RATIO:

Sulfur Compound Jt. Factor ☐

ANNUAL COST MAINT./REPLACEMENT ____ TO 1

TOTAL BENEFITS/REPLACEMENT ____ TO 1

REPAIR & INSTALLATION COSTS

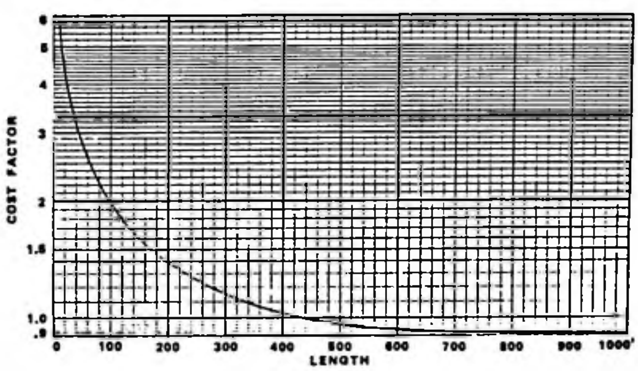
Figures are derived from cost experience and includes . for overhead.

REPAIRS

COSTS	SIZE & KIND: 2" MAINS	4" C.I.	6" C.I.	8" C.I.	10" C.I.	12" C.I.	16" C.I.	4" A.C.	6" A.C.	8" A.C.	12" A.C.
MINOR											
AVG.											
MAJOR											

INSTALLATION

SIZE & KIND	COST
6" A.C.	
8" A.C.	
6" STEEL	
8" STEEL	
12" STEEL	
16" STEEL	



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the utility (water, gas, electricity, and sometimes sanitary sewer using metered water use). Rate increases are problematical and it is difficult to finance a large rehabilitation effort this way. Nevertheless, many utilities are using this source of revenue to do some rehabilitation projects every year. It is handled as a budgeted maintenance item. Connection fees are almost exclusively used to finance utility system expansion. They are only useful in a growing city, and are not a dependable source for older cities.

beneficiaries can be clearly identified and vote to approve the project. It has potential for rehabilitation financing but determining who benefits will be more difficult, particularly in the central city where large through-city transmission pipes may be in need of repair. State and federal grants, commonly used for wastewater treatment, are diminishing and very little of the money has been used for rehabilitation.

General obligation bonds issued by cities are effectively constrained in some states

Table 4-4 Rehabilitation/Replacement Priority Development

Sewer	Block[a]	Structural condition priority group[b]	Failure impact priority group[b]	Flooding relief priority group[b]	Priority considering structural condition and failure impact[b]	Priority considering all factors, including flooding relief[c]
7th Street	D/E to F/G	1	4	4	2	2D
	F/G to G/H	1	4	4	2	2D
	G/H to H/I	4	4	4	4	4C
	H/I to I/J	3	2	4	2	2D
	I/J to J/K	4	2	4	3	3D
	J/K to K/L	4	3	4	4	4C
	K/L to L/Capitol	1	4	4	2	2D
	L/Capitol to Capitol/N	2	3	2	2	2B
	Capitol/N to N/O	4	3	2	4	4A
	N/O to R	4	3 to 4	4	4	4C
13th Street	F to G/H	3	4	3	4	4B
	G/H to H	3	3	3	3	3C
N Street	18th to 20th	3	2	1	2	2A
	20th to 22nd	3	1	1	1	1A
	17th to 20th (clay sewer)	4	2	4	3	3D

[a]K/L and L/Capitol, etc., designations refer to the alleys which intersect numbered streets between K and L Streets and L Street and Capitol Avenue, etc., respectively.

[b]Priorities vary from 1 to 4 in decreasing order of importance.

[c]Priorities vary from 1 to 4 in decreasing order of importance. The designations 1A, 1B, 1C, etc., indicate decreasing order of importance within the priority 1, 2, 3, etc., groups.

Source: Brown and Caldwell, Sacramento Central City Sewer System Study (See Chapter 3 References).

Financing Methods

More and more utilities are turning to new and innovative financing methods to come up with money for special projects, such as rehabilitation. Table 4-6 lists a number of methods that have been tried or suggested.

Special assessment districts are commonly used to build a new sewage collection system or local flood control project where the

(California, for example), and are difficult to get voter approval on in others. Revenue bonds are one of the best methods utilities can use to finance a major rehabilitation program. Identifying a revenue base from the project may be difficult, however. Revenue bonds are commonly used to build water and wastewater treatment plants. Certain types of utility agencies have authority to issue these bonds without voter approval. For additional information on these methods, the reader should consult a recent text on municipal finance.

Table 4-5 Revenue Methods for Utility Rehabilitation

Method	Normal purpose	Advantages	Disadvantages	Where used
User fees	Finance operations, pay off indebtedness	Equitable; secure	Difficult to get rate increases approved	Primary basis for funding small rehabilitation projects
Connection fees	Build capital reserve for expansion	Easier to raise than user fees	Only applicable if area growing	Not specifically used for rehabilitation
Property tax	Instead of user fees	Secure, steadily escalating	Unpopular now with voters	Not specifically used for rehabilitation

Competition for moneys from the Department of Housing and Urban Development (HUD) Community Development Block Grant Program is keen and in the past, about 20 to 25 percent of the money has been spent for public works projects (with water and sewer being about 10 percent). Almost exclusively these public works projects have been new utilities on the redevelopment site. Off-site utility improvements in the host city have rarely been funded, however, they are eligible for these moneys.

About 650 large cities (over 50,000 population) and 80 large counties (over 200,000 population) get money from the entitlement portion of this program. In 1983, about $2.5 billion was distributed based upon a statutory formula. The nonentitlement portion for small cities and counties (populations less than 50,000 and 200,000, respectively), is administered by most states. The money is usually awarded competitively by the state. Each state sets its own priorities. In 1983, about $1.0 billion was distributed this way. Rehabilitation projects within small cities and counties are also eligible for this money.

Tax-exempt commercial paper (TECP) is only used prior to issuing bonds or some other long-term financing method. It is popular in times of unstable financial markets. TECP can be reissued in maturities from 1 to 365 days. Hence, they are relatively low risk investments and carry low interest rates. A letter or line of credit is needed and there is a generally accepted $25 million minimum.

States have well used several ways to get low interest financing for city public works projects. A qualified bond program was set up in New Jersey in 1976 to get low interest money for Newark and Jersey City. The bonds are issued by the city but guaranteed by the state. These bonds carry a low interest rate, mainly because they are tax exempt. They are a variation on general obligation bonds.

At least seven states now have bond pool banks where a state agency will put several small bond issues together into a single larger issue. This provides considerable savings in underwriting costs, resulting in higher bond ratings and lower interest rates. If the bond pool bank is backed by the credit rating of a state, then interest rates can be lowered further.

The Texas Water Development Fund has similar characteristics but is different, and has been used since 1957 to finance municipal water projects. The cities' borrowing rate is one-half of a percentage point above the weighted average of the state's last three bond issues. In 1982, this rate worked out to 5.6 percent and the terms of the loans were 20 years or less. New Jersey is also setting up a similar type operation.

Various other types of bonds listed in Table 4-6 have been used by cities to try to attract capital.[11] Some of the more popular ones are floating fixed rate bonds and adjustable fixed rate bonds. They acheive interest rate nearly as low as those of TECP but the risk of the rise of interest rate changes to the borrower.

Privatization is a new financing method made possible by federal tax law changes in 1981 and 1982. However, new legislation may restrict its use in the future. Typically, private investors finance a new public works project with their own money and then take the tax benefits associated with private ownership. They sell the services the project provides to a city or other municipal agency but not directly to the public. Because of large tax write offs, the investors can offer these services at a lower cost than the city would have paid if it had financed and owned the project itself.

Table 4-6 Financing Methods for Utility Rehabilitation

Method	Normal purpose	Advantages	Disadvantages	Where used
Community Development Block Grants (HUD)	Redevelopment project funding	Substantial revenue source	Rehabilitated utility should serve redevelopment project. Competition for funds is high	Primarily used for on-site utilities
Special district	Fund construction of local serving projects	User fees pay entire cost	Requires majority approval, may not all benefit equally	Usually only for new construction
State and federal utility grants	Common for wastewater treatment	Lower cost to local users	Grant money now difficult to get. Time-consuming procedures to follow	Most cities have received grant in past
General obligation bonds	Fund capital improvements	Tax-exempt, low interest rates	Requires two-thirds voter approval, credit analysis is complex, may need to raise taxes, subject to debt ceiling	Not used for rehabilitation
Revenue bonds	Fund capital improvements	Usually does not require voter approval, tax-exempt, credit analysis is straight forward, often not subject to debt ceiling, users pay for facility	Relatively high interest rates, smaller market for bonds, may have restrictive covenants	Used for some large rehabilitation projects
Industrial development bonds	Promote industrial and commercial development	Low-cost financing, may attract economic investment, marketable due to high yield	May crowd out other demands on municipal bond market, public purpose sometimes questioned	New development and redevelopment
Tax-exempt commercial paper	Construction financing	Low interest rates, variable maturity, easy to increase amount outstanding	Temporary, high initial costs, usual $25 million minimum, need letter or line of credit	Used in anticipation of proven source of revenue or financing
Qualified bond program	Fund capital improvements	Utility may get a higher investment rating (lower interest rate)	State approval required, extensive reporting requirements	Newark, Jersey City, New Jersey
State bond pool bank and leveraged equity bond bank	Fund capital improvements	State's strong credit rating allows low interest loans to cities	Requires state legislation to form authority	Texas Water Development Fund; New Jersey bonding authority for water systems; Alaska, Maine, North Dakota, New Hampshire, and Vermont, have bond pool banks
Other types of bonds (see below)[a]	Fund capital improvements	More attractive to investors, lower interest cost	Issuer faces uncertainty in debt service planning, may require backup credit	Limited use to date
Privatization	Fund capital improvements	No voter approval, no risk to utility, lower annual costs. Tax incentatives for investors	Complex, subject to IRS interpretation, loss of day-to-day control	Chandler, Arizona, wastewater treatment plant

[a]Zero coupon, compound coupon, put option, floating fixed rate, adjustable fixed rate, bonds with warrants.

Investors use some combination of investment tax credits, (where applicable), tax-exempt financing involving industrial development revenue bonds or municipal leases, accelerated depreciation, limited arbitration during construction, and Public Utilities Regulatory Policy Act avoided-cost regulations for sale of excess electricity to utilities. Use of these tax benefits is subject to Internal Revenue Service constraints. Most of the tax benefits are unavailable to the investor if the public agency retains an economic interest in the project. Thus, the public agency must divorce itself from the project and give up day-to-day control. Arrangements with the investors are embodied in a long-term service contract with the investors.

The principal advantages to the public agency are:

- No voter approval required.
- No effect on bonding limits.
- No capital expenditure.
- Facilities are built to city specifications and performance is warranted.
- Financial risk shifted to investor.
- Annual costs are 10 to 20 percent lower than for conventional bond financing.

To date, privatization of public works projects has only been tried in a few places. The City of Chandler, Arizona's, new wastewater treatment plant is an example. To use this method for a public water distribution or sewer collection system, rehabilitation would require modifying the approach being used for treatment plants. The land under the pipe would need to be leased by the investor, the rehabilitated pipe would be privately owned, and a service contract would still be needed. It would probably be most practical to apply this concept to a larger portion of the collection/distribution system and then lease the nonrehabilitated portions back to the city. The service fee the city pays would reflect the investors lease payments for land and unrehabilitated pipe. Investor's tax benefits would be based only on rehabilitated pipe. The years ahead will undoubtedly see these and other private funding concepts put into action since it is clear the public sector does not have the money it needs for utility rehabilitation, and the private sector desires tax benefits and good investments. For additional information, the public agency should contact a qualified municipal finance consultant.

EVALUATING THE PROGRAM

After a utility rehabilitation program has been established, it should be evaluated every year and midcourse corrections made as necessary. Therefore, an objective evaluation system needs to be set up at the program onset. Guidelines are presented below.

Guidelines to Measure Effectiveness

To be effective, the rehabilitation program must improve the physical/capacity condition of the utility system and have a positive benefit-cost ratio. Techniques to evaluate the physical condition are presented in Chapter 4. Table 2-3 lists effectiveness measures which can be used for the different utilities. The selected parameter(s) should be tracked both in the rehabilitated area and in the entire utility service area. It should be expected that such parameters as water main breaks (No./year/mile) will continue to increase citywide until the length of rehabilitated water mains becomes a significant number compared to the total length. The number of main breaks on the rehabilitated pipes should show a dramatic drop to the level of new pipes in good condition. Other parameters such as friction-factors should come close to that predicted. Spot checks should be made to verify that this has occurred.

Recommended Monitoring Program

The following procedure is recommended for monitoring program effectiveness:

1. Select parameters to measure program effectiveness (see Table 4-7). The measures should preferably be the same as those used to justify initiating the program and be easy to extract from the system condition inventory.

2. Monitor costs of projects. Include consultant, contractor, and in-house costs allocated to individual projects. Verify or modify and keep current the cost estimating curves and procedures presented in this manual (see Chapters 5 through 7).

3. Physically inspect all work completed (see Chapter 3).

4. Perform tests to check predicted versus actual performance of installed system (see Chapter 3).

Table 4-7 Measures of Rehabilitation Program Effectiveness

Utility	Measure	Units
Water	Unaccounted-for-water	Percent of total sales
	Complaints	Rusty or red water
	Leakage	Gallons/mile/day
	Main breaks	Number/mile/year
	Friction factor	Dimensionless
	Fire flows	Test results; insurance rating
	Reduced pumping	kwhr/year
	Improved pressure	No complaints
Sewer	Infiltration/inflow	Gallons/inch-diameter mile/day[a]
	Back-ups/blockages	Number/mile/year
	Main breaks	Number/mile/year
Gas	Leaks	Number/mile/year
	Losses	Percent of total sales
Electric	Power outages	Customer-hours/year
	Excess capacity	Percent of total
	System aesthetics	Miles of overhead lines undergrounded/year
Solid waste	Litter	Appearance
	Public satisfaction	No complaints

[a]Normalized for certain conditions, e.g., 5-year storm with saturated soil. Alternative measure is percent of rain volume entering the sewer system for specific storm under saturated soil conditions.

5. Monitor repair work orders to determine if system failure rate is changing. Annually update project schedule to take care of most critical needs first.

6. Monitor changes in population density and/or land use (redevelopment activity) to determine if project priorities should be changed.

7. Develop rationale to justify continued program expenditures based on program's effectiveness and participate actively in utility's capital budgeting process.

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CHAPTER 5

This chapter focuses on rehabilitation methods for water, sewer, and gas pipelines, building laterals and service connections, manholes and sumps, and pumping stations. The most common and practical methods are described. A summary of these methods is presented below, which is followed by a more detailed section on each method.

It is important to note that this manual is intended to be used in planning rehabilitation projects. Therefore, the descriptions in this and succeeding chapters are not intended to provide the engineer with everything about a particular technique needed during design. Information from vendors of the specified products will be required before a complete evaluation can be performed.

SUMMARY OF METHODS

There are a number of proven methods for pipeline rehabilitation. In many situations, pipelines can be rehabilitated for about a third of the cost of replacement, that is, if it is done before it is too late (indicated by pipe collapse). Principal rehabilitation methods are summarized in Table 5-1.

Water Pipelines

Water utilities in many cities have used cement mortar lining of old cast iron pipelines, which have first been cleaned to remove scale and tuberculation. Only a few water utilities have tried pipe insertions. Many just replace the waterline as standard practice.

A few of the methods are applicable to district heating applications but pipe replacement is the most common solution to corroded hot water or steam pipes today.

Sanitary Sewer Pipelines

Sanitary sewer agencies have generally been concerned about removing infiltration/inflow from their system, usually by chemical grouting. Structural rehabilitation of sewer systems using reinforced shotcrete, pipe insertion or resin-impregnated fabric, have been used selectively to avoid impending collapse of the pipeline. Only in a few cities are these methods being done on a routine, annual basis. This is because little is known about the physical condition of most sewer systems and most agencies lack the money to launch large programs. However, a concerted, prioritized, long-range program can be shown to be cheaper than responding to crises.

All of the techniques in Table 5-1 are applicable to storm drainage pipes, depending upon the pipe material and local conditions. Concern over storm drains has been less; it may not matter if the joints leak because the water is not treated and many storm drains are still relatively new and have not yet failed. Some of the old ones function as combined sewers and are handled by sanitary sewer agencies. Some have been rehabilitated, generally with methods suitable to large pipes (reinforced shotcrete, for example).

Cost Estimating Example. Appendix A contains an example of selecting and making a cost comparison of rehabilitation alternatives for a hypothetical sewer rehabilitation project.

Gas Pipelines

The gas industry has, for many years, been inserting polyethylene pipe into old gas mains and service lines. An entire industry has evolved to support them. Their extensive experience can benefit the water and sewer industry; although, for the water industry, higher strength materials may be required since gas lines are under relatively low pressure.

Building Laterals

Often rehabilitating sewer main lines is not sufficient to substantially reduce infiltration/inflow. Building laterals must also be rehabilitated. Although basic methods used are the same as those used for sewer mains--chemical grouting, polyethylene sliplining, and resin-impregnated fabric--installation techniques differ somewhat due to the smaller pipe size. Many of these techniques are new and expensive. In the past, replacement has been the most common method for preventing infiltration/inflow into building laterals.

Manholes and Sumps

Sewer manholes are also a source of infiltration/inflow. They can deteriorate and collapse like pipelines. Rehabilitation methods are divided into two main categories: (1) frame and cover methods, and (2) sidewall and base methods. The methods in the second category also apply to sumps. Frame and cover methods include plugging holes in the cover, installing prefabricated lid inserts, raising the frame, and using joint-sealing tape or hydraulic cement. Sidewall and base methods include coating walls, chemical grouting, and installing structural liners.

Table 5-1 Principal Methods for Pipeline Rehabilitation

Method	Description	Application	Advantages	Disadvantages
Excavation and replacement	Total replacement in original trench.	Any pipe with major structural defects.	Only method that can increase pipeline capacity; substitutes modern pipe for obsolete materials, increasing service life.	Most costly method. Most disruptive method, physically and time-wise.
Chemical grouting	Application of grout to patch leaky joints and, in some cases, cracked pipe. Usually injected behind a packer.	Sewer pipes--used to control infiltration/inflow.	Costs less than replacement; minimal traffic and utility interruption; no excavation needed. Low flows tolerated.	Does not improve structural strength; can fail if dehydrated. Additives are available to minimize this possibility. Difficult to seal packers where surface is irregular. Point repairs may be required.
Cement mortar linings (several application methods)	Cement mortar is applied, either by spraying or with a mandrel. In larger lines, reinforcement is recommended.	Leading method for water pipe rehabilitation. Also used for concrete sewer pipe.	Minimal service interruption with temporary service. Improves structural integrity.	Not recommended for corrosive liquids.
Reinforced shotcrete	After placement of steel reinforcement, a mixture of fine aggregate cement and water is applied by air pressure.	Large sewers needing structural repair.	Higher strength than cement mortar linings; requires little excavation. Variation in cross section readily accommodated.	Only suitable for large pipes. Dusty, difficult to supervise and dependent on operator skill. Control of infiltration required.
Pipe insertion (slip lining) using polyethylene, polybutylene, reinforced thermosetting resin, reinforced plastic mortar, or ductile iron pipe.	A liner pipe of slightly smaller diameter is inserted into existing pipe, then connected to service laterals.	Leading method for gas pipe rehabilitation. Also used for cracked or deteriorated sewer pipes and to lesser extent--water pipes.	Less time, lower cost than excavation and replacement; minimal excavation and disruption. May improve hydraulics. Large radius bends accommodated.	If pipe diameter has been reduced in any way, liner pipe may have to be much smaller than existing sewer main.
Resin-impregnated fabric	Flexible liner installed from manhole, thermally hardened, cut by remote control.	Sewer pipes of any geometry.	Especially applicable to difficult repairs under busy streets, buildings, or large trees. Provides structural reinforcement. Twelve-hour return to service, usually no excavation.	Only used for mainline repairs. Patented system handled by relatively few contractors. Site set up costs high for small jobs.

Pumping Stations

Old pumping stations can often be rehabilitated for a fraction of the cost of a new station. Pumping stations are rehabilitated when there is either a need for additional capacity or the station has become unreliable (the equipment is old and difficult to maintain) or unsafe by today's standards. Methods employed in pumping station upgrading include:

- Change pumps and motors,
- Improve electrical equipment and instrumentation,
- Add standby pumps,
- Move pump motors above maximum flood level,

- Eliminate any direct connection between the dry and wet well (wastewater pumping stations),
- Add ventilation system,
- Add standby power (engine generators),
- Improve external appearance of station.

EXCAVATION AND REPLACEMENT

Replacement of deteriorated pipelines has been the most common rehabilitation practice. The popularity of pipeline replacement is, in part, attributable to lack of familiarity with pipeline rehabilitation methods, their effectiveness, and their frequently lower cost.

System rehabilitation through pipeline replacement can take the following two general forms:

- Excavation and replacement where the existing pipeline is removed and a new pipeline 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) a physically parallel alignment adjacent to the existing line or (2) a functionally parallel alignment along a different route.

The discussion in this manual is limited to pipeline excavation and replacement on the same alignment. This is frequently the only way to continue the complete service function of an existing line in an urban area when pipeline replacement is necessary.

Excavation and Replacement Applications

Excavation and replacement is a complete structural solution to deterioration of pipelines. It will allow pipeline capacity to be increased to meet present and future needs provided there are no downstream restrictions that affect the replaced pipe section. Removal and replacement of deteriorated pipelines is applicable:

- Where additional pipeline capacity is needed.
- Where rehabilitation methods that are 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 (in dollars and urban disruption) than other rehabilitation methods.

Because the prolonged service disruption associated with removal and replacement of major lengths of water and natural gas pipelines can usually not be tolerated, these kinds of pipelines are most often either abandoned and replaced with new parallel lines or rehabilitated in place. Removal and replacement of these lines is seldom feasible and is not discussed in this manual.

Solving Capacity Problems. While there is no question that replacing an existing deteriorated pipe with a larger line can provide needed added capacity, other capacity solutions should also be investigated. A well-planned rehabilitation program should consider:

- System rearrangement to shift tributary flows from pipelines with capacity problems to existing lines with excess capacity.
- System rearrangement to shift tributary flows from pipelines with capacity problems to new pipelines.

These two capacity solutions are discussed further in Chapter 3. They can be used separately or in combination to:

- Reduce the needed capacity of an existing deteriorated line to a level obtainable after rehabilitation of the pipeline.
- Minimize urban disruption by removing and replacing, at increased capacity, one or more deteriorated lines and allowing less disruptive (and usually less expensive) rehabilitation of other deteriorated pipelines.

The efficient use of removal and replacement in a pipeline system rehabilitation program requires an understanding of total system design capacities and future capacity needs. In complex systems, it is seldom safe to assume that the size of an existing pipeline is indicative of the pipe size needed for present and projected flows.

Point Repairs. Excavation and replacement is used in point repairs to:

- Correct isolated problems in an otherwise sound pipeline requiring no other rehabilitation.
- Correct isolated severe structural problems (e.g., crushed or collapsed pipe sections) which are found in deteriorated pipelines which are being rehabilitated by lining methods discussed elsewhere in this chapter. This is often required prior to grouting.

Complete Replacement. Excavation and replacement of the entire length of a deteriorated pipeline should be considered: (1) whether or not additional capacity is needed and (2) whether or not the pipeline can be rehabilitated by other methods. With exception of those cases where the urban disruption of pipeline replacement is estimated to be too costly, it may be desirable to bid excavation and replacement as an alternative to pipe rehabilitation. This may increase bidding competition and produce better bid prices.

Available Materials

Pipe replacement materials (Table 5-2) include traditional materials such as reinforced concrete, clay, ductile iron, and steel plus a variety of plastics and resins. As indicated in the table, several of the materials are used for insertion lining pipe rehabilitation. The characteristics of insertion lining materials are described elsewhere in this chapter.

Excavation and Replacement Methods and Problems

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 system tributary and/or service flow during construction.
- Removal and disposal of old pipe.
- Working through overlying or closely parallel to other utilities. (See Figure 5-1).

These special problems usually result in added construction costs which do not occur in new construction along a new pipe alignment.

Problems Common to All New Construction

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 (See Figure 5-2).
- Destruction of street paving.
- Trench shoring in deep construction involving unstable soil.
- Trench dewatering in high groundwater.

Figure 5-3 is a project sign used by the City of Salem, Oregon, to inform its citizens. These signs are but one part of the public information and relations program which Salem uses to improve public support of its pipeline rehabilitation and replacement program.

Some guidelines regarding street closure for various pipe excavation and replacement situations are shown in Table 5-3. Each situation must be examined for its own specific conditions and needs.

Construction 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 material and installation.
- Service reconnection in sanitary sewers.
- Street inlets reconnection in storm drains.
- Upstream flow diversion during construction.
- Maintenance of local service flows in sanitary sewers.
- Traffic control.
- Pavement restoration.
- Interference of other utilities.

Table 5-2 Pipe Replacement Materials and Service Applications

Material	Available diameter, inches	Municipal water	Sanitary and storm sewers	Natural gas
Reinforced concrete	8 - 238		X	
Clay	4 - 42		X	
Cement mortar lined and coated steel	12 - 54	X	X[a]	
Ductile iron[b]	4 - 60	X	X[c]	
Extruded polyethylene[b]	4 - 63	X	X	X
Spiral-ribbed polyethylene[b]	18 - 96		X	
Polybutylene[b]	3 - 42	X	X	X
Reinforced plastic mortar[b]	18 - 66	X	X	
Reinforced thermosetting resin[b]	4 - 192	X	X	
Steel	4 - 120	X	X[d]	X
Concrete cylinder (prestressed)	42 - >200	X	X[a]	
Concrete cylinder (pretensioned)	12 - 72	X	X[a]	
ABS (solid wall)	4 - 12		X	
ABS (composite wall)	8 - 15		X	
Asbestos cement	4 - 36	X	X	
PVC (composite wall)	8 - 15		X	
PVC (solid wall)	4 - 36	X	X	

[a]Pressure pipes only.
[b]Also used for insertion lining.
[c]Usually poly-lined for sanitary sewers.
[d]Storm water pressure pipes only.

The cost estimating basis for removal and replacement construction is in the form of a basic unit cost curve and tabular presentations of added unit costs. All costs are at January 1984 levels (Engineering News-Record 20-Cities Average Construction Cost Index of 4109).

Cost Effects of Job Scale. The scale of the removal and replacement project affects the unit costs. The unit cost curve presented here is for a 1,000 lineal feet job. The unit costs of shorter jobs can be significantly higher than those shown.

Cost Curve for Gravity Sewers. The basic cost curve (Figures 5-4 and 5-5) is the unit cost per lineal foot for removal of the existing pipe and installation of the new pipe.

- The cost curve is for gravity pipelines constructed in stable ground.
- The cost curve assumes minimal need for groundwater dewatering of the excavation.

Figure 5-1 Pipe Removal and Replacement is Complicated by Utilities, Railroads and Other Surface and Subsurface Features. Courtesy, City of Sacramento, California

- The existing sewer is assumed to be reinforced concrete, clay, brick, etc., of approximately the same size as the replacement sewer.

- The replacement sewer is assumed to be reinforced concrete at the larger diameters (above 42 inches) and reinforced concrete or clay at diameters 42 inches and less.

- Excavated material from below the top of the existing pipe is assumed to be waste not reused anywhere in the backfill.

Figure 5-2 Removal and Replacement of Large Diameter Pipes Requires Major Disruption of Streets. Courtesy, City of Sacramento, California

- Excavated material from above the top of the existing pipe is assumed to be usable in backfill.

- Select imported bedding and backfill is assumed to be used from 12 inches below the pipe to the top of the pipe.

- The unit cost curves are for average depths of trench ranging from 10 feet to 35 feet.

- The cost curves assume that the guidelines presented earlier for partial or total street closure are followed.

The gravity sewer removal and replacement unit cost curves include:

- Contractor mobilization, bonds, and insurance.

- All material, equipment, and labor for removal of the old pipe and installation of the new pipe.

- The cost of removing wasted material from the site and import of locally available select bedding and backfill.

Costs Not Included on the Unit Cost Curve for Gravity Sewers. The unit cost curve does not include the following:

- Design engineering, construction management (inspection, etc.) or design-related services during construction (i.e., the construction cost information is for preparation of bid price estimates).

- Bypassing of wastewater.

- Reconnection of services and/or street drain inlets.

- Traffic control during construction.

- Repaving.

- Cost of utility interference.

- Removal and replacement of manholes.

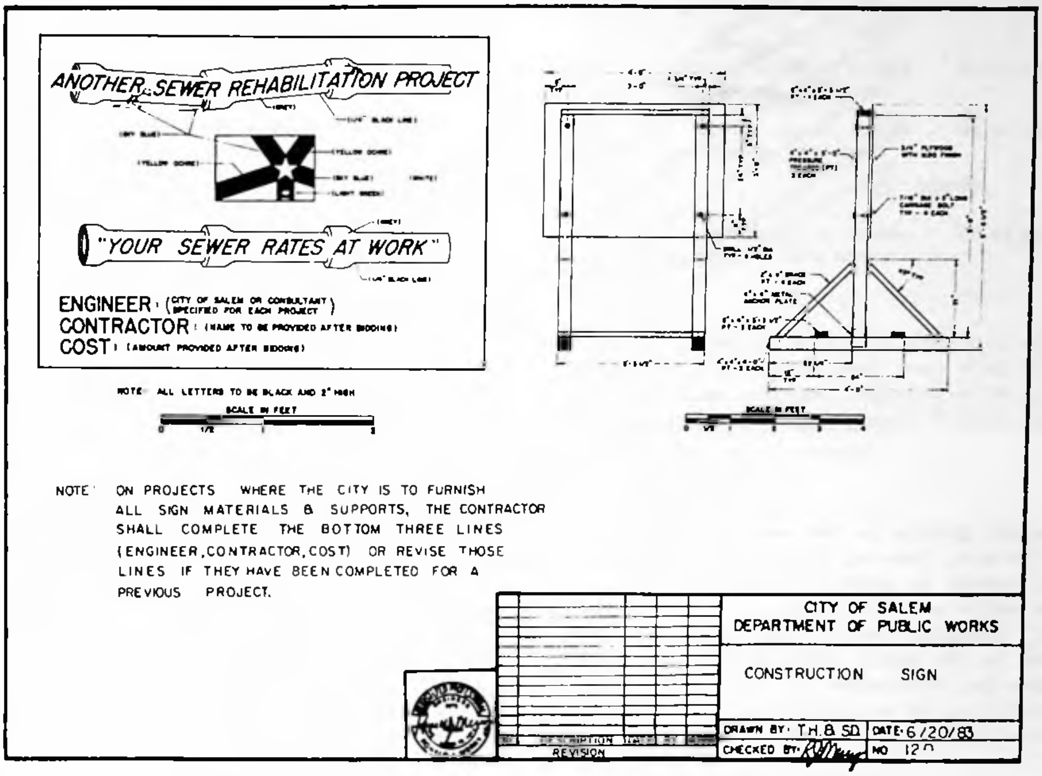
Added Construction Costs for Gravity Pipeline Removal and Replacement. These added costs are presented in Table 5-4. The presentation of added cost is limited to:

- Street repaving.

- Services and/or drainage inlet reconnection.

- Utilities interference.
- Manhole removal and replacement.
- Severe settlement and other foundation problems may be more permanently dealt with by replacement than by rehabilitation.

Figure 5-3 Sign Used by City of Salem, Oregon, to Inform Citizens of Project. Courtesy, City of Salem, Oregon.



All of the above added costs are highly job-specific. The unit costs in Table 5-4 are minimum allowances which should be used in estimates prepared in the planning phase.

Water Pipeline Replacement. Figure 5-6 shows a unit cost curve envelope for water pipelines based on information from Los Angeles Department of Water and Power, East Bay Municipal Water District (Oakland, California), and San Francisco Water Department data. Actual costs may vary from 0.5 to 2 times the cost curve values depending on the installation conditions. Costs do not include pavement removal and replacement.

Pipeline Removal and Replacement Advantages

Pipeline removal and replacement offers the following advantages over rehabilitation by methods discussed in this manual:

- Major capacity increases to the pipe being replaced can be made.
- Crushed or collapsed pipes are best dealt with by replacement.

Pipeline Removal and Replacement Disadvantages

When compared to rehabilitation of existing pipelines:

- Removal and replacement is usually more expensive.
- Removal and replacement construction causes considerably greater and longer-lasting traffic and general 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.

Table 5-3 General Rules Regarding Street Lane Closure for Pipe Removal and Replacement

Pipe diameter, inches	Pipe depth, feet	Four traffic lanes at 12 feet plus two parking lanes at 8 feet	Three traffic lanes at 12 feet plus two parking lanes at 8 feet	Two traffic lanes at 12 feet plus two parking lanes at 8 feet
<18 to 24	<15 to 20	Reduce to three traffic lanes and one parking lane	Reduce to two traffic lanes and one parking lane.	Reduce to half of street width.
<18 to 24	>15 to 20	Reduce to three traffic lanes with no parking[a]	Reduce to two traffic lanes with no parking[a]	Reduce to one traffic lane with no parking[b]
>24 to 30	<15 to 20	Reduce to two traffic lanes with no parking[c]	Reduce to one traffic lane with no parking[d]	Reduce to one "local only" lane with no through traffic and no parking[d]
>24 to 30	>15 to 20	Reduce to two traffic lanes with no parking[a,c]	Reduce to one "local only" lane with no through traffic and no parking[b,d]	Complete closure of street

[a]At depths greater than 25 to 30 feet, reduce by one additional traffic lane regardless of pipe size.
[b]At depths greater than 25 to 30 feet, complete closure of street may be necessary regardless of pipe size.
[c]At pipe sizes larger than 48 to 54 inches, reduce by one additional traffic lane regardless of pipe depth.
[d]At pipe sizes larger than 48 to 54 inches, complete closure of street may be necessary regardless of pipe depth.

CHEMICAL GROUTING

Grouting using chemical grouts is the most common method used to seal leaking joints and circumferential cracks in gravity (non-pressure) pipelines which are otherwise structurally sound. Chemical grouts came into use for this purpose in the early 1970s with the use of acrylamide gel developed in the 1950s and the introduction of polyurethane foam. The use of urethane grouts began in the early 1980s.

Materials

The principal chemical grouts currently available are acrylamide gel, acrylate gel, urethane gel, and polyurethane foam. The basic physical differences in foam and gel grouts are:

- Foam grout forms an in-place pipeline gasket and cures to a tough, flexible, and cellular rubber-like material. The seal is created within the joint with minimum penetration of the material to the outside of the joint and pipeline.

- Gel grout penetrates to the outside of the joint and pipeline, both filling the joint and forming an external seal as it mingles with the soil and fills voids outside the joint. The grout and soil mixture cures to a relatively impermeable and somewhat flexible collar within, and on the outside, of the joint.

- Cure time (5 to 15 minutes) is significantly longer for foam grout than for gel grout.

Gel Grouts. The most commonly used gel grouts are acrylamide gel, acrylate polymer, and urethane gel. All three are resistant to most chemicals found in sewer lines. All three produce a gel-soil mixture that is susceptible to dehydration and shrinkage cracking (important where alternate wetting and drying occurs with fluctuating groundwater levels). Dehydration and shrinkage cracking potential can be reduced by using chemical additives such as ethylene glycol.

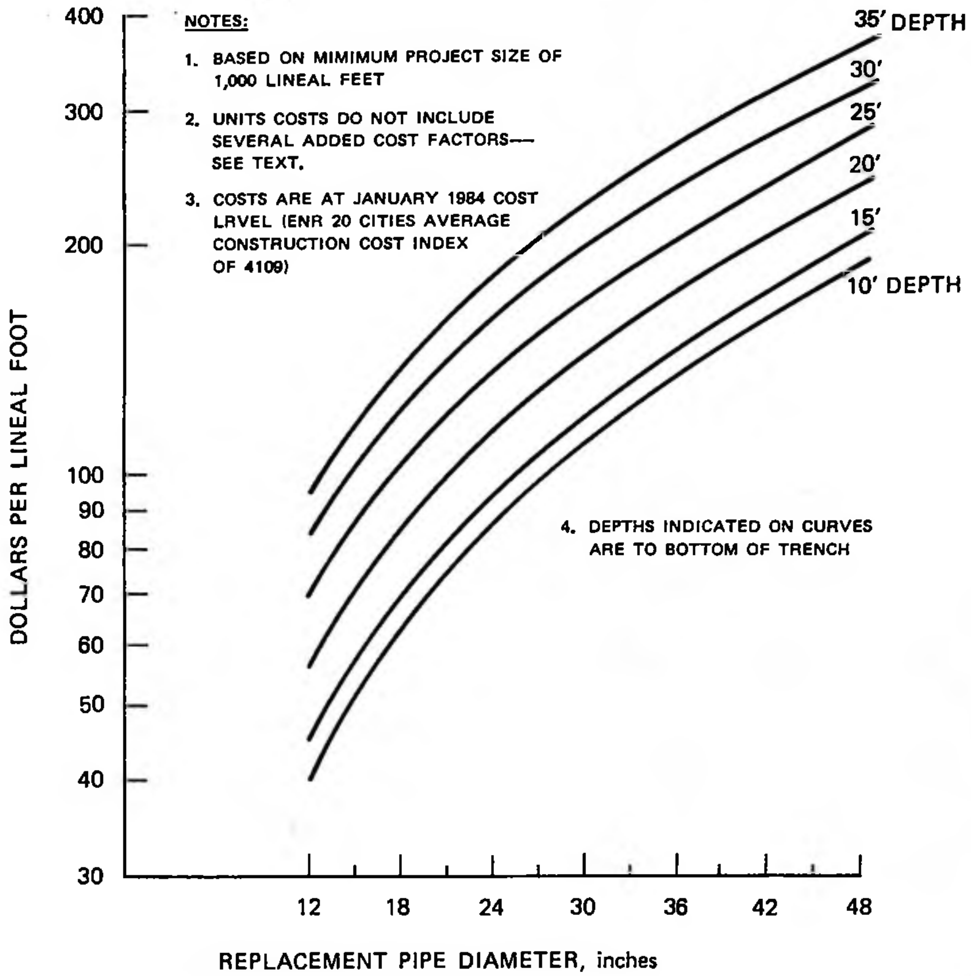
In addition to the chemical differences in the composition of the three gels, there are the following important differences:

- Acrylamide gel is significantly more toxic than the acrylate polymer or urethane gel grouts. (Grout toxicities are of concern only during handling for placement in the pipeline.)

- Urethane gel grout uses water as the catalyst. Chemical catalysts are used in the acrylamide and acrylate polymer gels. The difference is significant only in relation to avoiding any water contamination of urethane grout during handling prior to its injection.

Gel grouts should not be used where there are large voids outside the pipeline joint. In this case foam grouts should be used.

Figure 5-4 Added Construction Costs for Gravity Pipeline Removal and Replacement (ENR 20 - Cities Average Construction Cost Index of 4109)



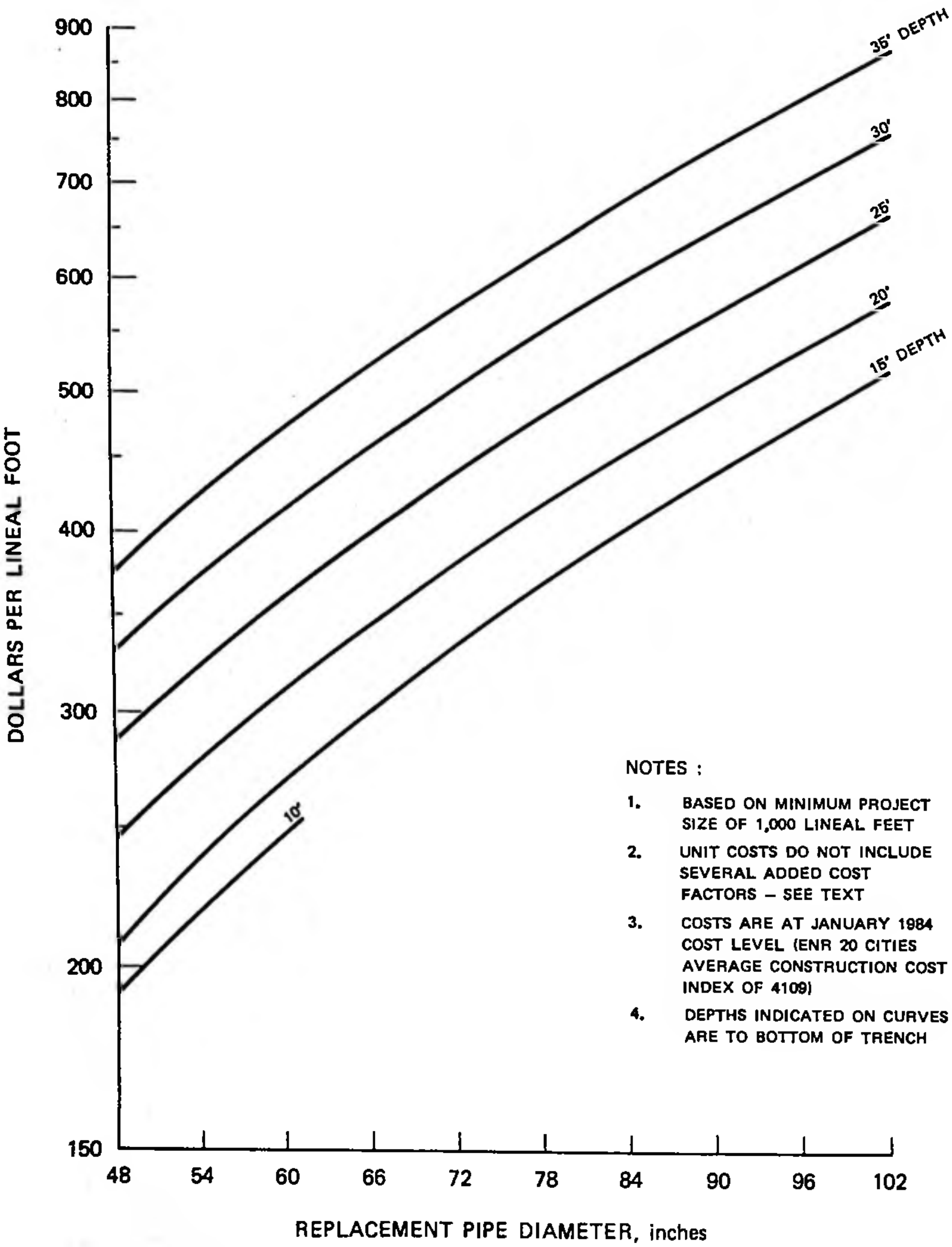
Foam Grouts. Foam grouts are liquid urethane prepolymers which are catalyzed by water during injection. Immediately upon injection, the foaming reaction of the grout and water, together with the injection pressure, expands the material into the joint cavity. If unconfined, the foaming and curing action expands the grout volume 10 to 12 times the initial volume.

Sometimes called elastomeric grouts, they are difficult to apply and more expensive than gel grouts. They may be superior to gel where water flows outside the trench, there is high external pressure, or there are large soil voids outside the pipe (or unconsolidated backfill) that would otherwise require a large amount of gel to seal.

Chemical Grouting Applications

Chemical grouting is useful only for the reduction of groundwater infiltration into nonpressure pipelines. It is applicable to leaking pipe joints or to circumferential cracking of the pipe wall at, or between, joints. Table 5-5 summarizes the capabilities and limitations of chemical grouting. It is seldom cost-effective to use chemical grouting to seal longitudinal cracks or to seal joints where the pipe near the joints is longitudinally cracked. Grouting cannot be done next to laterals. Chemical grouts have no structural properties capable of ensuring an effective seal where joint or circumferential cracking problems are due to ongoing settlement or shifting of the pipeline. Filling voids above the pipeline with grout will help create a uniform loading of the pipe and stop further creation of voids, thereby reducing the potential for structural damage. Joint and circumferential crack sealing using chemical grouts can be accomplished in pipe sizes of 6-inch diameter and larger. Grouting should be considered a touch-up rehabilitation method for pipes in good structural condition. Where suspected problems are extensive, other rehabilitation methods or replacement may be more cost-effective and should be considered.

Figure 5-5 Unit Cost for Pipe Removal and Replacement--48-Inch- to 102-Inch-Diameter Gravity Sewers



Installation Methods

All of the chemical grouts are applied under pressure after appropriate cleaning and testing of the joint. The work is done using closed-circuit television and remotely controlled equipment in small- and medium-sized pipes. Typically, a two-man grouting team is used on pipes large enough for manned entry (48-inch diameter and larger).

Table 5-4 Unit Cost for Pipe Removal and Replacement—12-Inch- to 48-Inch-Diameter Gravity Sewers

Item	Unit construction cost, dollars
1. Service connections and drainage inlet connections (4 inch through 8 inch)	800/connection
2. Street repaving	4 to 10/square feet of paving
3. General utilities interference	20[a]/lineal foot of total job
4. Manhole removal and replacement	
Remove existing manhole	600/manhole
Construct new 36-inch concrete manhole	
Saddle-type (to 10-foot depth)	2,400[b]/manhole
Full (to 15-foot depth)	1,500 to 2,000[b]/manhole

[a]Does not allow for major spot relocations of parallel or crossing utilities.
[b]Add $150 to $200/foot for depths greater than those indicated.

Inspection, Cleaning, and Root Removal. Before choosing to use grouting for joint rehabilitation, the pipeline should be inspected to:

- Determine pregrouting cleaning needs.
- Determine the extent of root intrusion.
- Identify crushed or broken pipe sections that must be replaced. (Note: deformed pipe sections will prevent passage of the packer which is used in remote grouting. Longitudinally cracked pipe sections cannot be effectively grouted and are apt to allow escape of grout injected at joints, making joint grouting ineffective.)
- Identify locations where the pipe wall is eroded near joints to an extent that the remote injection packer (or manned-entry injection joint sealing ring) will not effectively seal during grouting.

All root intrusions through the joints must be removed prior to grouting. In addition, future root growth should be inhibited. If root growths are not properly dealt with, root problems will return and the joint sealing will be ineffective. Proper root treatment includes:

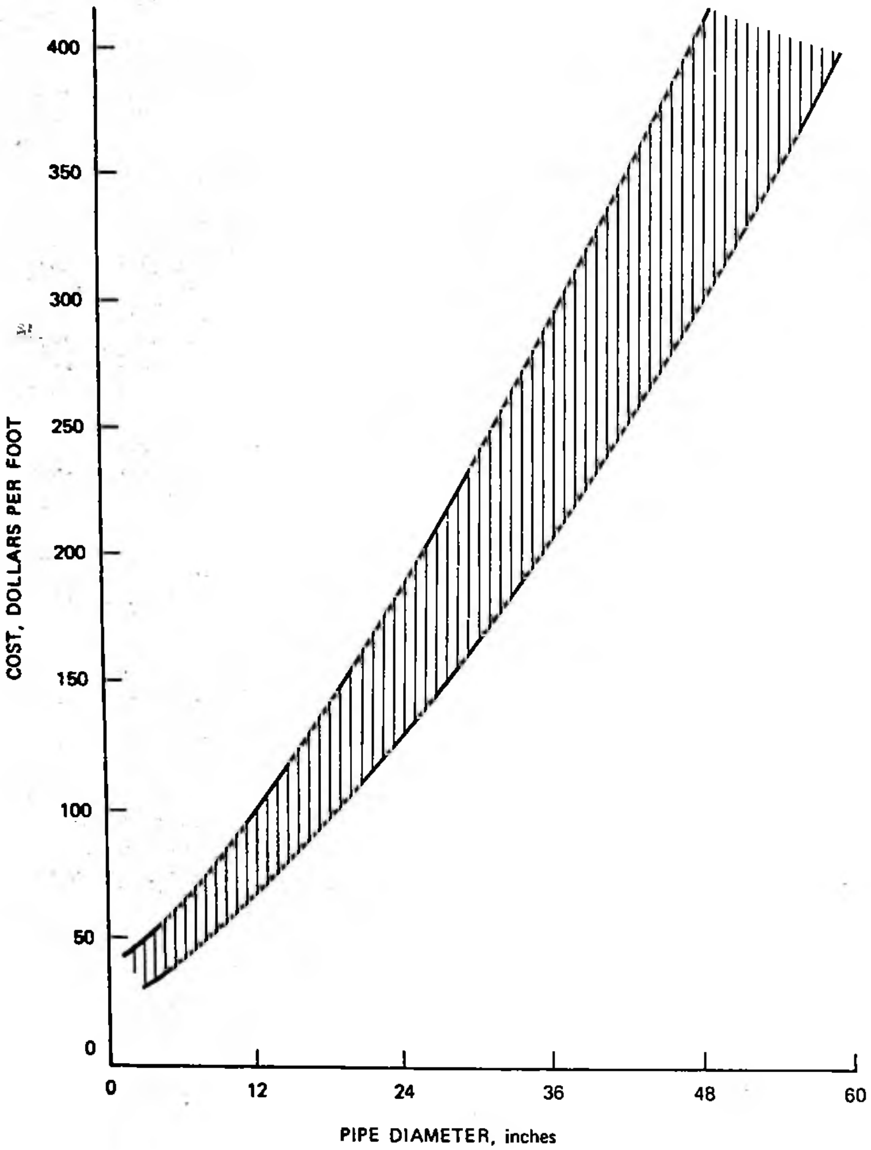
- Application, inside the sewer, of root herbicide (or hot water treatment) during the growing season and prior to grouting.
- Complete removal of intruded roots after sufficient time has elapsed (90 to 120 days) to allow applied root killer to have maximum effect.
- Use of a proven root inhibitor additive in the grout.

For grouting to be effective, the pipeline must be relatively free of sand, sediment, and other deposits. Cleaning should occur just prior to grouting.

Remote Grouting. Joints and circumferential cracks in small- and medium-sized pipes (6- to 42-inch diameters) can be remotely tested and grouted using a packer system monitored by closed-circuit television. Remote grouting can be conducted in a flowing sewer. A typical grouting setup is shown on Figure 5-7. The grout and catalyst solutions are mixed aboveground and conveyed to the packer in separate hoses. Stepwise:

- The packer (Figure 5-8) is pulled onto the joint (or crack).
- Inflatable sleeves at both ends of the packer are expanded to create a seal between the pipe wall and packer on both sides of the joint or radial crack.
- Compressed air is pumped through the packer to the suspect area to test the joint or crack.
- If the joint or crack fails the air test, grout and catalyst solutions are pumped under pressure into the void between the packer sleeves and forced into the joint or crack. Figure 5-9 illustrates the remote grouting process for gel and foam grouts.
- When the grouting of the joint or circumferential crack is completed, the packer sleeves are deflated and the packer is pulled to the next suspect area.
- After the appropriate curing time has elapsed, the packer can be used to conduct low pressure air testing of grouted defects or entire reaches of the pipeline can be air tested.

Figure 5-6 Unit Cost for Replacing Water Pipelines



Manned-Entry Grouting. In larger-diameter pipelines, either pressure grouting or manual placement of grout-soaked oakum may be used. Pressure grouting can be done either by (1) using manually placed sealing rings in a test and grout injection operation similar in concept to that described for remote grouting or (2) using a process of injecting grout through holes drilled into the pipe joint or through the pipe next to the joint. Sealing rings are not used in the latter process. Figure 5-10 illustrates manned-entry grouting using sealing rings. The insewer control panel and sealing ring is shown on Figure 5-11. Only minimal flow is tolerable in the pipeline during manned-entry grouting.

Chemical grouting has been used in brick sewer rehabilitation to fill voids in backfill outside the sewer wall. Such backfill voids can reduce lateral support of the wall and allow outward movement. When this occurs, the arch at the top of the pipe loses its support and the structure deteriorates rapidly. The development of voids in brick sewer backfill often occurs because of groundwater washing soil into the pipe through cracks and holes in the sewer wall (typically beginning where the mortar between the bricks has weakened and washed out). The factors and mechanisms involved can be complex as indicated on Figure 5-12. This figure shows the general failure sequence which likely began soon after construction of a large diameter brick sewer in Seattle, Washington. The rehabilitation sequence which saved the pipeline is shown on Figure 5-13. An important part of the rehabilitation involved filling of the backfill voids using both chemical and cement grouts. Great care was required in planning the rehabilitiation sequence and controlling grouting pressures to avoid further damage of the structure during the grouting process.

Construction Costs

The cost of grouting with chemical grouts is specific to individual job conditions including (1) the severity of root intrusion and pre-grouting cleaning problems, (2) the need for removal and replacement of pipe sections which are too badly damaged to permit either passage of grouting equipment or effective grouting of nearby joints, and (3) the number of joints which require grouting.

The basis of construction cost estimation presented for chemical grouting is unit cost curves displaying a range of cost for various pipeline diameters. The cost information is at cost levels in January of 1984 (Engineering News-Record, 20-Cities Average, Construction Cost Index of 4109).

Table 5-5 General Applicability of Chemical Grouting to Pipeline Problems

Problem	Remote application[a]	Ability to solve problem[b]
Existing pipe size		
<6-inch diameter	No	NU
6-inch to 42-inch diameter	Yes	U
>42-inch diameter	No	U
Existing pipe shape		
Circular	Yes	U
Irregular (i.e., ovoid, egg-shaped, horse-shoe, arched, etc.)	No	U
Structural problem		
Pipe crown or invert sag	-	NS
Reinforcing steel gone	-	NS
Reinforcing steel corroded	-	NS
Pipe joints deteriorated or open	-	CS
Pipe joints leaking or offset	-	CS
Pipe cracked	-	CS
Pipe crushed or collapsed	-	NS
Pipe cement corroded	-	NS
Pipe slabouts and holes	-	NS

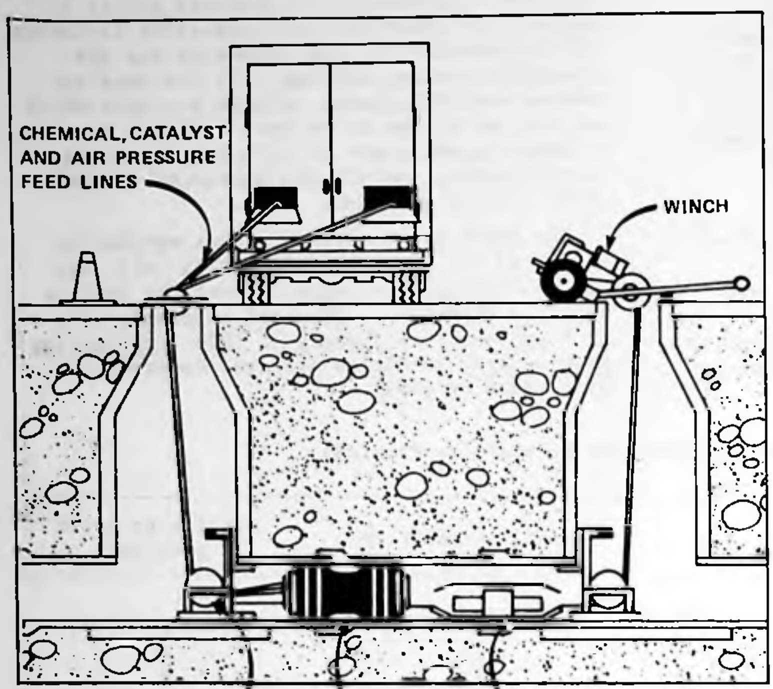
[a]Remote application using a packer system monitored by closed-circuit television.

[b]See legend for problem solution ability codes. Problem solution ability indications are generalized. Each structural problem in a particular pipeline must be subjected to expert examination.

Legend:

U = Usable in this size range or pipe shape.
NU = Not usable in this size range.
CS = Conditional solution to this structural problem.
NS = Does not solve this structural problem.

Figure 5-7 Typical Grouting Setup



The unit costs are in two categories:

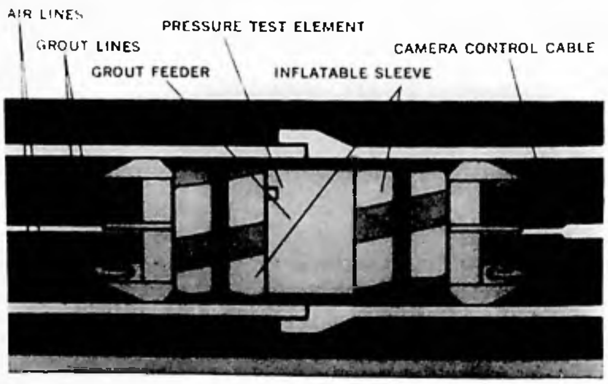
- Grouting preparation costs
- Grouting costs

Grouting Preparation Costs. Where remote grouting is used (6-inch to 42-inch diameter pipes) the costs shown on Figure 5-14 are incurred on a "per lineal foot" basis regardless of the number of pipe joints (or cracks) in the pipe reach. The grouting preparation cost curve includes:

- Root treatment using herbicide applied inside the pipeline.
- Root removal after appropriate herbicide treatment.
- Pregrouting cleaning of the entire pipeline reach.

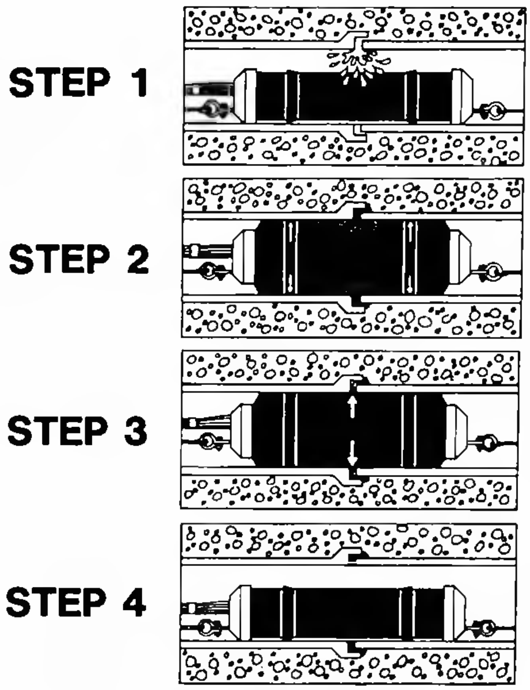
Grouting Costs. These costs (Figures 5-15 and 5-16) are incurred based on the number of joints (or cracks) in the pipe reach. Because the number of joints in a pipe reach varies considerably amongst different pipe materials and diameters and also varies within the same diameter and material, the grouting cost curves show a range of cost per joint for various diameters. The actual number of joints which require grouting will usually not be known until air testing has been done. A common estimating rule-of-thumb is that 50 percent of

Figure 5-8 Remote Chemical Grouting Packer



the joints will require grouting. If considerably more joints are in need of grouting then another rehabilitation method should be considered. The grouting cost curves include:

Figure 5-9 Remote Chemical Grouting Process Schematic, Courtesy of Cherne Industries, Inc.

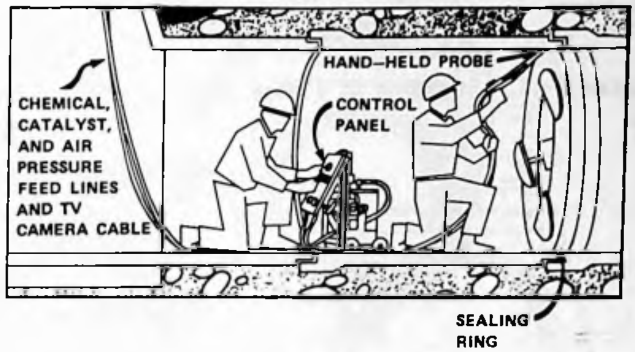


To seal a leak, a packer is positioned and the outer elements inflated Grouting compound is pumped into the isolated area and then forced into the cavity by inflating the center element The grout cures to form a tough gasket

- Contractor mobilization, bonds, and insurance.
- All material, equipment, and labor for the grouting process.

Figure 5-15 shows unit costs for grouting pipe in the 6- to 42-inch-diameter range using a remotely operated packer and either gel or foam grout. Figure 5-16 shows the cost for grouting pipes 48 inches in diameter and larger using the manned-entry ring seal method. The costs shown for manned-entry grouting include localized pregrouting cleaning and root removal at the joints and or radial cracks. The cost differences between the lower and upper limits of the cost bands on both grouting cost figures reflect cost penalities associated with grouting work during cold and/or wet weather and (2) the effect of limited bidding competition.

Figure 5-10 Manned-Entry Chemical Grouting, Courtesy of Cherne Industries, Inc.



<u>Cost Effects of Job Scale</u>. The scale of the grouting project affects the unit cost. The cost curves are for a 1,000-lineal-foot job with one set-up. The unit costs of shorter jobs can be significantly higher than those shown because more set-ups are required.

Figure 5-11 Control Panel and Sealing Ring Used for Manned-Entry Chemical Grouting. Courtesy of Cherne Industries, Inc.

<u>Costs Not Included on Unit Cost Curves</u>. The unit cost curves <u>do not include</u> the following:

- Design engineering, construction management (inspection, etc.) or design-related services during construction (i.e., the construction cost information is for preparation of construction bid price estimates).

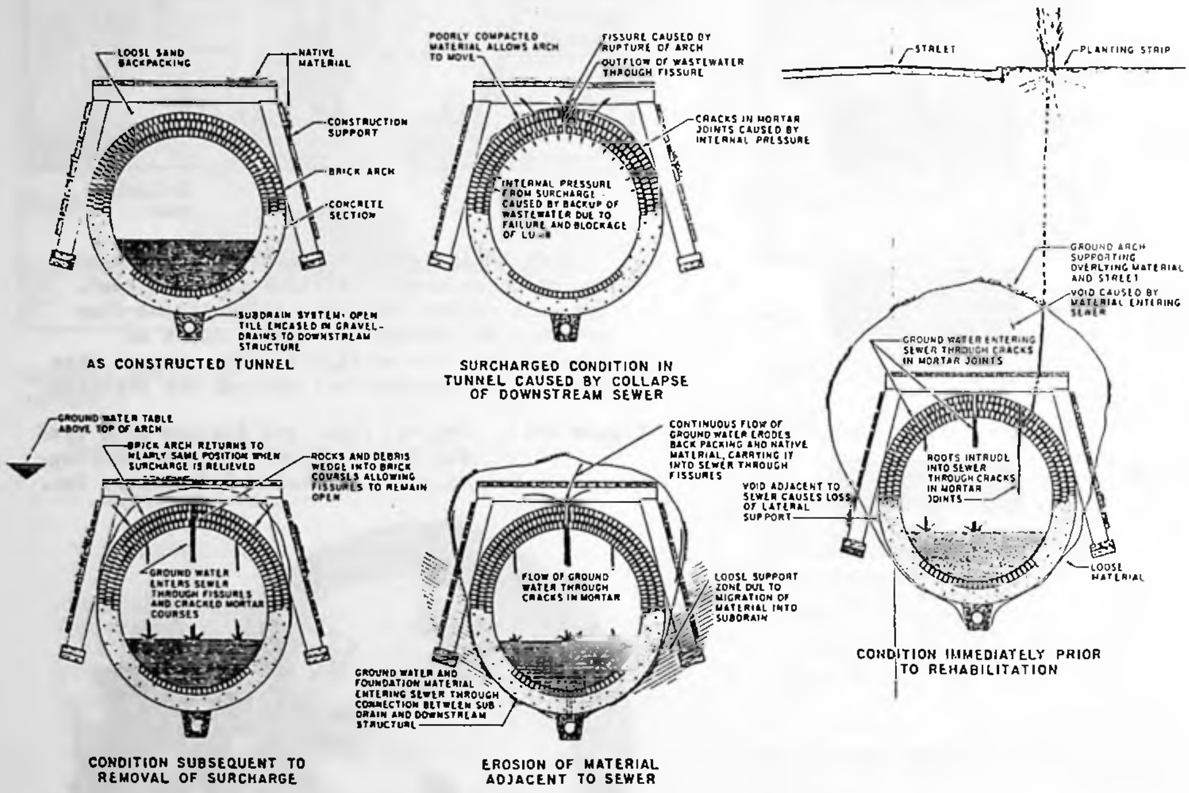
- The cost of the initial pipeline inspection and any related cleaning conducted to permit the inspection.
- Removal and replacement or other repair of damaged pipe sections.
- Bypassing of wastewater.

Disadvantages

Chemically grouted joints:

- Are only minimally resistant to reintrusion of untreated roots. Major regrowth of roots can destroy the grout seal (see discussion of need for effective root treatment and removal prior to grouting).
- Have no structural qualities and will not transmit shear or bending loads.

Figure 5-12 Sequence of Events Causing Structural Damage to a Brick Sewer in Seattle



Advantages

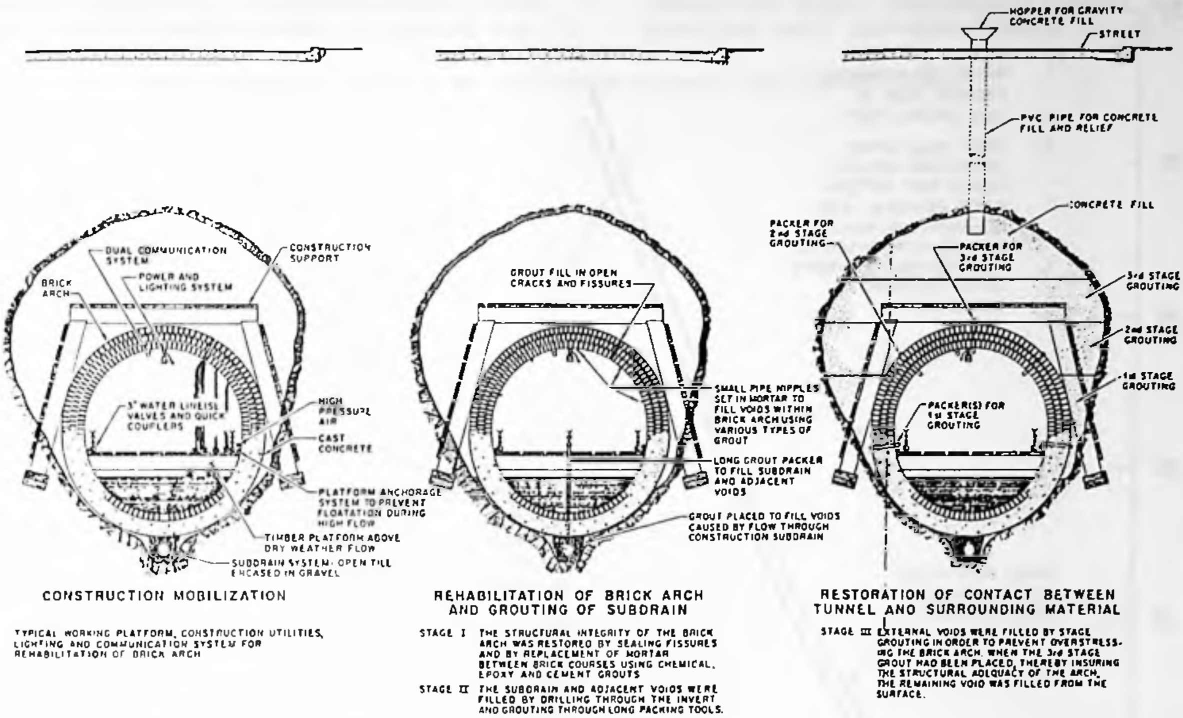
Where the pipeline problems are for the most part limited to joint deterioration:

- Grouting can be the least costly method of pipeline rehabilitation.
- Grouting can be accomplished quickly with minimal pipeline service and traffic disruption.

CEMENT MORTAR LINING

Deteriorated internal surfaces of concrete, steel, and cast iron pipe can be rehabilitated by applying a cement mortar lining. Lining material is usually a sulfate-resistant 1:2 Portland cement mortar. Ratios of cement, sand, and water are varied for different desired wall thicknesses, pipe wall conditions, and weather conditions. Mortar composition varies according to the conditions to which it will be exposed (e.g., corrosive agents).

Figure 5-13 Construction Sequence for Rehabilitation of Brick Sewer in Seattle



This process is most commonly used for water pipes but can also be used for pressure and nonpressure sewer pipes. It can provide a structurally sound lining that prevents further corrosion of the interior surface of the original pipe. This process is generally applicable to 8-inch-diameter and larger pipelines, although it can be used for 4- and 6-inch diameter pipes.

Methods of Installation

The cement mortar lining is applied by either a centrifugal or mandrel process. Both methods require thorough cleaning and dewatering. Methods of preparation, cleaning, and lining are described below.

Preparation for Cleaning and Lining

Preparation for cleaning and lining pipe primarily involves excavating access holes. Usual requirements are:

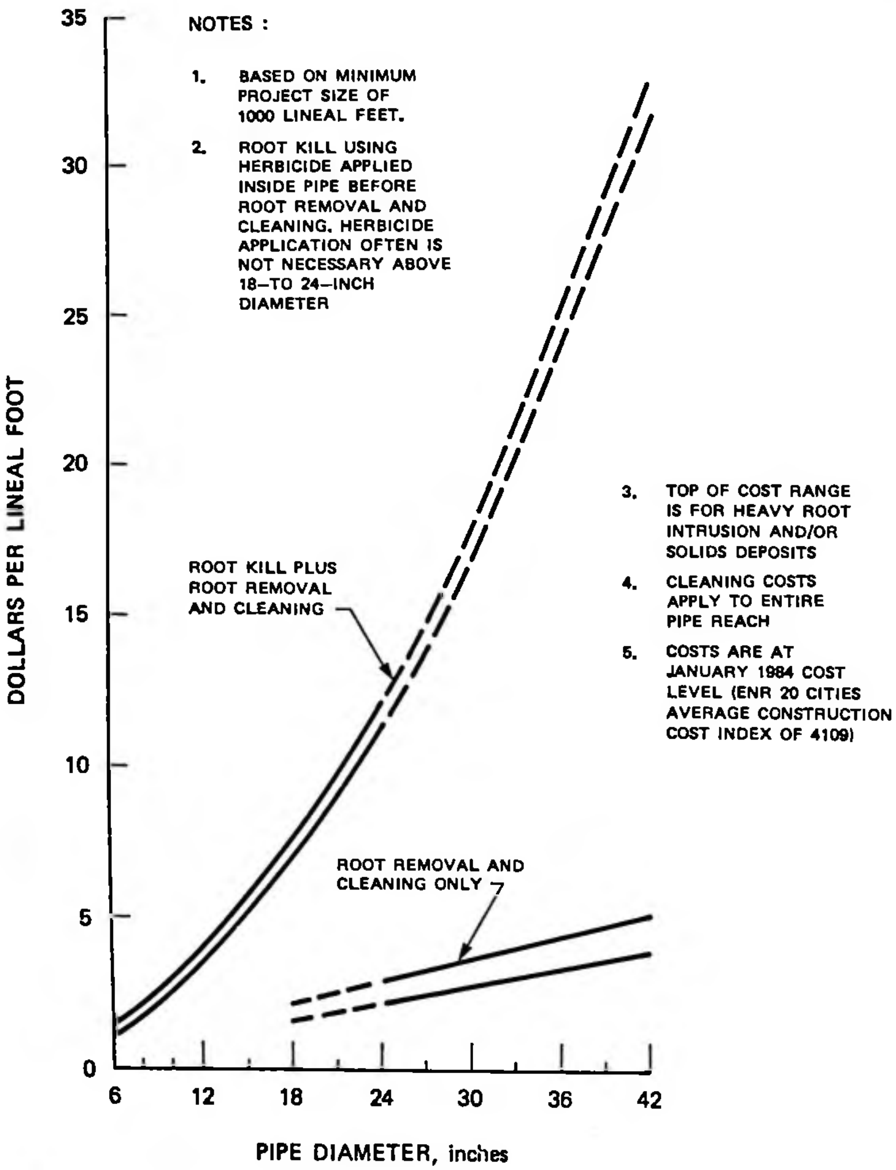
- Access holes about every 500 to 700 feet depending on pipe diameter.
- If pipe bends are too sharp for the lining machine to negotiate, an excavation can be made at the bend. The fitting can then be cut and separately cleaned and lined.
- If service to customers must be maintained, an aboveground temporary bypass must be installed prior to cutting into the existing pipeline.

Cleaning

Prior to lining, corrosion products and debris must be removed from the interior pipe surfaces. Three methods are available: hydraulic cleaning, mechanical or drag cleaning, and hand cleaning.

1. Hydraulic cleaning involves:
   - Steel frame cleaner with steel blades around a piston-like center.
   - Hydraulically propelled through pipe by either pumping water or using the natural gravity head.
   - Pipe cleaned by scraping and brushing action.
2. Mechanical or drag cleaning (see Figure 5-17):
   - Used instead of hydraulic cleaning when there is insufficient water pressure or the water pressure is too high for the pipe (smaller pipes).

Figure 5-14 Unit Grouting Preparation Costs



- Done with a series of brushes and steel scrapers around a core.
- Cleaner is attached to steel cables and pulled back and forth through the pipe using winches at either end of the pipe section until pipe is clean and smooth.
- Can also be done with a power-driven cleaner with revolving brushes or rotating arms that can be used for large-diameter pipes.

3. Hand cleaning:
   - Used for large-diameter pipes, usually greater than 48 inches in diameter.
   - Can be used to supplement mechanical cleaning of smaller-diameter pipes.

Following cleaning, the pipe is flushed with water to remove all debris. In small-diameter pipes, e.g., less than 24 inches in diameter, service connections are usually cleaned using compressed air fed into the service line from the individual services. Service connections to larger-diameter pipes are typically plugged prior to cleaning and lining. Prior to lining, all standing water must be removed by pumping or pulling a squeegee through the pipe. Groundwater seepage must be prevented until the cement mortar is applied.

Figure 5-15 Unit Grouting Costs for 6- to 42-inch-Diameter and Larger Pipes

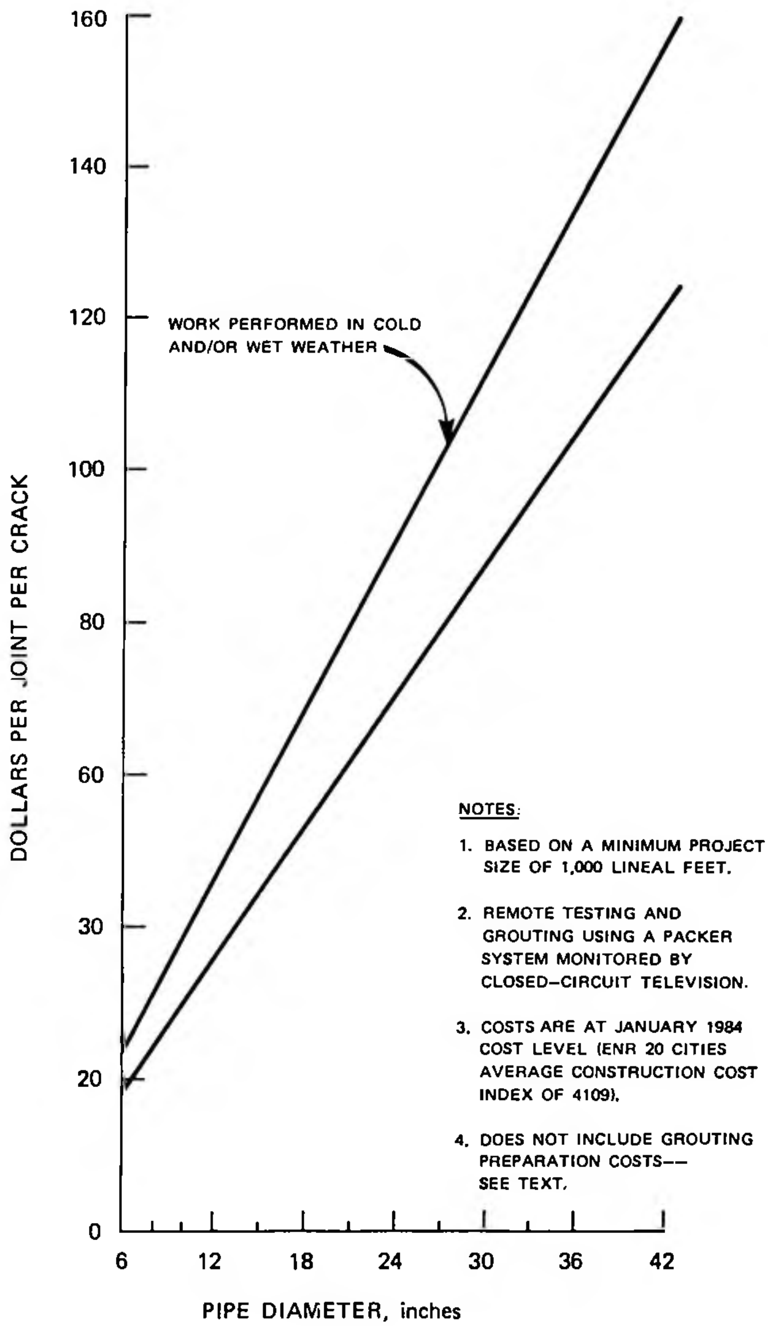
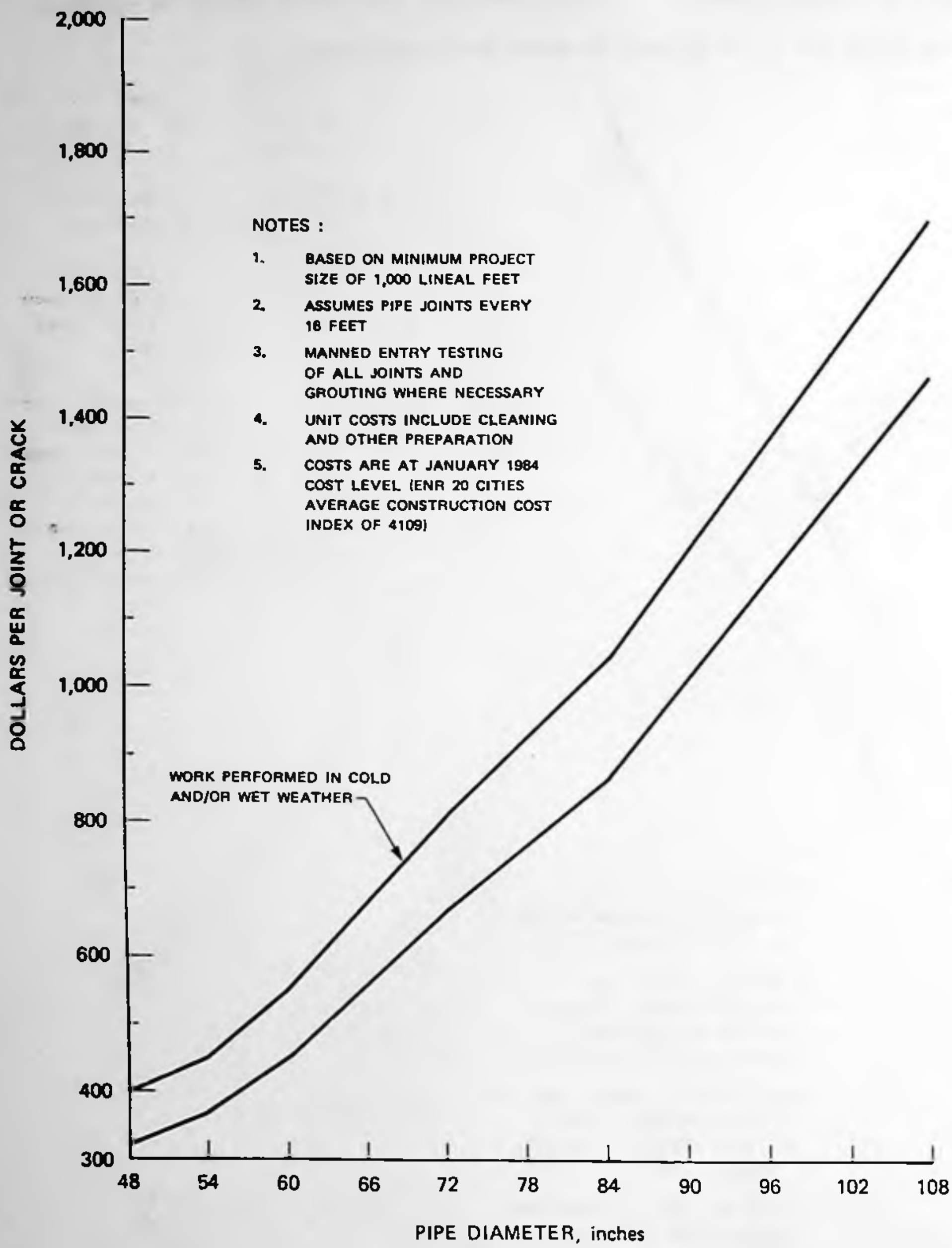


Figure 5-16 Unit Costs for Chemical Grouting of Pipe Joints and Radial Cracks--48-Inch- to 108-Inch-Diameter Pipes



Lining

The cement mortar application methods are described below.

Centrifugal Process. The most common method used to apply the cement mortar is a centrifugal process.

- Lining machine has a revolving, mortar-dispensing head with trowels on the back to smooth the mortar immediately after application (see Figure 5-18).
- In small-diameter pipe (less than 24 inches in diameter), a variable

speed winch pulls the lining machine through the pipe. The mortar is pumped to the machine through a supply hose (see Figure 5-19).

- In large-diameter pipe (24-inch-diameter and greater), the lining machine is self-propelling and controlled by a person riding it. Mortar is pumped to an electrically driven supply cart that shuttles mortar from the access hole to the feeder which is attached to the lining machine (see Figure 5-20).
- Different-sized lining machines are used for different-sized pipes.
- If reinforcing is required, a spirally wound reinforcing rod is placed in a thin layer of fresh mortar. A second layer of mortar is then applied to achieve the desired thickness.
- Service connections are cleared with compressed air if they were not manually plugged prior to cleaning and lining.
- Disadvantages of this method include the need to excavate and plug all service connections, slow speed, and limited diameter applicability.

Lining Thickness.

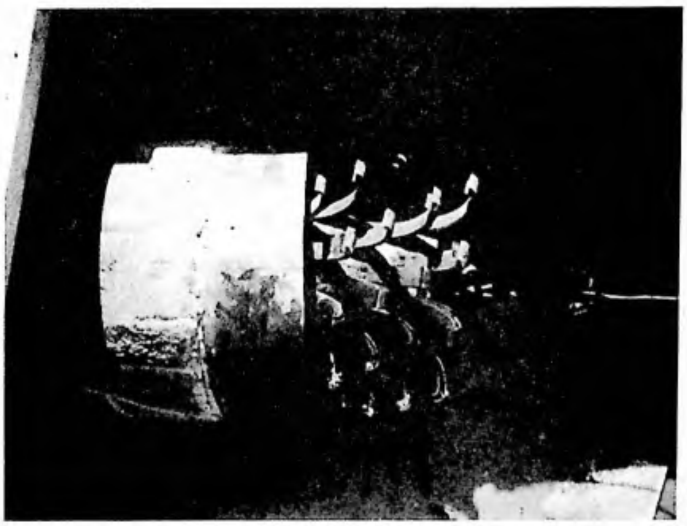
- Typical lining thicknesses range from 1/8 to 3/4 inch. Thicker linings can be provided when necessary.
- The speed with which the lining machine moves through the pipe determines the lining thickness.
- Lining thickness is periodically checked when possible by inserting a depth gage into the freshly applied mortar.

Construction Costs. As with the other pipeline rehabilitation methods, unit costs vary widely due to many factors. Figure 5-21 shows a curve for unit costs versus pipe diameter for cleaning and cement mortar lining water pipe lines. These costs were developed from cost data collected from cities around the country: Los Angeles, Oakland, and San Francisco, California; Denver, Colorado; Philadelphia, Pennsylvania; Boston, Massachusetts; and Hagerstown, Maryland.

Criteria for Unit Costs.

- Costs include cleaning and lining pipe only. Valve rehabilitation, bypass installation, pavement removal, etc., are not included. Costs are essentially base contractor bids.

Figure 5-17 Mechanical Drag Cleaner Being Pulled Into Pipe. Courtesy of East Bay Municipal Utility District.



Mandrel Process. A less common application method than the centrifugal process is the mandrel process.

- Used for 4- to 16-inch-diameter pipe with few service connections.
- Uses a pressurized extrusion technique that causes mortar to be forced over the conical mandrel and against the wall. Excess moisture is squeezed out, and mortar is troweled.

- Costs are in December 1983 dollars (Engineering News-Record 20-cities CCI = 4109).
- Costs are for rehabilitating pipe runs greater than 1,000 feet long.

Figure 5-18 Cement Mortar Lining Machine in Pipe. Courtesy of East Bay Municipal Utility District

Using the Curve. The cost curve is shown as a band since site specific conditions, size of job, and economic conditions have such a significant effect on unit costs. The lower boundary is for a simple, large job, with minimal traffic and noise restrictions. The upper boundary is for smaller jobs, with extensive complications due to traffic congestion, severe noise restrictions, groundwater seepage, etc. Job size is determined by the total amount of work contracted for at one time, not just the length of each pipe run to be rehabilitated.

Additional Cost Considerations.

- Necessary work in addition to the cleaning and lining is a substantial portion of the total cost. Los Angeles Department of Water and Power estimates the actual contractor's cost for cleaning and lining is only about 30 percent of the total job cost.
- Short pipe runs are more expensive than longer runs due to the fixed mobilization cost.
- The number of service connections and bends, traffic control requirements, noise restrictions, etc., substantially affect unit costs.
- Some cities reduce costs by having their own crews do some of the work. For instance, Hagerstown, Maryland, pays the contractor for two supervisors and equipment rental. The city buys all the materials and provides the labor. This can probably only be done effectively if the cement mortar lining program is extensive and will continue for several years.

Advantages.

- Minimal service interruption.
- Improved structural integrity of pipe.
- Expected pipeline life extended by 30 to 50 years.
- Several experienced contractors in the country exist which allows competitive bidding.
- Applicable for wide range of pipe sizes.
- Provides major improvement in flow characteristics and capacity.

Disadvantages.

- Not recommended for corrosive conditions unless sulfide control measures are incorporated (especially applicable to use in sewer lines).
- Cannot be used for pipelines with a lot of bends. This can preclude use of this method in cities with all underground utilities or underground structures near the street surface because the pipelines typically have many bends.
- Where there is danger of pipes freezing, work cannot be done in the winter.
- Where a small bypass line cannot supply needed peak water quantity, work must be done during off-peak seasons.

REINFORCED SHOTCRETE (GUNITE)

Shotcrete, sometimes referred to as gunite, is a mixture of sand, cement, and water applied by air pressure through a cement gun. The relatively dry cement and sand mixture is transported through a hose to a nozzle where water is added in a mixing chamber. Cement hydration begins as the material leaves the chamber and is shot into place under air pressure. Reinforced shotcrete is shotcrete applied to a cage of reinforcing steel.

Figure 5-19 Typical Cement Mortar Lining Operation in Pipes Less Than 24 Inches Diameter. Courtesy Raymond International Builders.

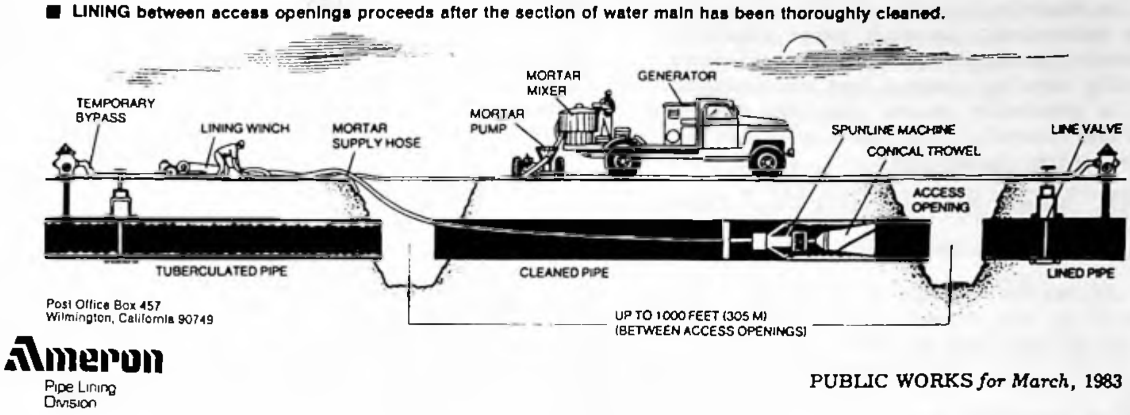
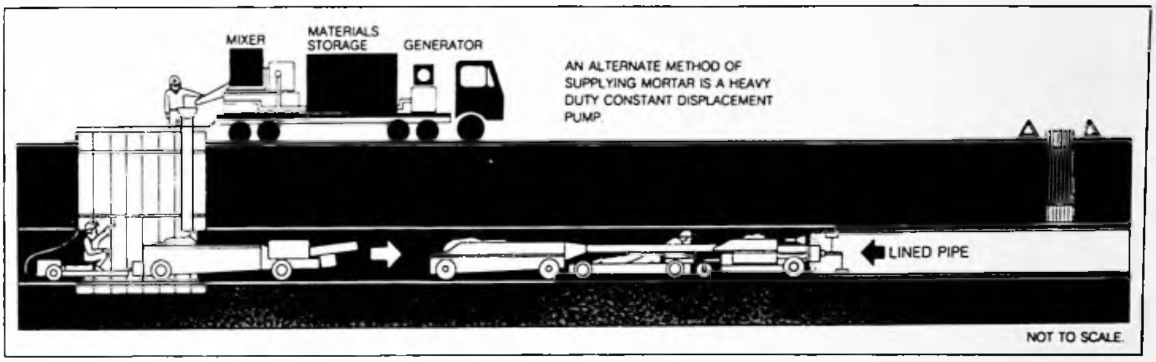


Figure 5-20 Typical Cement Mortar Lining Operation in Pipes 24-Inches Diameter and Greater. Courtesy Raymond International Builders.



Materials

The materials used are the cement and sand mixture (with or without additives) and reinforcing steel. Normal weight aggregates conforming to ASTM C33 are used in various gradations involving particle sizes 3/4 inch and smaller. Portland cement (ASTM C150, Type II or V) or blended hydraulic cement (ASTM C595, Type IS, IS-A, IP, or IP-A) can be used. Depending upon the structural needs, reinforcing steel can be deformed billet steel bars or steel mesh.

Reinforced Shotcrete Applications

Pipeline rehabilitation using reinforced shotcrete is applicable to sanitary and storm sewers and water mains. Because the method requires manned entry for construction, it is generally applicable to pipelines having inside vertical clearance of 36 inches or greater. Table 5-6 summarizes the capabilities and limitations of this method. Although the method has the capability to correct all of the deterioration problems which are correctable by other methods described in this manual, its use is usually limited to serious structural problems. This method is applicable to large diameter pipes such as concrete water and sewer pipes, brick sewers and unlined tunnels. For many pipeline defects, other methods are equally effective. Figure 5-22 shows reinforced shotcrete being used to rehabilitate a large diameter brick sewer.

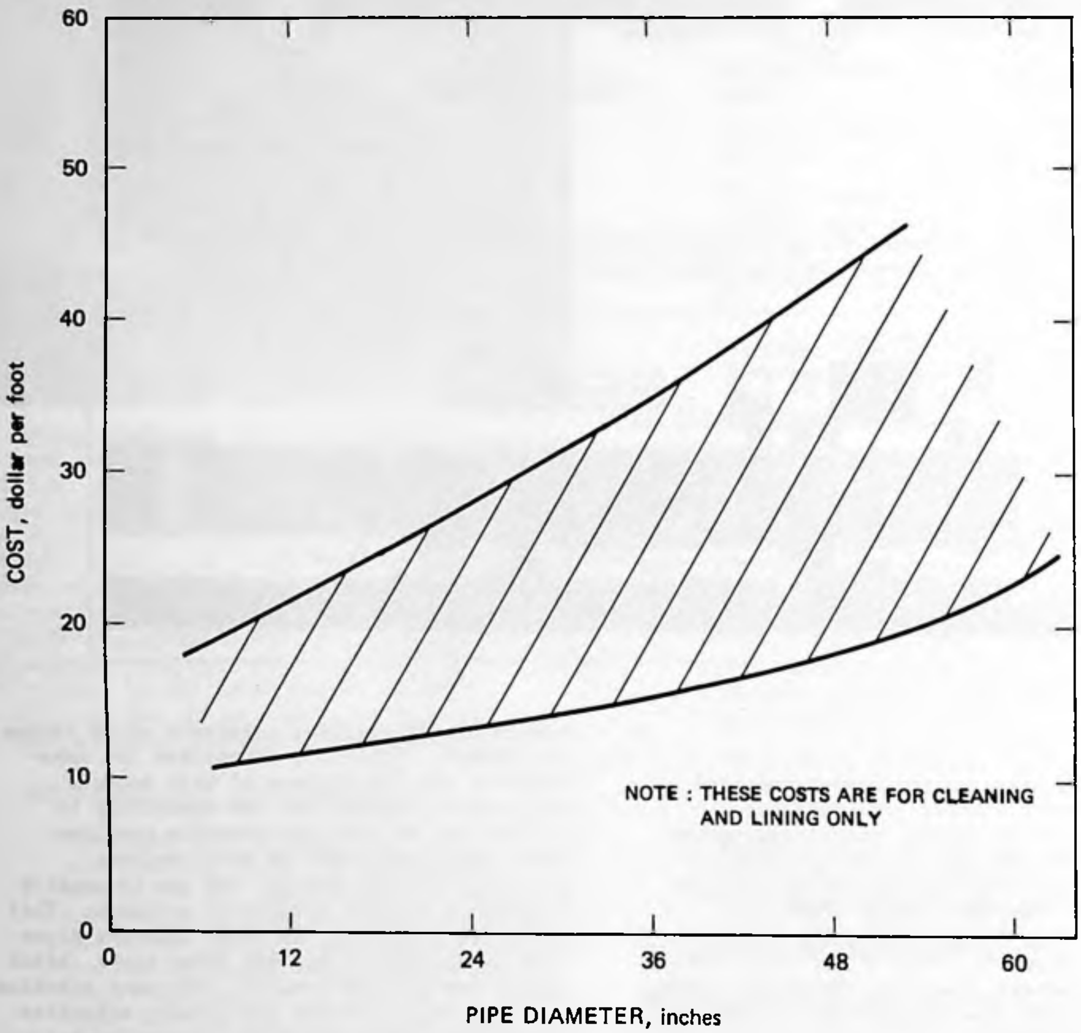
Correction of Structural Problems. This method has the greatest capability of dealing with serious structural problems of all of the rehabilitation methods. Structural strength of reinforced shotcrete work is highly dependent on the adequacy of the design and the quality of the construction. Expert examination of conditions in the deteriorated pipeline and design by an experienced structural designer is usually warranted. As with other rehabilitation methods, severely crushed or collapsed pipes usually require removal and replacement. Shotcrete is generally denser than the concrete in reinforced concrete pipe and has slightly greater corrosion resistance.

Therefore, the capacity reduction is only a function of the reduced cross section.

Methods of Installation

Reinforced shotcrete placement requires minimal excavation for access to the pipeline. Frequently in sewers, all needed access is available through manholes. The principal steps in the installation are as follows:

Figure 5-21 Cement Mortar Lining Unit Costs



Size Reduction and Capacity Considerations

Although the thickness of the reinforced shotcrete liner is dependent on its structural design, it is typically a minimum of 4 inches. Serious structural problems have required liner thicknesses of up to 1 foot. The hydraulic characteristics (Mannings "n" and Hazen-Williams "C") are similar to those for concrete pipe.

Throughout the reinforced shotcrete installation process, the pipeline segment is isolated from the remainder of the system, and all water or wastewater flow is diverted or bypassed around the pipe reach being rehabilitated.

- Unsound concrete or masonry materials and rust, oil, and scale (in steel pipes) are removed by chipping and sandblasting.

Table 5-6 General Applicability of Reinforced Shotcrete to Pipe Problems

Problem	Ability to solve problem[a]
Existing pipe size[b]	
<36-inch vertical clearance	NU
≥36-inch vertical clearance	U
Existing pipe shape	
Circular	U
Irregular (i.e., ovoid, egg-shaped, horseshoe, arched, etc.)	U
Structural problem	
Pipe crown or invert sag	CS
Reinforcing steel gone	S
Reinforcing steel corroded	S
Pipe joints deteriorated or open	S
Pipe joints leaking or offset	CS
Pipe cracked	S
Pipe crushed or collapsed	NS
Pipe cement corroded	S
Pipe slabouts and holes	S

[a]See legend for problem solution ability codes. Problem solution ability indications are generalized. Each structural problem in a particular pipeline must be subjected to expert examination.

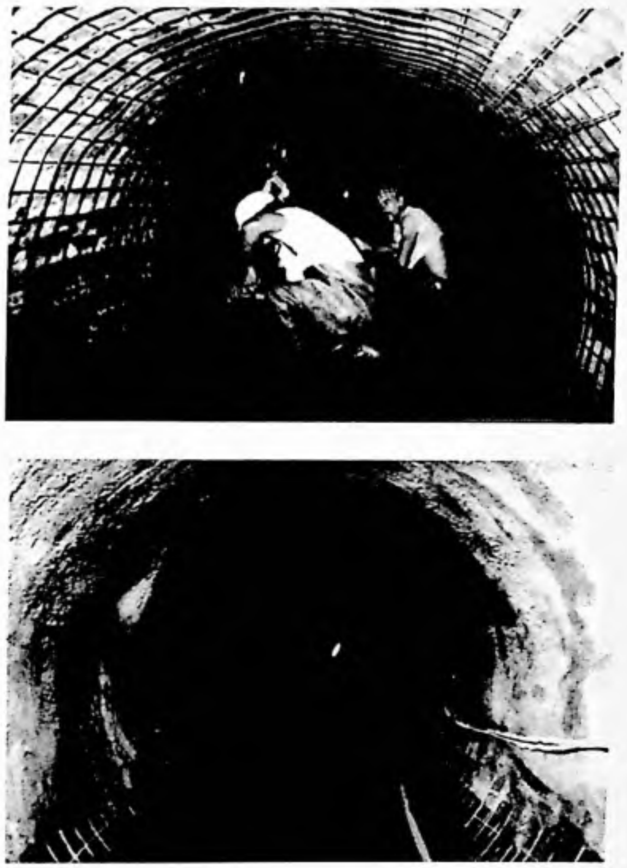
[b]The term "vertical clearance" is used to reflect the use of this rehabilitation method in noncircular pipelines. Vertical clearance and "diameter" of circular pipe are the same.

Legend:

U = Usable in this size range or pipe shape.
NU = Not usable in this size range.
S = Solves this structural problem.
CS = Conditional solution to this structural problem.
NS = Does not solve this structural problem.

- Offsets or protrusions which would cause abrupt changes in the shotcrete thickness are removed or additional reinforcement is provided.
- Edges are tapered to leave no square shoulders.
- The reinforcing steel is placed (steel must be free of rust, oil, etc.).
- All corners, cavities, and areas where shotcrete application rebound cannot escape or be blow free are filled. Voids outside the pipe are filled where detected.
- Surfaces are dampened prior to placement of the shotcrete to improve bonding and reduce premature loss of mixing water (reduces shrinkage cracking).
- Shotcrete is applied behind the reinforcement before any is allowed to accumulate on the face of the reinforcement.

Figure 5-22 Reinforced Shotcrete Being Used to Rehabilitate a Large Diameter Brick Sewer



- Shotcrete is not placed through more than one layer of reinforcing steel in one application unless tests have demonstrated that the steel can be properly encased.
- A shotcrete cover is applied to reinforcement to a minimum thickness of 2 inches in waterlines and sewers. (Note: Cover thickness required varies to thicknesses greater than 2 inches, depending on service conditions.)
- Natural gun finish is most common although other finishes can be used (i.e., broomed, floated, trowled, etc.).
- The initial curing of the shotcrete must be under continuously moist conditions for at least 24 hours beginning immediately after application.
- The total duration of curing is 7 days after shotcreting (3 days if high, early-strength cement is used) during which the shotcrete must be maintained moist and at a temperature above 40 degrees Fahrenheit.

Service Reconnections

Service reconnections are typically done from inside the rehabilitated pipe.

Construction Costs

Construction cost is highly specific to the conditions of individual jobs. It is influenced by the extent to which bidding competition is increased by allowing other specified rehabilitation alternatives as well as removal and replacement.

The basis of construction cost estimation presented for this rehabilitation method is a basic unit cost curve displaying a range of cost for various circular-diameter existing pipelines. Reinforced shotcreting can also be used in noncircular pipe sections. For noncircular sections, use the unit cost for a circular pipe of equivalent circumference.

All of the cost information is at cost levels in January of 1984 (Engineering News-Record, 20 Cities Average, Construction Cost Index of 4109).

Figure 5-23 is the unit cost curve for reinforced shotcrete using wire mesh reinforcing and a 4-inch thickness of shotcrete.

- The lower limit of the cost curve is for existing pipelines in good alignment with no need for spot repair and no significant groundwater.
- The upper limit of the cost curve is for poor pipe alignment, some need for spot repairs, and need for groundwater dewatering.

Cost Effects of Job Scale. The scale of a project using the reinforced shotcrete method affects the unit costs. The cost curves presented are for a 1,000-lineal-foot job. The costs assume that the liner is installed using an already-available access point such as a manhole or valve structure. The unit costs of shorter jobs can increase significantly from those shown on the curves.

Costs Included on Unit Cost Curves. The unit costs include the following:

- Cleaning of the existing line.
- Material, equipment, and labor for reinforced shotcrete placement.
- Bypassing of wastewater.
- Shutoff of water service where the method is employed in a water system.
- Restoration of up to 20 services.
- Contractor mobilization and demobilization, bonds, and insurance.

Costs not included on unit cost curves. The unit cost curves do not include the following:

- Providing temporary water service in water main rehabilitation.
- Design engineering, construction management (inspection, etc.) or design-related services during construction (i.e., the construction cost information is for preparation of construction bid price estimates).
- Traffic control.

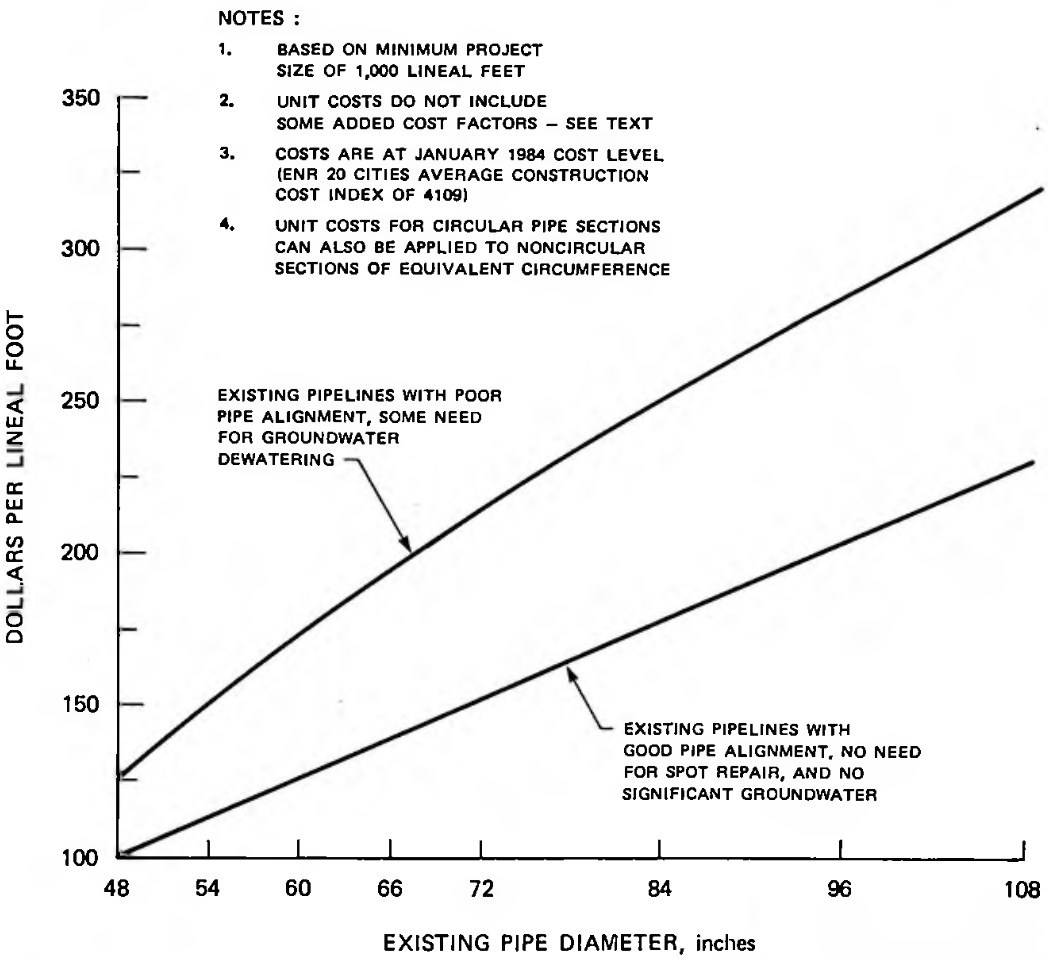
Advantages

Reinforced shotcrete pipe rehabilitation offers:

- The ability, in many cases, to conduct the entire rehabilitation project without excavation.

- The ability to structurally restore the pipe to the equivalent strength of a new pipeline (the method can provide greater structural strength than any other rehabilitation method).

Figure 5-23 Unit Cost for Reinforced Shotcrete



- The ability to restore pipelines that cannot be safely rehabilitated by any other method and which would otherwise have to be replaced.
- Less capacity reduction than pipe insertion when used in noncircular cross-sectional pipelines.

Disadvantages

This structural rehabilitation method requires:

- Complete diversion of flow and shutoff of services.
- Longer (3 to 7 days or more) shutoff of services than most other rehabilitation methods. This occurs due to the time required to prepare pipe surfaces for shotcreting and the cure time required after shotcrete application.
- Tolerance of some reduction in hydraulic capacity. Hydraulic capacity reduction occurs with all rehabilitation methods in most applications.

PIPE INSERTION, INCLUDING SLIP LINING

Pipe insertion is the pulling or pushing of new pipe material into a deteriorated pipeline to restore the integrity of the pipeline. Although the most familiar form of pipe insertion is slip lining using extruded polyethylene pipe material, a number of other materials can be used. Depending on the liner pipe material, the liner may either be pulled or pushed into the deteriorated pipeline.

Available Materials

Pipe insertion materials include a variety of plastics as well as ductile iron. Material selection is based on application design needs, economics, and, to some extent, space availability at the installation working area.

Table 5-7 General Applicability of Pipe Insertion to Pipe Problems

Problem	Extruded polyethylene[b]	Spiral-ribbed polyethylene[c]	Extruded polybutylene[d]	Reinforced plastic mortar[e]	Reinforced thermoset resin[f]	Ductile iron[a]	
						Cement lined	Polyvinyl lined
Existing pipe size							
<18-inch diameter	U	CUS	U	NU	U	CUC	CUC
18-inch to 33-inch diameter	U	CUC	CUC	CUC	CUC	CUC	CUC
≥36-inch diameter	CUS	CUC	CUC	CUS	CUS	CUS	CUS
Structural problem							
Pipe crown or invert sag	S	S	S	S	S	S	S
Reinforcing steel gone	S	S	S	S	S	S	S
Reinforcing steel corroded	S	S	S	S	S	S	S
Pipe joints deteriorated or open	S	S	S	S	S	S	S
Pipe joints leaking or offset	CS	CS	CS	CS	CS	CS	CS
Pipe cracked	S	S	S	S	S	S	S
Pipe crushed or collapsed	NS	NS	NS	NS	NS	NS	NS
Pipe cement corroded	S	S	S	S	S	S	S
Pipe slabouts and holes	S	S	S	S	S	S	S

[a]Available in nominal IPS diameters of 4 to 60 inches.
[b]Available in nominal IPS diameters of 2 to 48 inches.
[c]Available in actual inside diameters of 12 to 144 inches.
[d]Available in nominal IPS diameters of 3 to 42 inches.
[e]Available in nominal inside diameters of 18 to 66 inches.
[f]Available in actual inside diameters of 4 to 192 inches.

Legend:
- U = usable in this size range.
- CUS = conditionally usable--note maximum and minimum available liner size.
- NU = not usable in this size range.
- CUC = conditionally usable--major capacity reduction must be acceptable.
- S = solves this structural problem.
- CS = conditional solution to this structural problem.
- NS = does not solve this structural problem.

Pipe Insertion Applications

Pipe insertion can be used to rehabilitate water, sewer, and natural gas pipelines which have a variety of structural problems. Table 5-7 summarizes the capabilities and limitations of pipe insertion using the various liner materials discussed in this section.

Pipe insertion with the materials described in this section is capable of dealing with a variety of serious structural problems. Exceptions are severely crushed or collapsed pipes which generally cannot be rehabilitated by any of the methods described in this manual. These pipe sections will usually require removal and replacement.

Extruded polyethylene pipe. This is the polyethylene (PE) pipe most commonly used. PE pipes are characterized by the standard dimension ratio (SDR), and pipe grades are classified by stress-cracking resistance. Two national specifications are available for reference and design. They are ASTM D1248 and ASTM D3350. These standards apply generally to circular cross-sectional extruded PE pipe from 8 to 48 inches in diameter. Design guidance for use of PE pipe in sewer rehabilitation is provided in ASCE--Manuals and Reports on Engineering Practice No. 62, WPCF--Manual of Practice FD-6, Existing Sewer Evaluation and Rehabilitation which is a joint publication of the American Society of Civil Engineers and the Water Pollution Control Federation.

Extruded PE pipe is available in standard lengths of 40 feet and in several pressure ranges with the higher ratings available only in the smaller sizes. The temperature used in the pressure rating for PE pipe is important. For example, PE 3408 SDR 9 pipe rated for 200 psi at a water temperature of 75 degrees F is rated for only 140 psi at a water temperature of 125 degrees F. Temperature and pressure also affect service life. The manufacturer's literature usually shows these pressure, temperature, and service life relationships.

When PE pipe is used for natural gas service, pressure ratings are downgraded from those for the same material and SDR in water or wastewater service. For example, PE 3406/3408 SDR 11 pipe is rated at 80 psi for gas service (at 73 degrees F) whereas PE 3408 SDR 11 pipe is rated at 160 psi for water service (at 73.4 degrees F). The difference in pressure rating is due to the safety factor required by federal regulations for gas service use and not to any structural weakening occurring with exposure of polyethylene to gas.

Polyethylene pipe sizes are expressed in nominal iron pipe size (IPS) pipe size diameters which are nominal outside diameters. For sizes 14 inches and larger, the nominal IPS diameter and the actual outside diameter are the same. Below the 14-inch size, the actual outside diameter is larger than the nominal IPS diameter. Extruded PE pipe is available in nominal IPS diameters from 2 to 48 inches.

For a given nominal IPS diameter, the pipe inside diameter varies depending on wall thickness. Pipe catalogues and engineering manuals usually have dimension tables showing nominal IPS diameter, actual outside diameter, and the minimum wall thickness for their pipes of various SDR numbers. Factors for converting actual outside diameter to inside diameter for various SDRs are shown in Table 5-8.

Proper selection of the required pipe SDR takes into account:

- The internal working pressure.
- The time-corrected flexural modulus for the grade of polyethylene used to manufacture the pipe.
- A design factor to account for "installed out of roundness," variability in the estimation of internal working pressure, etc.

The previously referenced joint ASCE/WPCF manual describes the correct calculation of SDRs.

Polyethylene has excellent resistance to attack by acids, bases, and many other chemicals. Information is usually available from pipe manufacturers showing chemical resistance at various working temperatures for extensive lists of chemicals. Some chemicals and substances such as gasoline, oils, phenolics, and aromatic hydrocarbons may cause softening or swelling of PE pipe by adsorption into the wall. In wastewater lines, these chemicals are usually sufficiently diluted and exposure sufficiently intermittent as not to produce a problem. They should not occur in water or natural gas systems.

Table 5-8 Factors for Converting O.D. to I.D. for Various Standard Dimension Ratios

SDR	Factor, F
7.3	0.712
9	0.767
11	0.809
13.5	0.844
17	0.876
21	0.900
26	0.919
32.5	0.935

Note: I.D. = F x O.D

Spiral-Ribbed Polyethylene Pipe. This PE product is generally the same as extruded PE pipe. Differences lie in:

- The manufacturing process which allows spiral-ribbed PE pipe to be manufactured in any diameter between 12 and 144 inches and in virtually any length to meet handling and installation criteria. The flexibility in diameter production allows maximum outside diameter to be produced with minimum annular space between the PE liner and the existing deteriorated pipe. This often allows a greater inside diameter.
- Ability to adjust the load-bearing strength of spiral-ribbed PE pipe by adjusting both the wall thickness and the spacing and thickness of the reinforcing ribs. In larger diameters, this feature of spiral-ribbed PE pipe can produce good pipe economics.

The design guidance provided in the joint ASCE/WPCF manual includes design calculations applicable to spiral-ribbed PE pipe.

Extruded Polybutylene Pipe. Polybutylene (PB) pipe resembles PE pipe in stiffness and chemical resistance. Essential differences between PE and PB pipe materials are:

- PB pipe has higher strength than PE under sustained stress.
- PB pipe retains more of its initial strength with increasing temperature to an upper limit of about 180 degrees F.
- The maximum PB diameter currently available is a nominal IPS of 42 inches.

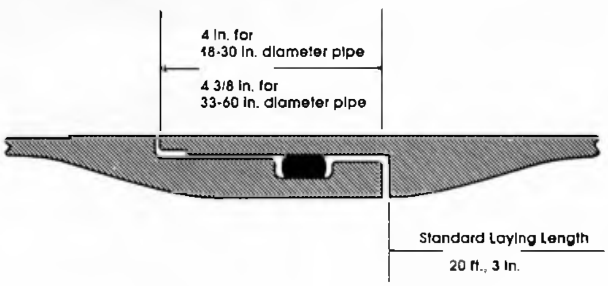
Standard specifications regarding PB pipe are ASTM D2666 and D3000. Standard pipe length is 40 feet.

Reinforced Plastic Mortar Liner Pipe. The use of reinforced plastic mortar (RPM) pipe for sewer rehabilitation has been extensive. It is frequently specified as an acceptable alternative to polyethylene. For use in insertion lining, the pipe should generally conform to the "Standard Specification for Reinforced Plastic Mortar Pipe" ASTM D3262. The material is a thermosetting composite of resin-saturated strands of fiberglass together with sand and resin applied to a rotating mandrel in manufacture. There are two manufacturing processes. One process controls inside diameter and permits pipe of different pressure ratings but the same inside diameter to be made on the same machine. The other process controls outside diameter.

RPM liner pipe is available in standard lengths of 20 feet at pressure ratings to 50 psi. Standard diameters range from 18 to 66 inches. Large diameters can be fabricated on special order as can higher-pressure rated pipe.

Diameters of RPM liner pipe are expressed as nominal inside diameters. Nominal inside diameters are used because there is some inside diameter reduction at the inverted bell and spigot joints (Figure 5-24). Inverted joints allow the liner overall inside diameter to be as close as possible to the original pipe diameter. The maximum outside diameter occurs at joints and varies from about 1 to 2 inches larger than the nominal inside diameter across the 18- to 66-inch pipe size range (e.g., maximum outside diameter of an 18-inch pipe is about 19 inches and maximum outside diameter of a 66-inch pipe is slightly more than 68 inches). These dimension details may vary slightly depending on manufacturer and are available in the manufacturer's literature. Minimum wall thicknesses for RPM pipe are based upon stiffness factors developed from ring compression, ring buckling, and longitudinal compression criteria.

Figure 5-24 RPM Liner Pipe--Joint Detail--Source: CorBan Piping Products



RPM pipe has good chemical resistance and is corrosion-resistant for sewer applications. Friction losses are low due to smooth interior surfaces. This pipe has high strength and a high modulus of elasticity when compared with polyethylene, polybutylene, and other thermoplastics.

Reinforced Thermosetting Resin Pipe. Reinforced thermosetting resin (RTR) pipe is similar in many respects to RPM pipe. For use in insertion lining, the pipe should conform to ASTM C4184. The essential differences in RPM and RTR pipe are:

- Sand is added to the fibers and resins in RPM manufacture but is not added in RTR manufacture.
- RTR pipe is available in a wider range of sizes (4 to 192 inches) than is RPM pipe. However, maximum outside diameters for the same inside diameter are significantly larger for RTR pipe than for some brands of RPM pipe.
- RTR pipe is available in standard lengths up to 80 feet, depending upon diameter.

RTR pipe has high axial and longitudinal strength and good corrosion, erosion, and abrasion resistance. Interior smoothness is generally comparable with that of RPM pipe.

Ductile Iron Pipe. Ductile iron (DI) pipe, Class 50, has been successfully used as an insertion liner in sewer rehabilitation. It has a high modulus of elasticity, i.e., it is very strong. Where corrosion is not a problem, the standard DI pipe with a cement lining is normally sufficient. Where the existing pipe has experienced serious corrosion, polyvinyl-lined DI pipe should be used.

This pipe can be used with less concern for postlining collapse of the old pipe than can the less-rigid plastic liners. Continuous grouting or sand filling of the annular space between the existing pipe and the liner pipe is seldom needed to protect DI liners. It may be desireable to prevent the piping of groundwater, however. If necessary, a heavier class pipe may be utilized with the same outside diameter. The longitudinal compressive strength is very high, permitting the pipe to be pushed relatively long distances. DI pipe, Class 50 is available in nominal IPS diameters of 4 to 60 inches. Standard pipe length is 20 feet.

Insertion Methods

Once the insertion lining material has been selected and the lining job designed, the following are key steps in the insertion process:

1. For sewer lines, inspect line by walk-through or closed-circuit television to identify all obstructions (e.g., displaced joints, crushed pipe, protruding service laterals, etc.) and locate all service connections. For water and gas lines, visually inspect pipe sections.

2. For sewer lines, clean line of solids deposits, cut roots, and remove service connection protrusions. If cleaning is necessary for gas lines, use a polly-pig or reaming device.

3. Proof-test line for insertion by pulling a test pipe section (short section of liner) or a test mandrel through the pipe section which is to be lined.

4. Insert liner pipe.

5. Reconnect services.

6. Fill or seal annular space between liner and existing pipe as necessary.

7. For pressure pipe (water and gas), pressure test the inserted pipe.

There are two basic insertion methods, known as:

- The "pull method" where the liner insert is drawn through the existing pipe using a winch and cable system attached to a pulling head which, in turn, is secured to the liner pipe (see Figure 5-25.)

- The "push method" where the liner insert is pushed into the existing pipe.

Figure 5-25 Modern Truck-Mounted Winch and Specially-Designed Boom Easily Pulled a 700-Foot, 24-Inch Polyethylene Liner in Less Than a Day

These two basic methods are illustrated on Figure 5-26. Several variations are illustrated for the push method.

- On small (diameter and length) projects, a backhoe can be used to push the liner into the existing pipe. The illustration shows this being done with butt-fused liner pipe. It is also applicable to insertion of jointed pipe (RPM, RTR, DI, etc.).

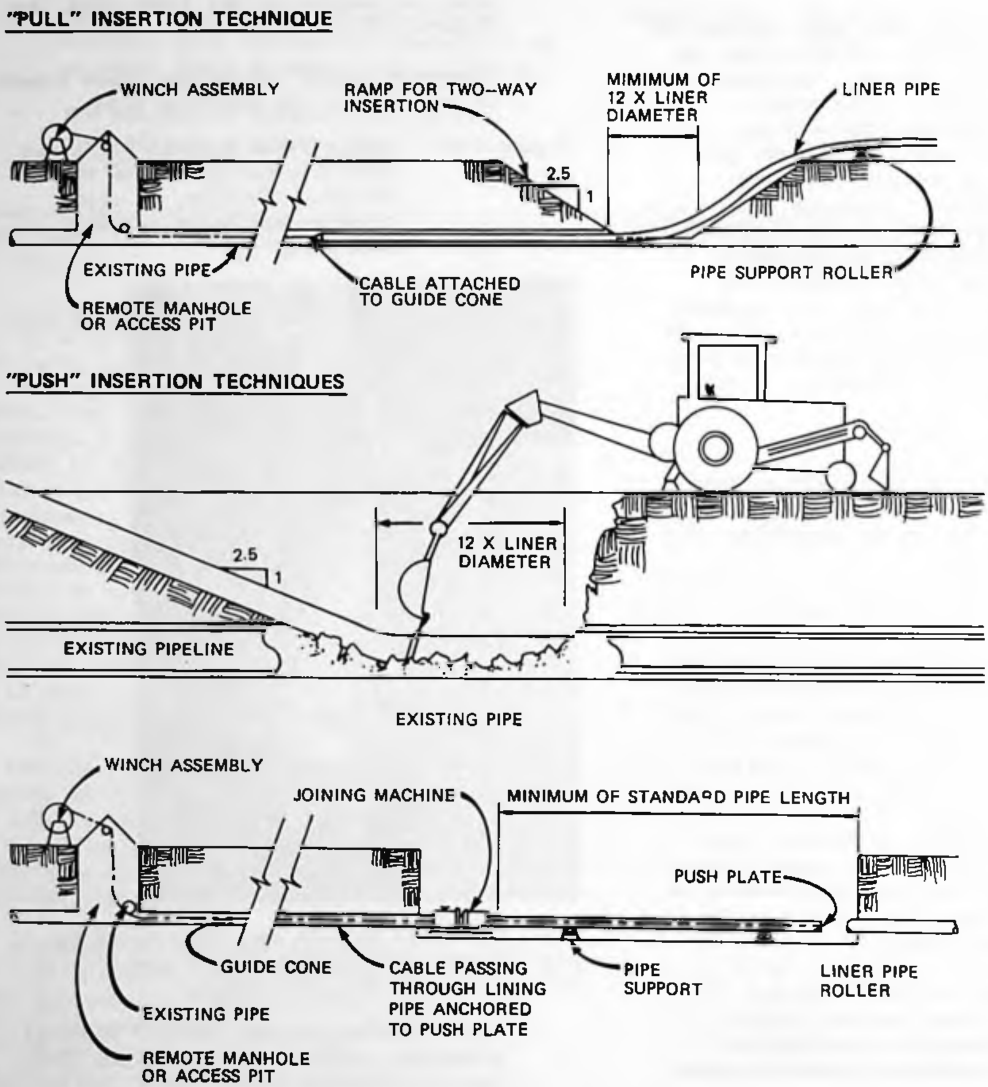
- The winch and cable push method is applicable to either butt-fused or jointed pipe.

- The jacking machine push method (Figure 5-27) is used for long pushes of jointed pipe.

The most common insertion and joining methods for the various liner materials are shown in Table 5-9. Figure 5-28 shows heat fusing equipment.

- In using the push or pull method in sewers, the necessary below surface equipment at the winching end usually fits into standard-size manholes.

Figure 5-26 Two Basic Methods for Polyethylene Insertion

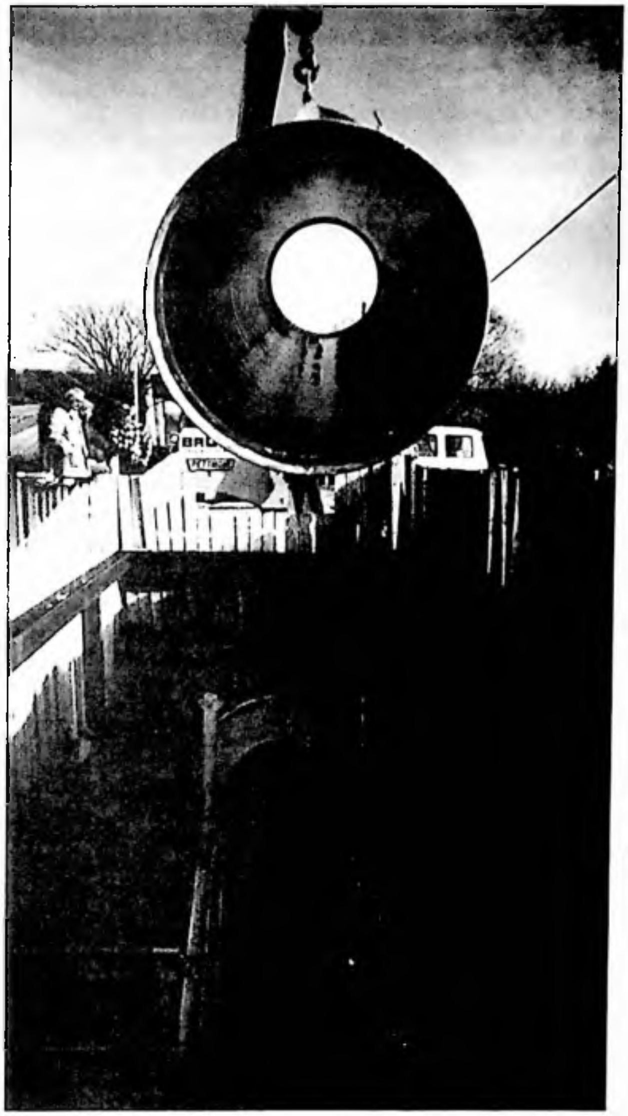


<u>Access Pits</u>. As shown on Figure 5-26, an access pit is required for both the push and the pull-insertion methods. Figure 5-29 shows a 26-inch polyethylene liner being pulled into the pipe at an access pit.

- An access pit is usually required only at the insertion end of the job.
- It is most economical to site access pits where prelining inspection has shown changes in alignment or grade or major pipe failures.
- General pit bottom length dimensions in terms of liner pipe diameter are shown on Figure 5-26. The maximum pit ramp slope (2.5:1) is important and reflects the flexibility of plastic pipe materials.

- General pit width dimensions are shown in Table 5-10. The pull method has the least pit width requirement when used with polyethylene or polybutylene liner pipe with the joining occurring aboveground outside the pit. The push method requires placement of jacking and/or joining equipment in the pit.

Figure 5-27 Push Insertion Using Jacking Machine. Courtesy of CorBan/Armco



The number of access pits required and their spacing along the job are a function of the length of line to be inserted and the material to be used. In straight runs, continuous pulls or pushes up to 1,000 linear feet and greater are possible. Insertion pulls or pushes in both directions from a single pit are common.

Table 5-9 Common Insertion and Joining Methods for Various Liner Materials

Material	Most common insertion method	Joining
Extruded polyethylene	Pull	Heat fusion
Spiral-ribbed polyethylene	Push	Bell and spigot
Polybutylene	Pull	Heat fusion
Reinforced plastic mortar	Push	Bell and spigot
Reinforced thermosetting resin	Push	Bell and spigot
Ductile iron	Push	Bell and spigot

Service Reconnections

Service reconnections after liner insertion currently require excavation at each service location. Stepwise:

1. The service connection is excavated.
2. The existing service piping is removed.
3. A cutting tool is inserted into the old pipe, after any necessary breakout of the old pipe wall, and a service hole is cut through the liner pipe.
4. The new service connection is made.

Figure 5-28 High Density Polyethylene Pipe is Heat Fused Into a Continuous Liner for Insertion by Slip Lining

A remote connection technique is available for connections to polyethylene liners in sewers. This technique limits the excavation to exposure of the service lateral. The necessary cutting tools and connectors are inserted down the existing lateral to the new liner. All other service connection methods require excavation of the services to the junction with the relined pipe.

Figure 5-29 Polyethylene Liner is Pulled Into the Deteriorated Pipe at an Insertion Access Pit

For gas services, it is standard practice to reline the service pipe at the same time the main is being relined. This way the service connection to the main only has to be excavated once and there is no difficulty from joining dissimilar pipe materials together. Polyethelene tubing, 5/8-inch diameter, is frequently used to reline the pipe from the main to the gas meter.

Table 5-10 Pipe Insertion Access Pit Minimum Widths--General

Insertion method	Minimum pit width
Pull--aboveground joining	2 x liner diameter (6 feet minimum)
Pull--in-pit joining	3 x liner diameter (8 feet minimum)
Push--winch and cable with in-pit joining	3 x liner diameter (8 feet minimum)
Push--jacking machine	3 x liner diameter (8 feet minimum)

Note: Does not include space for necessary pit wall shoring.

Annular Space Treatment

Treatment of the annular space between the liner and the existing pipe depends on the type of pipeline. In general:

- In gravity and pressure sewers, a chemical or cement grout and oakum seal is placed in the annular space for a length of 1 to 2 feet upstream and downstream from each manhole.
- In water pipelines, grouting is usually done throughout the entire length.
- In gas pipelines, the annular space is usually left open.

In sewers, grouting or sand filling of the annular space along the entire length of the liner is often desirable in addition to the sealing at manholes. It is recommended when, if the original pipe collapsed, it would cause a hole in the street or might cause the new liner pipe to collapse because of increased loading from the overburden. Filling the annular space is difficult to do and to inspect, however, the equipment is improving. It is normally done from manholes and service reconnections. The trend is to do it more now than in the past.

Size Reduction and Capacity Considerations. All pipe insertion methods reduce the pipe cross section. Evaluation of system capacity needs as part of the overall evaluation of pipe rehabilitation, versus pipe replacement,is discussed in Chapter 4. Size reduction results because of:

- Liner pipe wall thickness (varies with liner pipe strength and diameter).
- Liner exterior thickness at joints (occurs with all liner materials except polyethylene and polybutylene which are butt heat fused at joints and some RPM and RTR materials which have inverted joints).
- Need to clear obstructions (offset joints, protruding services, etc.) in the existing pipe.
- Need to have minimal clearance to insert the liner (clearance requirement ranges from 3 to 10 percent of existing pipe inside diameter in straight reaches).
- Existing pipe not being round. Many early sewers were brick and noncircular (egg shapes, ovals, elipses, horseshoe shapes, etc.) or only approximately circular. Even modern clay pipe may not be perfectly round.

Liner pipe manufacturers in general claim that the smoothness of liner interiors is greater than that of the concrete and clay interiors of existing pipes. Their calculations tend to show that this compensates for the cross-sectional reductions which occur in lining jobs. Typical values of Mannings "n" and Hazen-Williams "C" claimed applicable in hydraulic calculations for the various liner products are shown in Table 5-11.

Table 5-11 Comparison of Mannings "n" and Hazen-Williams "C" Values for Liner Pipe and Typical Existing Pipe Materials

Material	Mannings "n"	Hazen Williams "C"
Extruded polyethylene	0.009[a]	155[a]
Spiral-ribbed polyethylene	0.009[a]	-
Extruded polybutylene	0.009[a]	155[a]
Reinforced plastic mortar	0.011	140
Reinforced thermosetting resin	0.011	140
Cement-lined ductile iron	0.012	130
Polyvinyl-lined ductile iron	0.009[a]	155[a]
Vitrified clay	0.012	-
Concrete	0.013	120
Cement-lined steel	0.012	130
Brick	0.014	-

[a]The values shown for these plastics are manufacturer claims.

Pipe Insertion Construction Costs

The construction cost of pipeline rehabilitation using pipe insertion is highly specific to the conditions of individual jobs. It is also influenced by the extent to which bidding competition is increased by allowing specified liner material alternatives as well as removal and replacement. The basis of construction cost estimation presented for the several pipe insertion materials and methods is basic unit cost curves displaying a range of unit costs for various liner diameters plus tabular presentation of added costs which are specific to individual jobs and not readily generalized on the curves. All of the cost information is at cost levels in January of 1984 (Engineering News Record, 20 Cities Average, Construction Cost Index of 4109).

Cost Effects of Job Scale. The scale of the liner project affects the unit costs. The cost curves presented here are for a minimum job size of 1,000 lineal feet with a single setup and run from a single access pit (i.e., 500 feet in each direction from the pit or 1,000 feet in one direction). The unit costs of shorter jobs can increase significantly from those shown on the unit cost curves.

Costs Included on Unit Cost Curves. The unit costs include the following:

- Cleaning of the existing line.
- Closed-circuit television inspection of the existing line.
- Material, equipment, and labor for liner insertion (after access pit preparation which is not included).
- Plugging of the "liner pipe/existing pipe" annular space at manholes and other junctions.
- Working in an active sewer (wastewater or drainage flowing through the liner).

Costs Not Included on Unit Cost Curves. The unit cost curves do not include the following:

- Preparation of insertion access pits.
- Connection of services to the new liner.
- Grouting or sand filling of the entire "liner pipe/existing pipe" annular space.
- Bypassing of wastewater or providing temporary water or natural gas service.
- Costs of design engineering, construction management (inspection, etc.), or design-related services during construction (i.e., the construction cost information is for preparation of construction bid price estimates).

Added Construction Costs Applicable to All Pipe Insertion Methods and Materials. These added costs are presented in Table 5-12. They are the same regardless of the pipe insertion material used.

Unit Cost Curve--Insertion with Extruded Polyethylene or Polybutylene Pipe. Figures 5-30 and 5-31 are unit cost curves for pipe insertion using either extruded high-density PE pipe or extruded PB pipe. As noted on the figures, the unit costs do not include the added construction costs presented in Table 5-12.

- The lower limit of the cost curve is for existing pipelines with good pipe alignment and with no need for spot repair and no significant groundwater.
- The upper limit applies to existing pipelines with poor pipe alignment, some need for spot repairs, and need for groundwater dewatering.
- Polybutylene pipe is not available in sizes larger than 42 inches.

Unit Costs--Insertion with Reinforced Plastic Mortar, Ductile Iron, or Spiral-Ribbed Polyethylene Pipe. The unit cost curve for insertion with RTR pipe (Figure 5-33) is used with adjustments to estimate the unit costs for pipe insertion using RPM, DI, or spiral-ribbed PE pipe. These adjustments are shown in Table 5-13 as percentages of the unit costs for RTR pipe. The lower and upper limits of the resulting unit costs are as described for extruded PE pipe and do not include the added costs shown in Table 5-12.

Advantages

Pipe insertion rehabilitation of pipelines offers the following advantages over pipeline removal and replacement:

Table 5-12 Added Construction Costs Applicable to All Pipe Insertion Methods and Materials

Item	Service connection size, in.	Depth of existing pipe at service connection, ft	Unit construction cost, dollars/service connection[a]	Unit grouting cost, dollars/cubic yard of grout	Pit depth, ft	Pit cost, dollars/foot of depth[b]
Service connections	1 or 2	4 to 8	300			
	4 or 6	4 to 8	400			
	4 or 6	8 to 12	550			
	4 or 6	12 to 16	750			
	4 or 6	16 to 20	1,000			
Grouting of "liner pipe/existing pipe" annular space				200		
Access pits					<10	1,000
					10 to 20	800
					>20	1,000

[a]Costs do not include repaving (add $50 to $100 per connection) or traffic control.

[b]Costs are for average traffic conditions and include pit sheeting and shoring in reasonably stable soil where groundwater dewatering is not necessary.

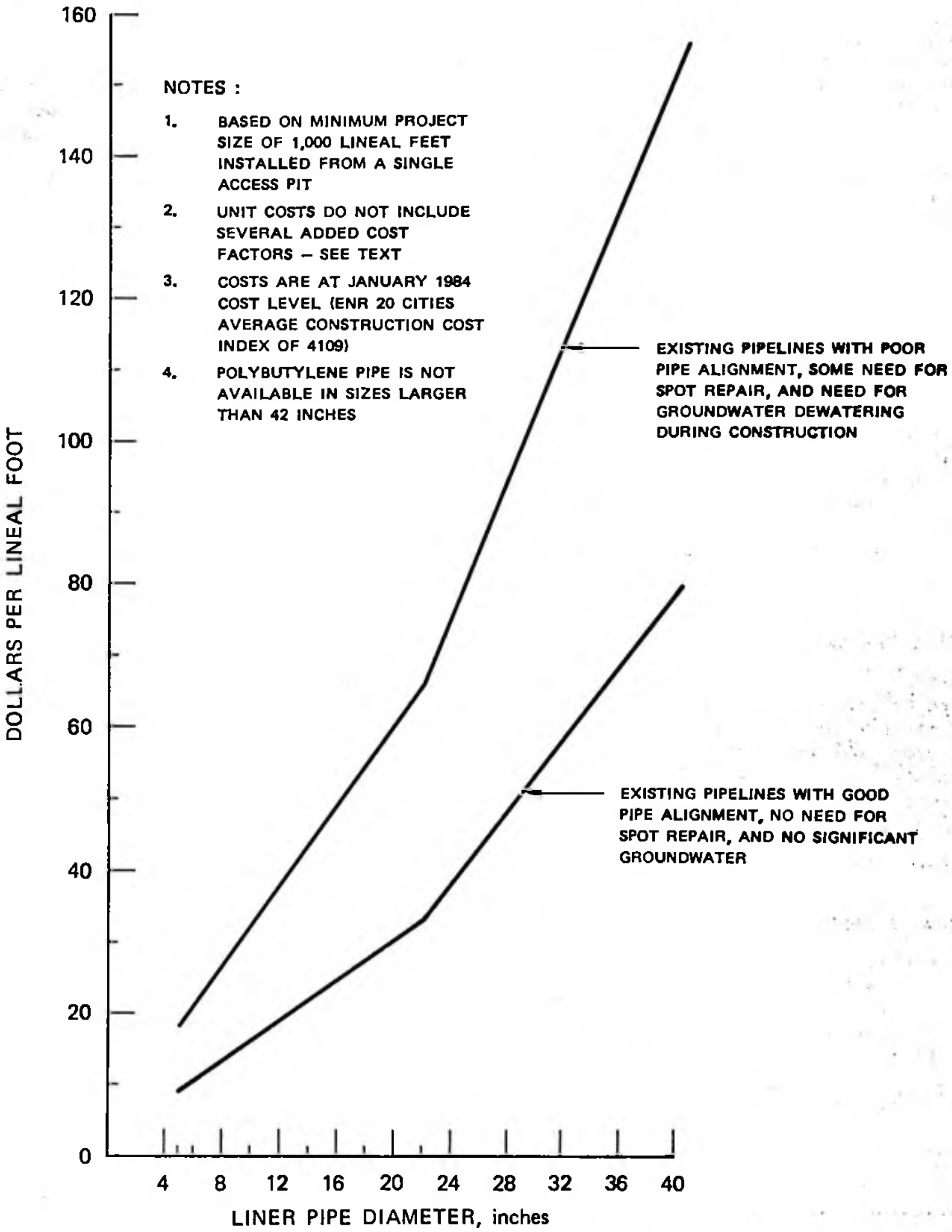
Note: Costs are adjusted to 20 Cities ENR December 1983 Construction Cost Index of 4109.

Costs of Gas Pipe Insertion With Extruded Polyethelene. The unit cost curves do not apply for gas pipe insertion (Figure 5-31). In 1981 Wisconsin National Gas Company was spending $8.90 per foot for insertion of 2-inch polyethelene in nonpaved areas and, $12.80 per foot in paved areas.[1] This included $1.23 for the material cost. Updating these costs to January 1984 results in unit costs of $11.15 to $16.10 per foot. Cost data supplied by Philadelphia Electric showed similar costs.[2]

Unit Cost Curve--Insertion With Reinforced Thermosetting Resin Pipe. Figure 5-32 is a unit cost curve for pipe insertion using either RPM or RTR liner pipe. The lower and upper limits of the cost band are as described for extruded PE pipe. The curve does not include the added costs shown in Table 5-12.

- As with all of the rehabilitation methods, pipe insertion takes advantage of the existing hole under streets and through what is often a maze of other buried infrastructure. It places the renewed pipeline within the space already occupied by the existing pipeline and minimizes the potential for disruption of other utilities.
- Excavation is limited to insertion access pits and the smaller excavations needed to restore service connections. Accordingly, both damage to surface features (pavement, sidewalks, landscaping, etc.), and disruption of traffic and urban activities is substantially less than that associated with pipeline removal and replacement.

Figure 5-30 **Unit Cost for Pipe Insertion Using High Density Extruded Polyethylene Pipe or Extruded Polybutylene Pipe--Liner Diameters 4 to 40 Inches**



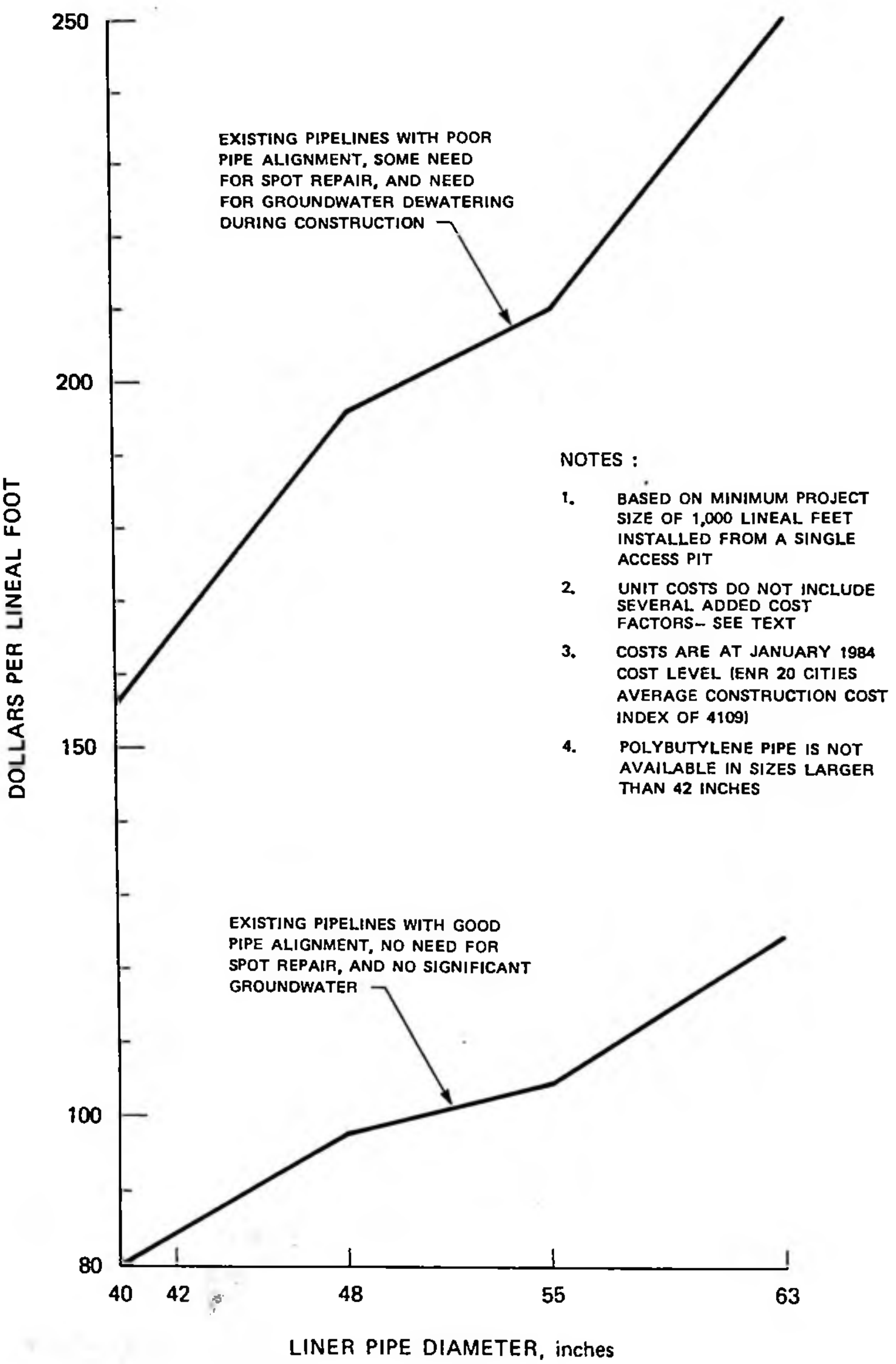
- Insertion renewal of existing pipelines can be significantly less expensive than removal and replacement. This lower cost occurs in the measurable costs associated with construction and in the nonquantifiable costs associated with major surface disruption in urban areas.

Disadvantages

Pipe insertion has the following disadvantages:

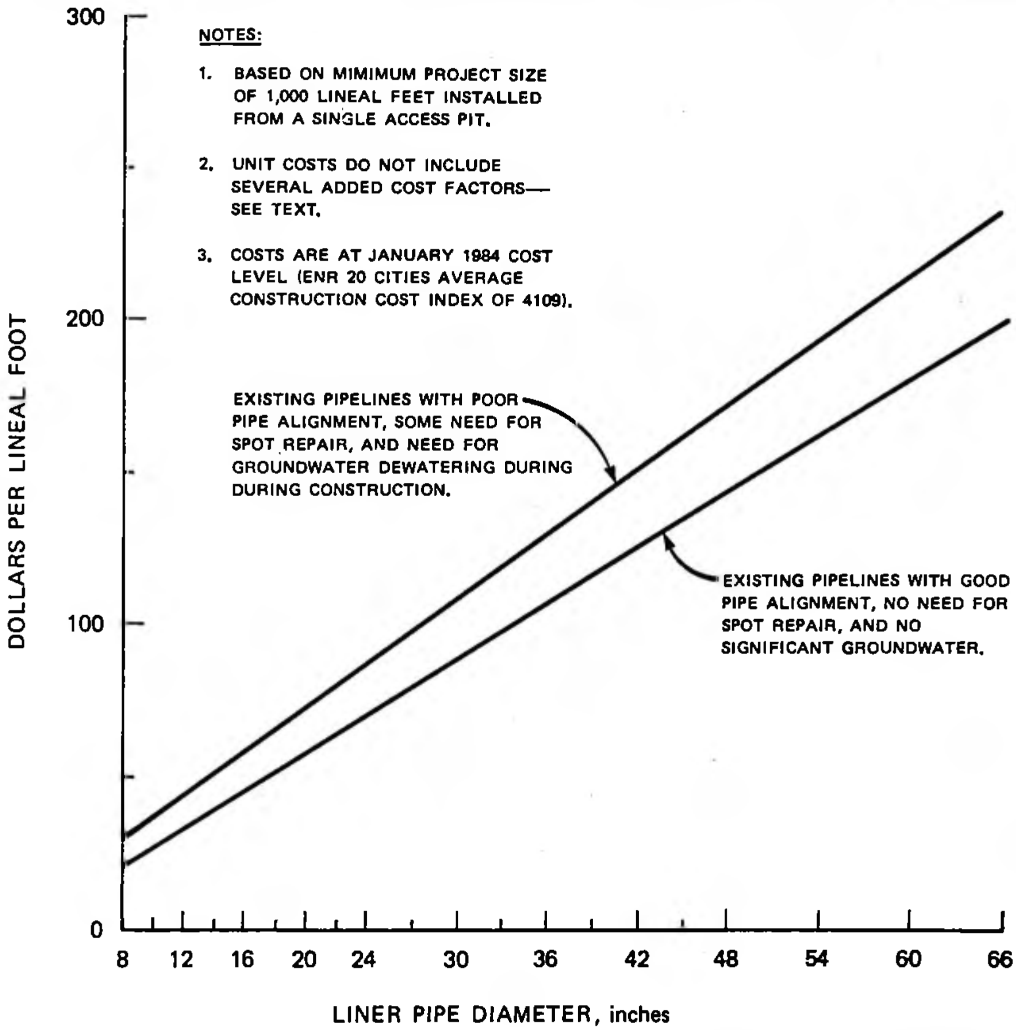
- All pipe-insertion methods and materials result in reduced pipe cross sections and an associated reduction in pipe capacity.

Figure 5-31 Unit Cost for Pipe Insertion Using High-Density Extruded Polyethylene Pipe - Liner Diameters 40 to 63 Inches



This reduction can be substantial where the existing pipeline is not circular in cross section. In circular pipes, the cross-sectional reduction is nearly always 10 percent of the existing pipe inside diameter and may be greater, depending on individual case conditions.

Figure 5-32 Unit Cost for Pipe Insertion Using Reinforced Thermosetting Resin Pipe



• All pipe-insertion methods and materials currently require excavations at each service connection.

RESIN-IMPREGNATED FABRIC INVERSION LINING

Resin-impregnated fabric is used to reline deteriorated pipelines in a patented process developed in Great Britain in 1971. The process, known as Insituform, was introduced in the United States in 1977. It is marketed under the same name by a number of contractors.

<u>Materials</u>

The materials used in the inversion lining process are polyester felt with a bonded-on membrane backing (polyurethane, polyvinyl chloride, or similar membrane material), and either polyester or epoxy resins. The materials used by Insituform have recently been toxicity-tested and approved by the U.S. Environmental Protection Agency for use in potable water supply lines.

<u>Liner Tube Design and Fabrication</u>. The polyester felt fabric is made into a tube having the same circumference as the inside of the pipeline which is to be lined.

- The manufacturer's design manual provides guidance for structural design of the liner wall thickness for a variety of existing pipe shapes and failure conditions under both open channel and pressure flow service.

Figure 5-33 Insituform Felt Tube is "Wetted-Out" With Resin at Contractor's Shop

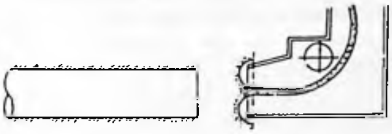
- According to design needs, the fabric thickness in the tube can be increased by adding layers of polyester felt in increments of 1.5 millimeters (mm) (0.059 inches).
- The manufacturer's literature currently shows tube wall thickness up to 30 mm (1.181 inches) and capability to line pipelines up to the circumferential equivalent of a 72-inch-diameter circular pipe.
- A plastic membrane is bonded to the outside of the fabric tube. This membrane is about 0.25 mm (0.01 inch) thick and serves to retain resin in the felt tube prior to installation. In the finished job, this membrane becomes the inside surface of the rehabilitated pipeline.

Table 5-13 Unit Costs of Pipe Insertion with RPM, DI and Spiral-Ribbed PE Pipes as Percent of Unit Costs for RTB Pipe

Line pipe diameter, inches	Type of pipe			
	RTR	RPM	DI	Spiral-ribbed PE
8	100	NA	50	NA
10-16	100	NA	70	NA
18	100	85	70	55
20	100	NA	75	NA
21	100	85	NA	60
24	100	85	75	65
27	100	85	NA	70
30	100	85	75	75
33	100	85	NA	80
36	100	85	80	80
39	100	85	NA	NA
42	100	85	80	80
45	100	85	NA	NA
48	100	85	80	85
54	100	85	80	120
60	100	85	80	120
66	100	85	NA	120

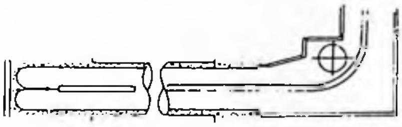
Note: The percentages shown in the table are for use with the RTR unit cost curve. "NA" indicates the pipe material is not currently available at this size.

Figure 5-34 The Insituform Inversion Process, Courtesy of Insituform of North America, Inc.



1. A polyester needle-felt tubing, saturated with thermo-setting resins and coated on one side with an impermeable coating, is inserted into a vertical inversion standpipe cuffed around the outlet and banded.

2. Cold water is fed into the standpipe, forcing the impregnated felt tube to turn inside-out and into the damaged pipe.



3. Once fully extended into the line, the cold water is heated, curing the heat sensitive resins to form a hard Insituform® pipe.

4. After curing, the ends are cut off and finished, any lateral connections are reopened with an Insitucutter and the process is complete.

Resin Selection and Resin Application. Two resin types (polyester and epoxy) are available. Both types are liquid thermosetting resins.

- All of the resins have excellent resistance to normal domestic sewage.
- Polyester resin composites are the least costly and tend to have slightly better resistance to acids than do the epoxies (there are some exceptions and the manufacturer should be consulted for specific cases).
- Vinylester resins are often used where superior corrosion resistance is needed at high temperatures.
- Epoxy resins are used where adhesion to the existing pipeline is desired (polyester resins do not have the adhesive properties of epoxies). Certain residual products, such as phenols which may be present in existing pipelines with previous tar linings, can interfere with the proper curing of polyester resins and lead to selection of epoxies.
- Resin application usually takes place in the contractor's shop (Figure 5-33). The "wetting-out" process in which the felt tube is impregnated to saturation with catalyzed resin usually takes place within 24 hours of the beginning of field installation. Longer times between wet-out and installation are possible depending on the resin which is used.
- Resin/catalyst mixtures are determined by the contractor based on the specifics of a particular job.
- Resins are applied to the inside of the fabric tube under vacuum in this critical step of the liner preparation process.
- Once the resin is applied, the impregnated tube must be maintained at a temperature less than 40 degrees F until installation.

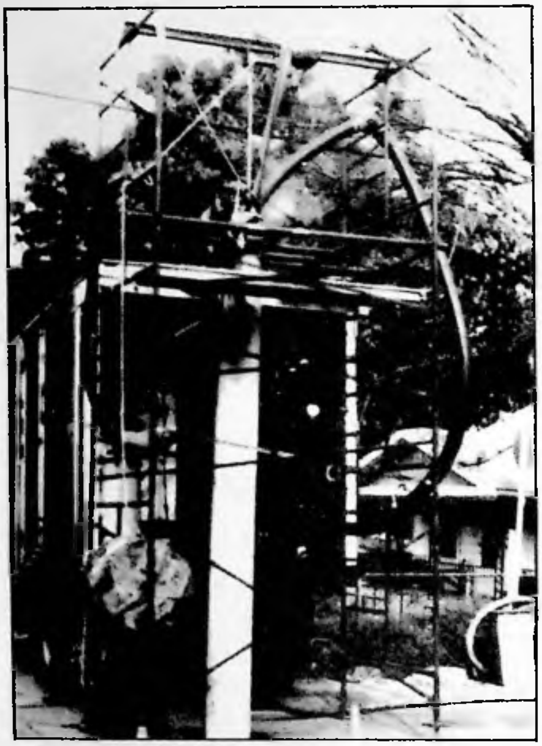
Installation

The resin-impregnated fabric tube is inverted (turned inside out) into the existing pipeline and cured in place using heated water or air which triggers the thermosetting resin (Figure 5-34).

- Prior to liner inversion, the pipeline section must be cleaned to remove loose debris. Roots and protruding service connections must be removed from sewers, and excessive solids deposits and tuberculation must be removed from waterlines.
- During inversion of the liner into the pipeline, the pipeline segment must be isolated from the remainder of the

system and all water, wastewater, natural gas, etc., flow diverted or bypassed around the pipe reach being rehabilitated.

Figure 5-35 Hot Water is Circulated From a Boiler Through the Resin-Impregnated Liner to Cure it.



- Typically in sewers, the fabric tube is inverted into the existing pipeline through a manhole without need for excavation. Junction and valve structures in water and gas mains can be similarly used.

- The inversion process uses cold water or in some instances air to extend the liner and press it firmly against the existing pipe wall.

- Once the liner is in place, a hot water (or air) circulation hose is inserted and the thermal curing process begins. Water is generally used for liner inversion and curing when the pipe diameter is 48 inches or less. Figure 5-35 shows the hot water being circulated from a truck-mounted boiler down the standpipe.

- Larger-pipe diameters, to an equivalent of 108 inches, have been inverted and cured using air. (Note: In early 1984, a continuous 48-inch liner, 850 feet long, was inverted and water-cured in a steel pressure line. In the combination of length and diameter, this was the largest job installed in the United States to that time.)

- Following curing, the ends of the liner are cut and sealed at manholes, water, or gas valve structures, etc., and service connections are restored. Figure 5-36 shows the end of the fabric tube.

<u>Service Reconnections</u>

For services 8 inches or more in diameter, service reconnections are done using a remote cutter operating from within the lined pipe. Figure 5-37 shows the remote cutter and television camera.

- Closed circuit television is used to locate services to be restored. The liner dimples into service connections forming a distinct outline of the hole to be cut.

- Using a television monitor, the cutting device is positioned and a pilot hole drilled to alow drainage of any accumulated water. (See Figure 5-38).

- Services are typically restored in sewer lines working from the downstream end of the relined pipe section, thus minimizing the interference between the cutting operation and flow from restored services.

<u>Inversion Lining Applications</u>

Inversion lining can be used to rehabilitate water, sewer, and natural gas pipelines suffering corrosion, leakage, and minor structural problems. Table 5-14 summarizes the capabilities and limitations of this rehabilitation method.

<u>Correction of Structural Problems</u>. Inversion lining is successful in dealing with a number of structural problems. Caution must be used in the application of this method to any structural problem involving major loss of pipe wall, reinforcing steel, or exterior side and bedding support. Loss of exterior support is frequently evidenced by pipe crown or invert sag and/or severely offset joints. Within limits, the liner can be designed to deal with these more serious structural problems. Expert examination is essential in determining which problems can be effectively corrected. As with other rehabilitation methods, severely crushed or collapsed pipes usually require removal and replacement.

Figure 5-36 End of the Resin - Impregnated Liner During Inversion. Courtesy of Insituform of North America, Inc.

Size Reduction and Capacity Considerations

Inversion lining produces only minor and usually insignificant reduction in pipe cross section. It has particular appeal for pipes of irregular cross section and produces the least size and capacity reduction of any of the rehabilitation methods.

As is the case with other rehabilitation methods using plastics, the manufacturer claims significantly better hydraulic characteristics than are commonly accepted as applicable to cement, clay, and other nonplastic pipes. The manufacturer claims Mannings "n" values of 0.008 to 0.010 on "reasonably straight lines with constant grade."

Construction Costs

Construction cost is highly specific to the conditions of individual jobs. It is also influenced by the extent to which bidding competition is increased by allowing other specified rehabilitation alternatives as well as replacement. Because this method is a patented process with licensed contractors assigned geographical regions, there is generally no competition between different inversion lining contractors on a given job. The exception is in those geographical regions which have yet to be assigned.

The basis of construction cost estimation presented for this rehabilitation method is a basic unit cost curve displaying a range of cost for various circular diameter existing pipelines and equivalent (in terms of section circumference) noncircular sections.

All of the cost information is at cost levels in January of 1984 (Engineering News-Record, 20 Cities Average, Construction Cost Index of 4109).

Figure 5-37 Insituform Cutter (foreground) and television camera (background)

Figure 5-38 Insituform Remote Cutter Reconnecting a Service Lateral

Figure 5-39 is the unit cost curve for inversion lining using resin-impregnated polyester fabric. The curve costs are based on the use of polyester resin and the minimum bag thickness recommended by the manufacturer for each liner diameter.

- The lower limit of the cost curve is for existing pipelines in good alignment with no need for spot repair and no significant groundwater.
- The upper limit of the cost curve is for poor pipe alignment, some need for spot repairs, and need for groundwater dewatering.

Cost Effects of Job Scale. The scale of a project using the inversion lining method affects the unit costs. The cost curves presented are for a minimum job size of 1,000 lineal-feet conducted with two setups. The costs assume that the liner is installed by running 500 feet of liner in each of the setups using an already available access point such as a manhole or valve structure. The unit costs of shorter jobs can increase significantly from those shown on the curves.

Costs Included on Unit Cost Curves. The unit costs include the following:

- Cleaning of the existing line.
- Closed-circuit television inspection of the existing line.
- Material, equipment, and labor for liner inversion.
- Bypassing of wastewater.
- Shutoff of water or natural gas service where the method is employed in those kinds of systems.
- Restoration of up to 20 services.
- Contractor mobilization, bonds, and insurance.

Costs Not Included on Unit Cost Curves. The unit cost curves do not include the following:

- Providing temporary water or natural gas service.
- Design engineeering, construction management (inspection, etc.) or design-related services during construction (i.e., the construction cost information is for preparation of construction bid price estimates).

Advantages

Inversion lining offers all of the advantages identified for pipe insertion, plus:

- The ability, in many cases, to conduct the entire rehabilitation project, including service reconnections, without excavation.
- The ability for rapid return of the rehabilitated line to full service. In many instances, up to 500 feet of lining can be placed and the pipeline fully returned to service within 18 hours of the beginning of the job.

Table 5-14 General Applicability of Resin-Impregnated Fabric Inversion Lining to Pipe Problem

Problem	Remote restoration of service connections[a]	Ability to solve problem[b]
Existing pipe size		
<4-inch diameter	-	NU
4-inch to 8-inch diameter circular pipe equivalent	No	U
>8-inch to 72-inch diameter circular pipe equivalent	Yes	U
>72-inch diameter circular pipe equivalent	No	U
Existing pipe shape		
Circular	Yes	U
Irregular (i.e., ovoid, egg-shaped, horseshoe, arched, etc.)	Yes	U
Structural problem		
Pipe crown or invert sag	-	NS
Reinforcing steel gone	-	CS
Reinforcing steel corroded	-	CS
Pipe joints deteriorated or open	-	S
Pipe joints leaking or offset	-	CS
Pipe cracked	-	S
Pipe crushed or collapsed	-	NS
Pipe cement corroded	-	S
Pipe slabouts and holes	-	CS

[a]Equipment for remote cutting for service restoration is currently not available for sizes less than 8 inches in equivalent circular pipe size. At sizes greater than 48-inch in equivalent circular pipe size, man entry for cutting is more efficient.

[b]See legend for problem solution ability codes. Problem solution ability indications are generalized. Each structural problem in a particular pipeline must be subjected to expert examination.

Legend:

U = Usable in this size range or pipe shape.
NU = Not usable in this size range.
S = Solves this structural problem.
CS = Conditional solution to this structural problem.
NS = Does not solve this structural problem.

Disadvantages

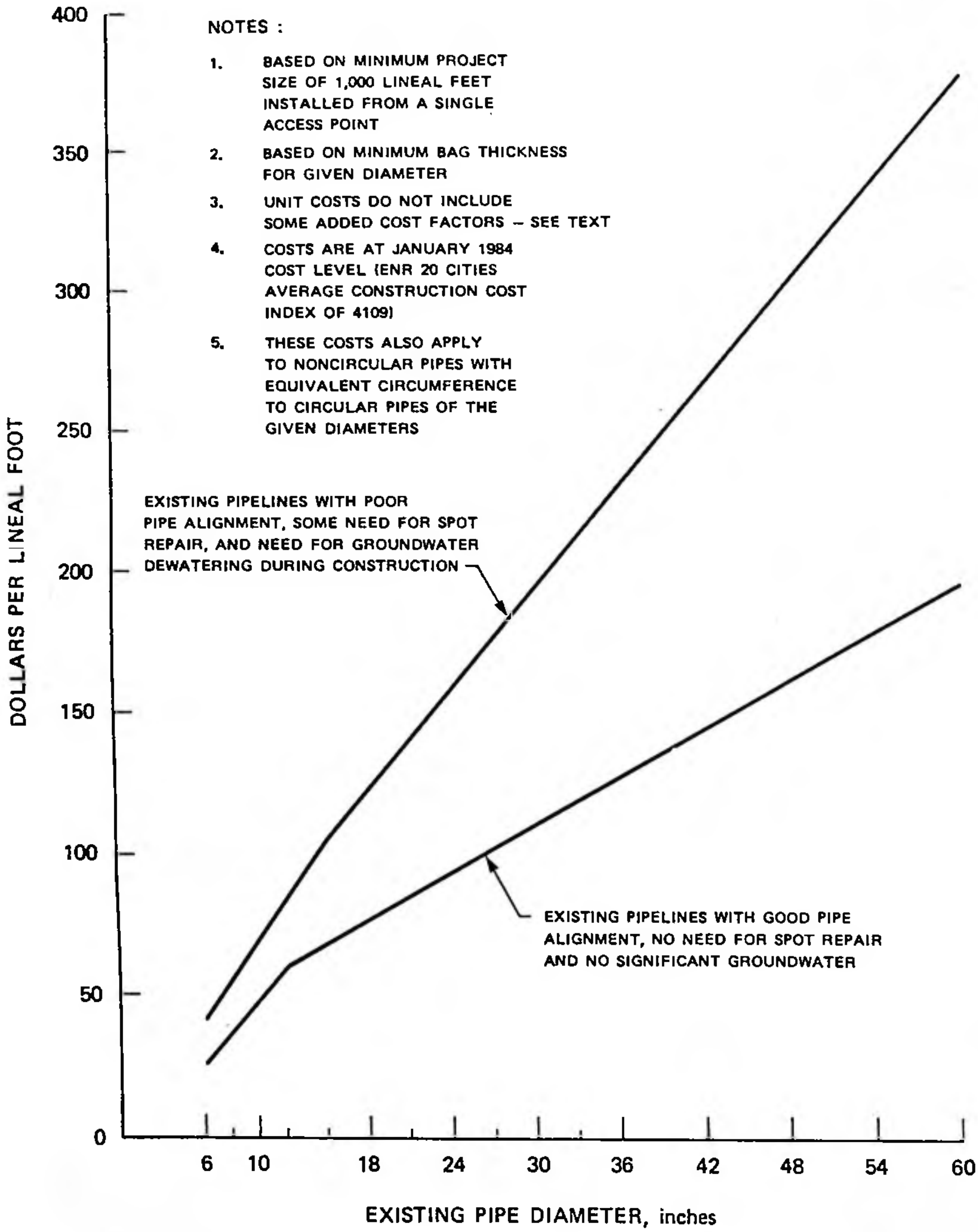
- The main disadvantage of inversion lining rehabilitation of pipelines is that the method is patented, with licensed contractors assigned discrete geographical regions, virtually eliminating cost competition.

OTHER METHODS

The preceding discussion of pipeline rehabilitation methods has been limited to the several methods and materials that are in common use in the United States. Pipeline rehabilitation technology continues to develop. Other methods which have been used outside the United States or are in limited use here include the following:

- Interior coating with nonsolvented hybrid polyurethane resins.
- Interior coating with phenolic epoxy.
- Insertion of expandable (hinged) PVC repair sleeves.

Figure 5-39 Unit Cost for Resin-Impregnated Fabric Inversion Lining



- Expansion breakout of existing pipes in advance of a polyethylene insertion liner.
- Vibratory rerounding of deformed flexible pipes.
- Lining with segmented fiberglass reinforced cement or plastic panels.
- Water pipe cleaning by Pipesavers.
- Pipe Insertion Machine.
- Weko-Seal joint rehabilitation.

Polyurethane Resin Coatings

These coatings have, for several years, been used in industrial applications in pipelines, storage tanks, and on marine pilings and ships. They have more recently been introduced as a corrosion protective coating for the inside of wastewater pipelines and structures. The manufacturer claims:

- Corrosion resistance to acids, bases, and salts over a wide range of concentrations.
- High abrasion resistance.
- High impermeability to water and gases.
- Good adhesion to steel, concrete, and wood substrates.
- Ability to apply the material in coatings of from 20 mils to several inches in one application.
- Rapid cure time (can be water immersed in 2 hours, walked on in 6 hours, and completely cured in 7 days without heating, baking, or other treatment).

These coatings appear capable of protecting pipelines and municipal wastewater structures from corrosion. They are not a remedy to structural problems. Manufacturer of these materials is Zebron USA, Inc., 19723 S.W. Teton Avenue, Tualatin, OR 97062.

Phenolic Epoxy Coatings

These coatings have essentially the same applicability as described for polyurethane resin coatings except that the material is brushed on rather than sprayed on.

Manufacturer of these materials is Wisconsin Protective Coatings.

Expandable PVC Repair Sleeves

This pipeline repair system was introduced in Canada in 1980. The manufacturer advocates its use for:

- Spot repair of cracked concrete, clay, or brick sewer pipe.
- Sealing of abandoned sewer service connections and leaking sewer pipe joints.
- Rehabilitation of manholes.
- Sealing of leaking joints in water mains.
- Repair of cracked culvert sections.

The repair system (Figure 5-40) uses 4-foot-long PVC modules each of which consists of six segments of Normal Impact Type 1 PVC 1120 material. These six PVC segments are joined by hinges which allow the modules to be collapsed for insertion in the existing pipeline. A flexible polyethylene foam is glued to the outside of the liner module. The collapsed module is inserted through a manhole or other access point and pulled by cable to the repair location. At the repair location, a remotely operated jacking device is used to expand the module into place.Finally, the jacking device is withdrawn and the repair is complete. The rights for this patented process are owned by Link-Pipe International Ltd., 1001 Meyerside Drive, Mississauga, Ontario, Canada L5T 1J6.

Vibratory Rerounding

This process uses a vibrating head to reround flexible pipe materials which have become deformed due to poor design and/or installation. The vibrating head is pulled from manhole to manhole in pipes of diameters from 6 to 30 inches. The vibration induced through the pipe wall to the surrounding soil redistributes the bedding and backfill materials as the head forces the pipe back to its original cross-section. However, rerounding will not correct the initial problem; poor bedding or backfill practices. Rights to this process are held by Williams Testing, Inc., 9180 Parker Road, Harrod, Ohio.

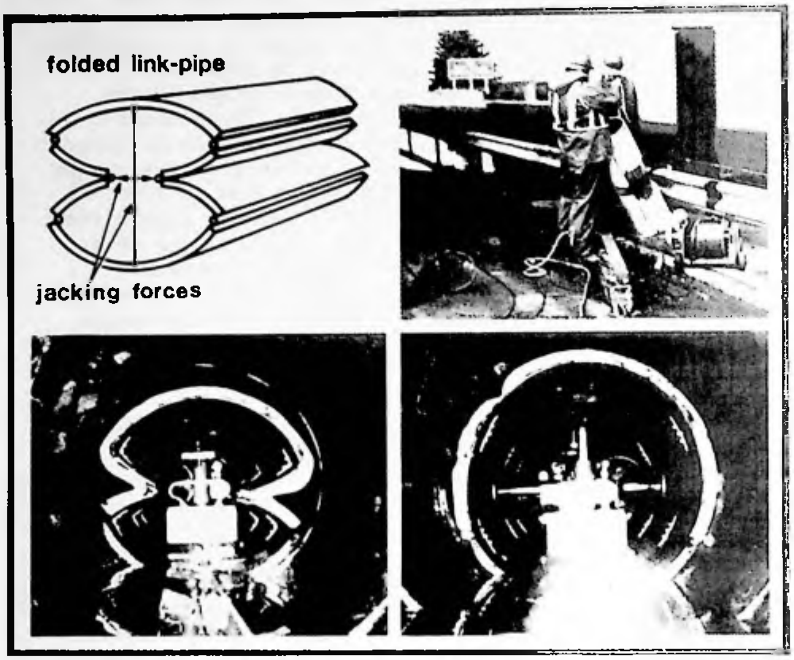
Segmented Fiberglass Reinforced Cement Liners

Fiberglass reinforced cement liners are thin panels developed to rehabilitate sewers above 42 inches in nominal size. These linings are segmented to fit the diameter required. Circular, oval, rectangular, elliptical, ovoid, or V-shaped sewers can be lined.

The linings are manufactured in a composite of cement and glass fibers. The normal wall thickness is 3/8-inch; however, this is occasionally modified. The linings have high mechanical and impact strength with good acid and alkalinity resistance. They are also highly resistant to abrasion with negligible absorption and permeability.

After a thorough line cleaning and dewatering, the segments are installed in 4-foot lengths which overlap at the joints, and the flanges on the segments may be predrilled for fixing by screw or impact nail gun (see Figure 5-41). The segmented rings are anchored on spacers; and upon final assembly, the entire section is cement-pressure grouted. Side laterials are cut in and grouted prior to final erection.

Figure 5-40 Expandable PVC Repair Service.
Courtesy, Link-Pipe International, Ltd.



This method provides flexibility to accommodate variations in grades, slopes, cross-section, and deterioration. The linings are not designed to support earth loads; however, so they should only be used in a structurally sound sewer. The interior smooth surface improves hydraulic capabilities.

Although the segmented sections are light and easy to handle, the installation of these linings is labor-intensive and slow (see Figure 5-42). It is not a recommended method for structurally inadequate sewers. These linings (invented in England) are available on a custom-designed basis in the United States.

Segmented Fiberglass Reinforced Plastic Liners

Similar in nature to glass-reinforced cement liners these liners are used predominantly in sewers above 42 inches. Formed in segments with a range of available wall thicknesses and shapes, (see Figure 5-43) they are not structural components, but do provide an adequate corrosive barrier and smooth lining for structurally sound sewers.

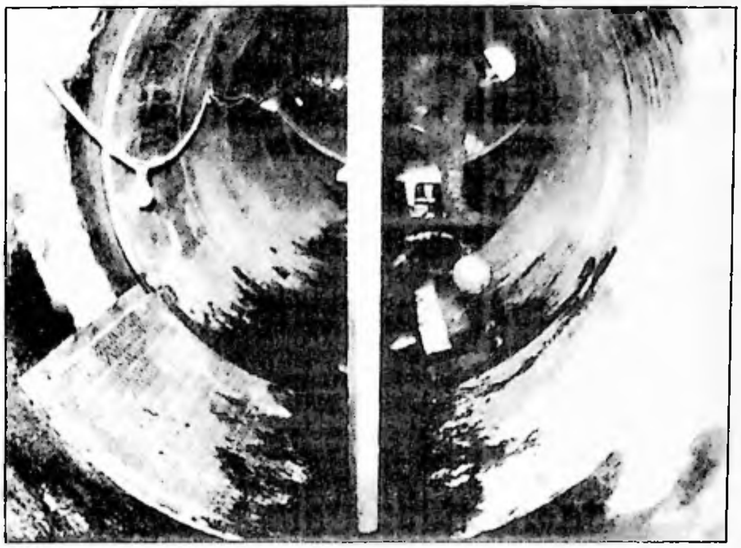
These segmented liners are manufactured from fiberglass and a choice of resins from polyester to vinylester. Choices of resins can be made based on the corrosion resistance required. This composite of fiberglass and resin provides excellent hydraulic characteristics due to the smooth inner surface. The material has high mechanical and impact strength and good abrasion resistance. The linings have little absorption and no apparent permeability. Wall thickness and laminate designs can be varied easily for custom installations.

The installation of segmented glass-reinforced plastic (GRP) liners is not difficult due to the light weight of the segments. After thorough cleaning and dewatering of the sewer, the segments are placed in the sewer with mechanically locking joints, bolts, or impact nails at each joining section. They are locked in place and after the entire section is complete, the space between the linings and the existing sewer is cement pressure-grouted in place to prevent sagging and deformation.

Water Pipeline Cleaning by Pipesavers

Pipesavers is a proprietary process for cleaning tuberculated water pipes. It involves use of a cleaning tool (Figure 5-44) developed in Switzerland in the early 1950s, used since then in Europe and in the United States since 1981. The tool consists of two sets of flat, steel cutting blades hinged and offset to cover the full diameter of the pipe.

Figure 5-41 Installation of Segmented Fiberglass Reinforced Cement Liners



Propulsion is provided by a valved, hydro-mechanical device that pushes the blades forward at about 2 to 3 feet per second. The unit operates with 10 to 45 psi nominal water system pressure. The device forces jets of water at up to 60 feet per second through the blades to flush out particles ahead of the machine.

The cleaning tool can be adapted to most types of pipes from 4 to 96 inches in diameter. Pipelines 65 percent or less encrusted can be cleaned by this method. Thousands of feet can be cleaned at one time. According to the company licensed to do the work in the United States, costs range from $3 to $5 per foot if the water utility digs the excavations (at the beginning and end of the pipe length to be cleaned). Increases in C-factors from the low 40s to 120 have been reported.

When using this method, evaluation and possible adjustment of the water chemistry is vitally important because no lining is provided. If the water is corrosive the pipe may be subjected to increased corrosion. Most soft waters are corrosive. There are two ways to solve this problem.

- Control the water treatment process to obtain a slightly positive Langalier Index so that a thin protective layer of calcium carbonate is deposited on the pipes. This is done by pH adjustment. Lime, caustic soda, and soda ash are commonly added for this purpose. If too much is added the turberculation problem will return.

- Use inorganic chemical inhibitors, commonly available under a variety of trade names, involving phosphates. These products control scale as well as corrosion and have a number of advantages but represent an added cost to the rehabilitation project if the utility is not presently using them.

Pipesavers is a service of Pipesaver Technology, Inc., 34 West Burlington Street, Westmont, Illinois, 60059.

Pipeline Insertion Machine

The Pipeline Insertion Machine (PIM) can be used to replace an existing pipe with a new pipe without trenching. The machine (Figure 5-45) works by shattering the existing cast iron (or other pipe), pushing it aside and enlarging the annular space. As it is pulled through the existing pipe it pulls a PVC sleeve behind, preventing the void from closing in. Where ABS, PVC or asbestos cement pipe is involved, insertion of a new PVC or polyethelene main is made directly. Where cast iron is being replaced, the PVC sleeve protects the new polyethelene main from fragments of cast iron pipe. The polyethelene main is inserted into the PVC liner in a separate operation.

Installation is continuous from the sending and receiving access pits, which can be up to 350 feet apart. Figure 5-46 shows the polyethelene main being inserted. Access windows are cut into the PVC sleeve and services reconnected (Figure 5-47). Excavations are made at the access two pits and each service connection. Installation of 250 to 350 feet per day are normal. Customers are only out of service for several hours.

Figure 5-42 Segmented Fiberglass Reinforced Cement Liners are Easy to Handle

The PIM was developed in England by D. J. Ryan and the British Gas Corporation. It has been used for gas and water pipeline replacement in England and for gas lines in the United States since 1983. It can replace the existing pipe with the same or one size larger pipe as the table below shows.

Existing cast iron main	PVC sleeve	New polyethelene main
3 inches	5 inches	4 inches
4 inches	5 inches	4 inches
4 inches	7 inches	6 inches
6 inches	7 inches	6 inches
6 inches	9 inches	8 inches

The ability to replace the existing line with the same size or one size larger is the principal advantage of this technique over doing pipe insertion with polyethelene directly (which requires a size reduction). This enables low pressure gas pipelines to maintain pressure or small water pipes to be upgraded to higher capacity.

Costs for use of PIM are about $16 per foot for 4 inch pipe and $20 per foot for 6 inch pipe. To this must be added the cost of the polyethelene liner and access pits. The polyethelene adds about $10 per foot (excluding service line reconnections).

National Energy Leasing, One Elizabeth Town Plaza, Elizabeth New Jersey 07707, holds the U.S. license for PIM. Two contractors can use the PIM including Miller Pipeline Corporation, P.O. Box 34141, Indianapolis, Indiana 46234 who provided the above information.

Weko-Seal Joint Rehabilitation

Leaking joints can be repaired from the inside using a proprietary process called Weko-Seal. Applicable to pipelines 18 inches through 138 inches diameter the standard joint seal can span joint gaps up to 4 1/2 inches and an extra wide seal is available to span gaps of 9 inches. Over 250,000 installations (individual joints) have been made world wide on reinforced concrete, cast iron, ductile iron, steel cement lined or unlined pipe. Weko-Seal has been used for water, wastewater and gas piping repair.

The seal shown on Figure 5-48 is made of rubber (ethylene propylene diene monomer) and stainless steel. It can withstand operating pressures to 300 psi and infiltration head pressures in excess of 50 feet. It can accommodate normal pipe movement resulting from ground movement, thermal expansion/contraction, or vibration.

A six step installation procedure is used:

1. The pipe surface is prepared.
2. Seal is positioned in joint area.
3. Stainless steel retaining bands are fitted into place.
4. Seal expanding tool is moved into position.
5. Seal is expanded.
6. Finished seal is air tested.

Installation requires access pits that can be up to 5,000 feet apart. Typcially a 7 ft x 11 ft opening is needed for an 18- to 36-inch pipe. Installation costs vary with pipe size and number of joints needing repair in the pipeline reach. The process is handled exclusively by Miller Pipeline Corporation, P.O. Box 34141, Indianapolis, IN 46234.

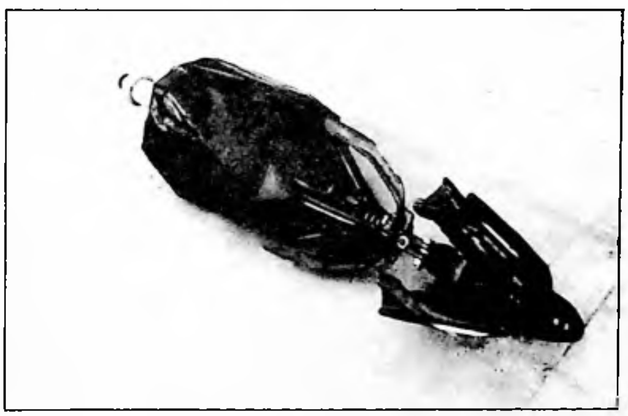
Poorly constructed or deteriorating service connections are major sources of water infiltration (sewer lines) and leaks (water and gas lines). The point where the lateral or service connection joins the main line may also allow infiltration or leaks. Protruding sewer laterals identified during television inspection should be dug up and replaced with a proper wye connection to prevent blockage and equipment hangups.

Figure 5-43 Segmented Fiberglass Reinforced Plastic Liners Can be Made in Many Shapes

BUILDING LATERALS AND SERVICE CONNECTIONS

Building laterals and service connections are pipelines that branch off the water, sewer, or gas main to individual buildings. Sewer laterals may be as small as 3 inches in diameter, while water and gas service connections are typically 3/4 to 1-1/4 inches in diameter.

Figure 5-44 Pipesavers Cleaning Tool. Courtesy of Pipesavers Technologies, Inc.

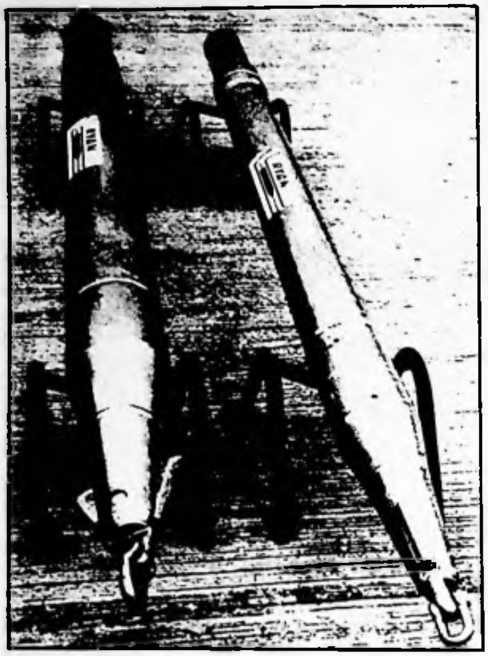


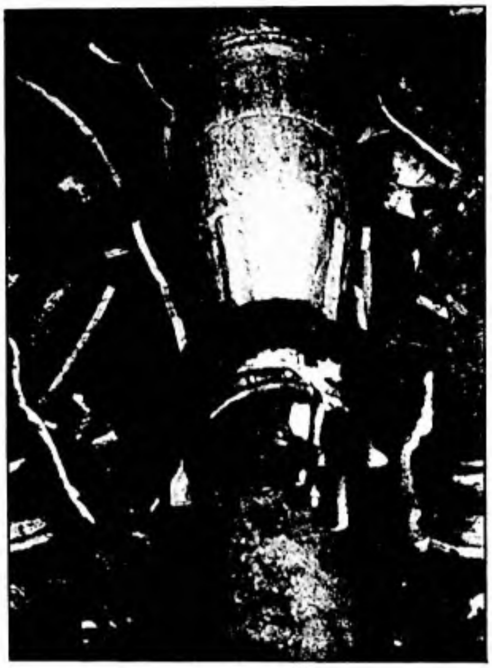
Gas service connection rehabilitation is very common. Water and sewer lateral rehabilitation is much less common. Cities and districts are moving towards more sewer service connection rehabilitation because recent studies show it can substantially improve system efficiency and capacity.

Descriptions and Common Uses

The methods for service connection rehabilitation are similar to those used for water, sewer, and gas mains, only on a smaller scale. These include chemical grouting, slip lining (called insertion for gas lines), resin-impregnated fabric lining, replacement, and repair or replacement of leaky meters. Table 5-15 lists some techniques and their applications. Replacement is by far the most common technique used for sewer laterals and essentially the only method used for water service connections due to their small size. Chemical grouting is the most common house lateral rehabilitation method used. The pump-full chemical grouting method is an older method not widely used now. Only limited experience exists for the inflatable tube, inversion tube, and test and grout methods.

Figure 5-45 Pipe Insertion Machine (left) and Breaking Out Cast Iron Pipe (right). Courtesy of National Energy Leasing Company.





Methods of Installation

General methods of installation of chemical grouting, polyethylene slip lining or insertion, resin-impregnated fabric lining, and replacement are described in previous sections of this chapter for water, sewer, and gas mains, as applicable. However, there are some differences, especially in equipment, which are described below. Repair and replacement of meters is not discussed further since methods are straightforward and well known.

Chemical Grouting. The installation methods for the four chemical grouting techniques applicable to sewer lines are briefly described below.

1. The pump-full method involves injecting a chemical grout through a conventional camera-sealing packer unit from the sewer main up the service connection to an installed plug. (The camera is used to position the packer over the lateral connection.) As the grout is pumped under pressure, it is forced through the pipe faults into the surrounding soil where a seal is formed when the gel has set. After sealing, excess grout is augered from the lateral and the sewer is returned to service.

2. The inflatable tube (also called sewer sausage) method is similar to the pump-full method in that it requires the use of a camera-packer unit in the sewer main, and the injection of grout from the sewer main up the service connection to seal the pipeline. The primary difference is that a long, flexible, polyethylene tube or "sock" is inserted through the clean-out into the service connection and inflated, using water to force it through the pipe to the main. The grout is injected from the camera-packer unit into the annular space between the tube and the pipe wall which reduces the quantity of grout used and minimizes the amount of cleaning required after the sealing has been completed. The grout is pumped under pressure around the tube, up the service connection, and through any pipe faults into the surrounding soil where the seals are formed when the gel sets.[3] The lateral is then air tested to verify a watertight condition.

3. The inversion tube method, developed by CUES, Inc., Rodding-Cleaning Services, Inc., and WSSC, is similar to the inflatable tube method in that a tube is inflated into the lateral and grout is

ejected between the tube and the pipe wall. A video camera, followed by the "Lateral Sealing Packer," is inserted into the main (minimum 8-inch diameter) through a manhole. The sealing packer contains the inversion tube and air and grout lines connected to a van. The camera and sealing packer are pulled through the main, and the sealing packer is positioned over the lateral connection, and the tube is inflated into the lateral using air. The tube goes 3 to 8 feet into the lateral. The lateral is air tested and grouted if the air test indicates it is necessary. The tube is then retracted, the sealing packer end-bladders are deflated, and the camera and packer are pulled to the next connection. It is important to note that this method only tests and seals the first 3 to 8 feet of the lateral from the main. This can be an effective method if, as Salem, Oregon, found, most or all infiltration/inflow occurs in this region. Figure 5-49 shows the sealing packer and inflated tube and Figure 5-50 is a close-up.

4. Two test and grout methods have been developed: one by Westech Engineering in Salem, Oregon, called the Snake; and one by Pacific Pipeline Surveys in Vacaville, California. These methods use a rubber packer that air tests and grouts the lateral in 7- to 8-foot sections (the "Snake") and in 4-foot sections (Pacific Pipeline Surveys). The machine is inserted in the sewer cleanout and can grout the entire service line, depending on the degree, number, and location of bends. These are new systems and have limited experience.[4,5]

Slip Lining or Insertion. There is limited experience with slip lining sewer laterals. It has been done by the City of Salem, Oregon. Insertion is very common for gas service lines. As with sewer and water mains, high-density polyethylene is used for sewer laterals. Medium-density polyethylene is used for gas service connections. The liner provides a complete watertight pipeline from the building to the main line.

1. Procedures used to slip line a sewer lateral are similar to the procedures used to slip line the main line. A pushing hole, instead of a pulling hole, is dug at the main where the old service lateral is connected. Then, a hole is excavated at the house connection and a nipple is cut out of the lateral at both ends. The old lateral is cleaned, roots

Figure 5-46 Insertion of Polyethelene Pipe After Using Pipe Insertion Machine. Courtesy of National Energy Leasing Company.

Figure 5-47 Reconnection of Gas Service Line. Courtesy of National Energy Leasing Company.

are removed, and the required length of liner pipe is cut. The nose cone is attached to the end and the liner is inserted into the lateral. Once the liner has been inserted, the connection is made to the main line. The building plumbing is connected to the liner. All excavation is then backfilled, taking special care around the sewer tap to provide adequate support for the newly attached lateral.

Figure 5-48 Weko-Seal Installation Being Inspected. Courtesy of Miller Pipeline Corporation.

2. Procedures used to insert polyethylene into gas service lines are very similar to slip lining water or sewer lines. A 10-inch nipple of the service line is cut out near the main, which requires excavation at this point. The service line is then blown out from the meter end near the building using compressed air. The liner is pushed through and anchored, and a new 10-inch section is clamped on over the liner to replace the cut-out nipple. If the liner cannot be pushed through, the service connection is reamed out, and insertion is tried again.[6]

Resin-Impregnated Fabric Lining. Limited experience with using resin-impregnated fabric sewer laterals indicates that the basic technology for sealing lines as small as 4 inches has been developed. Washington Suburban Sewer Commission (WSSC) and the City of Salem have used this method developed by Insituform of North America, Inc. As with sewer mains, resin-impregnated fabric will reduce infiltration and, to some degree, improve the structural integrity of the existing lateral.[3]

The steps for lining a service connection using the inversion process are similar to those for lining a sewer main. An access point requiring excavation, however, is usually needed on the upstream side of the lateral. Another variation from sewer main installations is the use of a special pressure chamber to provide the needed pressure to invert the fabric material through the lateral. The fabric is also terminated at the entrance of the sewer main, instead of at a downstream manhole. After the curing process is completed, the downstream end of the liner is opened by excavation or via a remotely controlled cutting device placed in the sewer main. The upstream end is trimmed and the newly lined pipe is connected to the rest of the existing service connection line, restoring sewer service.[3]

Replacement. Partial or complete replacement of service connection lines is required when the pipeline is collapsed or severely deteriorated. Procedures for excavation and replacement of service laterals is the same as replacement of pipeline segments. Air testing should be conducted on all replaced laterals to ensure proper construction.

Construction Costs

Cost data on rehabilitating service connections are limited due to lack of experience for sewer lines. Gas companies who use insertion for service connections do it so routinely that they often do not track costs separately for this type of insertion only. Service connection insertion is often done at the same time as it is done for the mains.

Estimated costs for some of the rehabilitation methods described in this section are shown in Table 5-16. They are adjusted to an Engineering News Record-Construction Cost Index, 20 cities, December 1983, of 4109. Costs vary significantly depending on the line size, access difficulty, excavation required, number and degree of bends in the lateral, and length and condition of the lateral.

Table 5-15 Service Reconnection Rehabilitation Methods and Applications.

Method	Application
Chemical grouting	
Pump full	Structurally sound sewer laterals; grouts entire line if configuration permits.
Inflatable tube	Structurally sound sewer laterals; grouts entire line (Gelco method).
Inversion tube	Structurally sound sewer laterals; grouts first 3 to 8 feet from main. (CUES Inc., "Lateral Sealing Packer"), including main line connection.
Test and grout	Structurally sound sewer laterals. (Westech Engineering "Snake" system).
Slip lining or insertion with polyethylene	Sewer and gas lines.
Resin-impregnated fabric lining	Sewer and water lines (Insituform system).
Replacement	Sewer, water, and gas lines.
Meter repairs and replacement	Water and gas lines.

In sewer lateral rehabilitation, a significant cost factor is whether or not surface access to the lateral is needed. Often, adequate surface access can be gained through a cleanout connection. If such a connection exists, surface access is not a major cost. Some extra cost would occur if the cleanout is on private property because of the need to get the owner's permission to enter the property. This cost can be significant for a large lateral rehabilitation project where permission must be obtained from many property owners. Often more than one visit is required to contact an owner. If no cleanout connection exists or it is inaccessible, access must be gained by excavation which is very expensive.

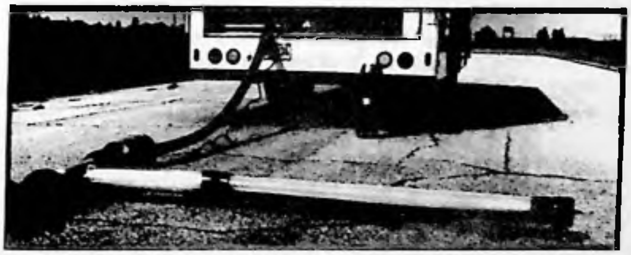
Advantages and Disadvantages

Table 5-17 lists some of the advantages and disadvantages of the service connection rehabilitation methods described in this section. One disadvantage common to all the pipeline rehabilitation methods except replacement is that they cannot be used on lines with many bends or with sharp bends.

REHABILITATION OF MANHOLES AND SUMPS

Manholes and sumps require rehabilitation to stop surface water or groundwater inflow, to repair structural damage, and to protect surfaces from damage by corrosive substances, (primarily sulfuric acid).

Figure 5-49 Lateral Sealing Packer[R] and Fully Inflated Inversion Tube Used for Inverted Tube Method, Courtesy CUES Inc.



Description and Common Uses

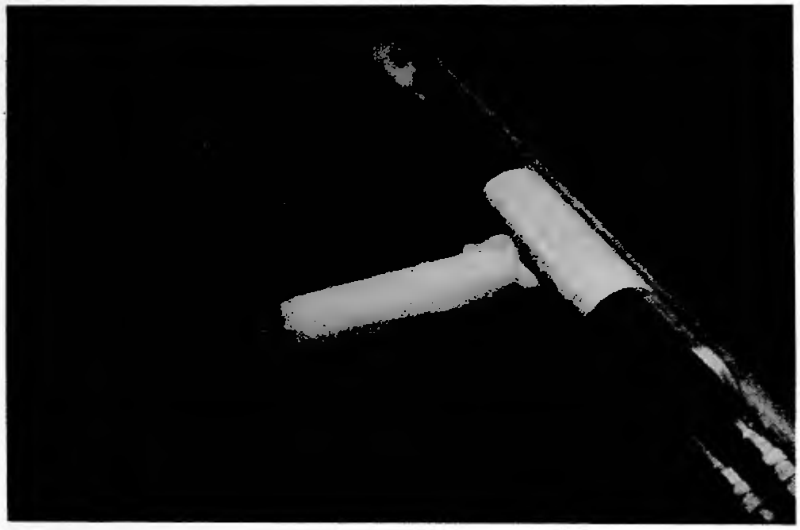
Manhole rehabilitation methods are directed at either (1) the frame and cover, or (2) the sidewall and base. Table 5-18 lists the common rehabilitation methods and their applications. Manhole replacement can also be done if rehabilitation methods will not solve the problems cost-effectively. In selecting a method, the type of problem, physical characteristics of the structure, location, condition, age, and type of original construction should all be considered. The extent of experience and cost varies with the different methods, which should also be considered.[3]

Methods of Installation

Information on the common methods for rehabilitating frames and covers and sidewalls and bases is presented below.

Frame and Cover Rehabilitation. Five primary methods are available for rehabilitating manhole frames and covers.

Figure 5-50 Close Up of Lateral Sealing Packer and Inflated Tube. Courtesy of CUES, Inc.



Frame and Cover Rehabilitation. The primary reason for frame and cover rehabilitation is to prevent surface water (storm runoff) from flowing into the manholes. This type of problem is not typically applicable to sumps. Water can flow into the manhole through the holes in the cover, through spaces around the cover between the frame and the cover, and under the frame if it is improperly sealed.[3] Frost action can also cause frames to crack or separate which allows inflow.

Sidewall and Base Rehabilitation. The primary purpose for rehabilitating sidewalls and bases is to stop and prevent infiltration from groundwater. The structural integrity of the manhole or sump is one of the main factors for determining the best method to use. Coatings and/or patches can be used for structurally sound sidewalls, while structural liners or complete replacement are more appropriate for badly deteriorated manholes and sumps. New steps may also be required since they often deteriorate.

1. Install stainless steel bolts with caulking compound, neoprene washers, or corks to plug holes in the cover. (This does not allow venting of the manhole).

2. Install a prefabricated lid insert between the frame and the cover, as shown on Figure 5-51. See Reference 10 for the manufacturer's name and address. Characteristics of this insert are:

   - Plastic polymer material to prevent corrosion and damage by sulfuric acid or road oils.
   - Spring-loaded gas relief and vacuum relief valves at bottom of insert allows gas to escape.
   - Prevents water, sand, and grit from entering manhole.
   - Easy to install with no excavation required. Rim must be cleaned prior to placement of insert.
   - Custom-sized to fit any manhole.

Table 5-16 Lateral Rehabilitation Costs

Method	Cost, dollars per lateral unless otherwise noted
Chemical grouting	400 - 1,000
Slip lining (sewer lines)	1,500[a]
Insertion (gas lines)	59[b,c] 76[b,d] 93[b,e]
Replacement (sewer lines)	2,500[a]
Replacement (gas lines)	16[f]

[a]Reference 7; entire lateral.
[b]Reference 8.
[c]Cost for service line in earth.
[d]Cost for service line in asphalt.
[e]Cost for service line in concrete.
[f]Cost in dollars per foot.

3. Install joint sealing tape between metal frame and cone section. Figure 5-52 shows tape being pressed onto epoxy seal and the completed installation with epoxy seal over the tape and bottom edges of tape. See Reference 10 for the manufacturer's name and address. Features are:

   - Resin-based material.
   - Flexible so it moves with ground shifting.
   - Can be used for brick, block, or precast concrete manholes.

4. Seal frames in place by chiseling cracks and openings and apply hydraulic cement coated with waterproofing epoxy.[3]

   - Oakum rope is sometimes placed in large openings to provide some sealing before hydraulic cement is applied behind it.
   - Freeze-thaw cycles may reduce life of patch.

5. Raise frame to minimize flow through cover or frame.

   - Use manhole adjusting rings or frame extension rings.
   - Coat exposed exterior of manhole with cement mortar or bituminous material to protect surface.

Sidewall and Base Rehabilitation. Three common methods exist for rehabilitating manhole sidewalls and bases.

1. Apply coating to interior wall of manhole or sump.

   - Epoxy, acrylic, and polyurethane coatings are available.[10,11]
   - Coatings can be applied to brick, block, and precast concrete manholes and sumps.
   - Coatings are waterproof and corrosion-resistant.
   - Typically, epoxy coating is applied by troweling, acrylic coating is applied with a brush, and polyurethane coating is applied with an airless sprayer.
   - Surface must be very clean, free of debris, structurally sound. Surface must be thoroughly rinsed after using detergents or hydrochloric acid solution or after mechanical abrading (by sandblasting, high-pressure water (e.g., 3,000 psi), or other techniques). Surface must be dry for polyurethane coating application.
   - All leaks must be plugged using patching or grouting material. Most materials are quick-drying. Material can be troweled, kneaded, or pumped into holes and cracks. For large areas, holes can be drilled in wall to provide several injection points. Cement patches, polyurethane foam, and any of the chemical grouting materials described earlier in this chapter can be used to stop leaks.
   - Unless all leaks have been previously found, do work at high groundwater times to ensure all leaks are plugged.

2. Apply chemical grout from interior wall to exterior.

   - Used to stop infiltration through cracks and holes.
   - Amount of grout required varies widely and cannot be determined prior to application.

- See Chemical Grouting section of this chapter for more information on materials and application.
- Liners are typically fiberglass of the reinforced polyester mortar type.

Table 5-17 Advantages and Disadvantages of Lateral and Service Connection Rehabilitation Methods

Method	Advantages	Disadvantages
Chemical grouting		
Pump full	Can be used to grout main line connections.	Cannot predict amount of grout required; cannot grout very far up line; inefficient and expensive since grout is injected into whole line; must auger excess grout; estimated 5- to 10-year service life.[9]
Inflatable tube	Uses less grout per foot than pump full method.	Requires access to adequate cleanout; cannot predict amount of grout required; estimated 5- to 10-year service life.[9]
Inversion tube	Does not require access to cleanout or private property; uses less grout than pump full method; air tests prior to grouting; can be used to grout main line connection.	Only tests and seals first 3 to 8 feet of lateral; estimated 5- to 10-year service life.[9]
Test and grout	Grouts only sections with cracks or leaks; grouts entire line; best control of amount of grout used.	Requires access to adequate cleanout; estimated 5- to 10-year service life.[9]
Slip lining or insertion	Relatively inexpensive for straight lines; 50-year life; provides integral watertight pipe.	Cannot be used for lines with many or sharp bends; requires excavation at junction to main (gas and sewer) and building connection (sewer).
Resin-impregnated fabric	Provides some structural strength; provides integral watertight pipe.	Relatively expensive; positioning and sealing at ends is difficult; cutting end at main is difficult; requires access at cleanout.
Replacement	Provides new, watertight lateral; 100-year life.	Expensive; requires extensive excavation.
Meter repairs and replacement	Stops meter leaks.	Does not correct leaks that may be present in pipeline.

3. Insert structural liner inside existing manhole or sump. Figure 5-53 shows a typical fiberglass liner installation.
   - Area around top of manhole must be excavated to remove old frame, rings, cover, and cone section.
   - Bottom of liner is cut to fit existing manhole or sump base as closely as possible. Cuts are also made to accommodate existing inlets, drops, and cleanouts.[12] Quick-setting grout mixture is placed on base to

reshape as necessary. Flow can be blocked from half of manhole to allow work without completely stopping flow through sewer.

Table 5-18 Summary of Application of Manhole and Sump Rehabilitation Methods

Method	Application
Frame and cover	
Stainless steel, neoprene washers on corks in holes in cover.	Stops inflow of surface water through pick holes in manhole cover.
Prefabricated lid insert	Stops inflow of surface water, sand, and grit through manhole cover.
Joint sealing tape	Seals space between frame and manhole cover section.
Hydraulic cement	Seals manhole frame in place. Prevents infiltration between frame and cone section.
Raise frame	Prevents surface water inflow through manhole cover.
Sidewalls and base	
Epoxy or polyurethane coatings on interior walls	Structurally sound manholes and sumps. Protects wall from corrosion and infiltration.
Chemical grout	Structurally sound manholes and sumps. Stops infiltration.
Structural liner	Structuraly damaged or disintegrated manholes and sumps. Provides new, structurally sound interior.

- Liner is lowered into existing manhole or sump and set into the grout mixture.
- Annular void between liner and existing manhole or sump is filled with grout.
- Liner must be carefully fit prior to final placement to ensure correct height and bottom fit.
- New frame and cones are placed after backfilling and compaction.
- Install steps if desired.

Construction Costs

As with rehabilitation of pipelines, manhole rehabilitation costs vary significantly from job to job due to manhole condition, nature of the problem (s), location, diameter, depth, material, etc. Some example minimum cost ranges are shown in Table 5-19 for some techniques. Often techniques are combined, depending on the physical condition of the manhole and the extent, type, and nature of rehabilitation required.

Advantages and Disadvantages

Table 5-20 lists some advantages and disadvantages of the methods discussed in this section.

REHABILITATION OF PUMPING STATIONS

Pumping stations are an integral part of water distribution and wastewater collection systems. Pumping station structures

Figure 5-51 Watertight Manhole Insert. Courtesy of FOSRAC PRESCO

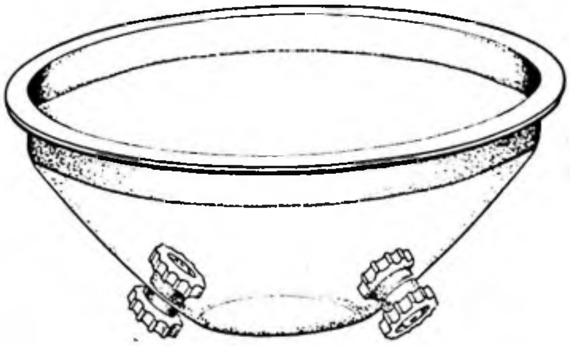


Figure 5-52 Placement of Joint Sealing Tape Between Manhole Frame and Cone Section

(particularly substructures) represent valuable investments that should be retained if possible. The mechanical, electrical, and instrumentation systems often require upgrading to new standards during a rehabilitation project. Pumping stations are usually rehabilitated every 15 to 25 years depending upon the useful life of the equipment, the need for additional capacity, and other factors. Invariably, pumping stations can be rehabilitated for a fraction of the cost of a new station. Material presented in this section is specifically oriented to water and wastewater pumping stations.

Identifying Pumping Station Deficiencies

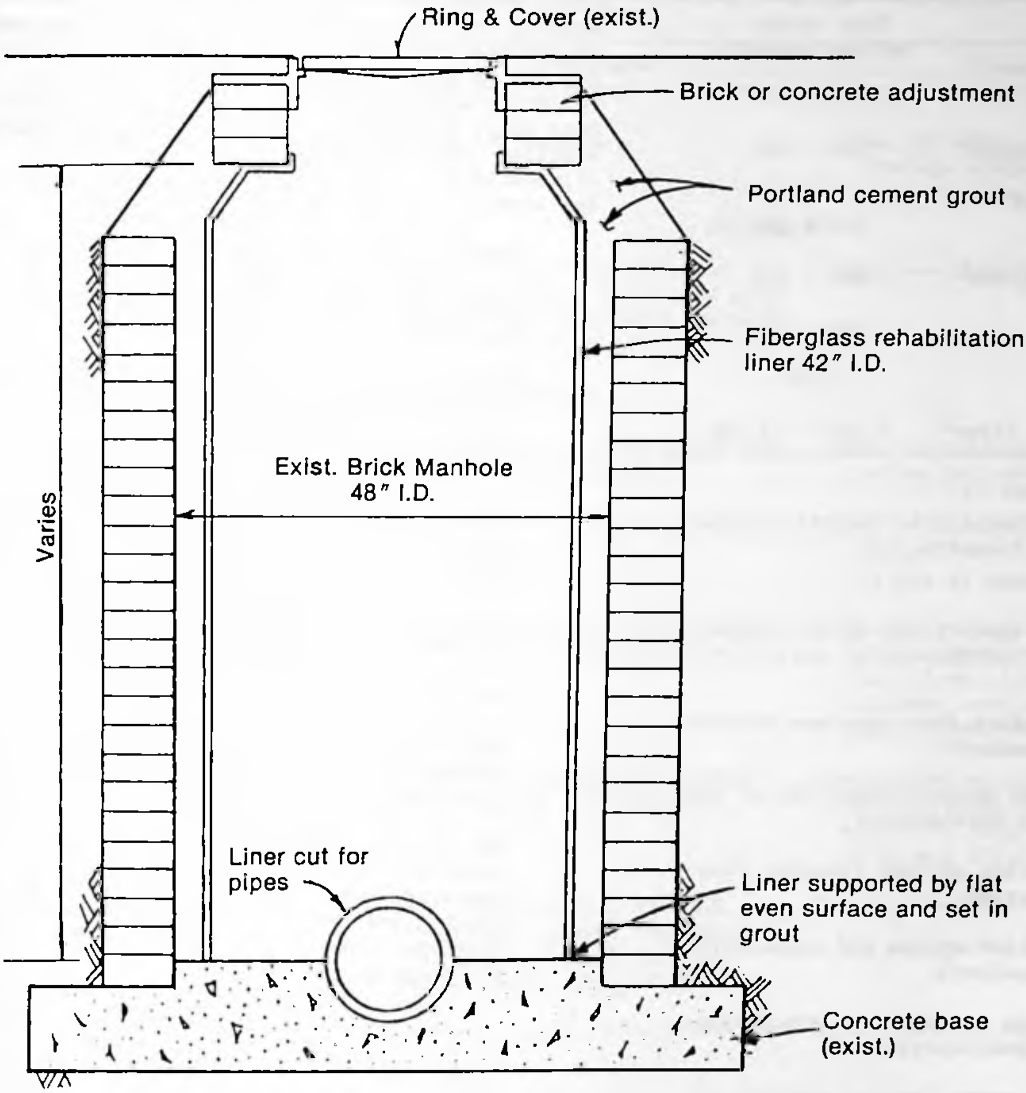
Deficiencies of pumping stations are usually inadequate capacity, poor reliability, or unsafe conditions. Each of these factors should be evaluated any time a pumping station is targeted for major rehabilitation.

Need for Additional Capacity. Capacity requirements are normally developed by evaluating the entire system, or at least a portion of the system, using one of the methods described in Chapter 3. The pumping station should have the capability to operate over a sufficiciently wide range of flows and expected variations in pumping head. Signs of inadequate water pumping station capacity are low-water pressures or inability to keep up with peak water demands on hot days. With wastewater pumping stations, backups and overflows occur when capacity is inadequate. This is most likely to occur in wet-weather periods.

Factors Affecting Reliability. Unreliable pumping stations fail frequently. This can be caused by:

- Power failure (loss of commercial power and no backup supply available).
- Component failure (critical components include the station pumps and supporting equipment--seal water pumps, air compressors, sump pumps).
- Explosions (wastewater may contain gasoline, industrial solvents, or other volatile agents that can collect in a poorly ventilated wet well).
- Vandalism (many pumping stations are unattended and subject to vandalism).
- Catastrophic phenomena (earthquakes, floods, etc., can render a station inoperable).
- Inadequate maintenance (proper care can extend the life of equipment).

Figure 5-53 Typical Fiberglass Manhole Liner Installation. Courtesy National Association of Sewer Service Companies



Safety. Pumping stations must meet the safety requirements and regulations published by the Occupational Safety and Health Administration (OSHA), the National Fire Protection Association (NFPA), and the National Electrical Code (NEC). The NEC classification (Class 1, Division 1 or 2, or unclassified) for a pumping station is determined prior to design. Classification is based upon expected hazard level (low or high) and the type of ventilation (none, natural, or mechanical). Below-grade portions may be classified as more hazardous than above-grade portions if the latter have forced ventilation. All electrical equipment in the pumping station must comply with Article 501 of the NEC for the appropriate classification.

Methods to Upgrade Pumping Stations

The basic technique for rehabilitating pumping stations is to design modifications that meet future capacity requirements and bring the rest of the pumping station and its equipment into compliance with current codes and regulations. Table 5-21 lists methods that can correct identified deficiencies and their attendant problems. The methods normally employed in a pumping station are:

- Change pumps, motors, and electrical equipment.
- Add standby pumps;

Table 5-19 Manhole Rehabilitation Costs

Item	Cost range, dollars/manhole
Chemical grouting[a]	465 - 725
Seal frames to corbels[b]	340 - 360
Chemically seal and plaster walls[b]	340 - 370
Raise manhole to grade[b]	560 - 950
Replace frame[b]	360 - 560
Replace cover[b]	150
Insert structural liner[c]	4,000 - 12,000

[a]Based on Reference 13.

[b]Based on contractors' bids to Metropolitan St. Louis Sewer District.

[c]Based on References 14 and 15.

Note: Estimated costs based on 20-cities December 1983 ENR-CCI of 4110.

- Move pump motors above maximum flooding level (wastewater);
- Eliminate any direct connection of wet and dry well (wastewater);
- Protect station against flooding from external sources;
- Add ventilation system and dehumidification (if required);
- Change lights to explosion proof type (wet well, wastewater);
- Add standby power (engine generators) if consequences of power outage are unacceptable;
- Installation system to minimize damage and outage.

Costs of upgrading pumping stations are highly site-specific. Construction estimates are prepared after the project has been designed. An excellent reference on upgrading techniques is the proceedings of a conference held in 1981 at Montana State University.[16]

Example of Pumping Station Upgrading. An example of a wastewater pumping station rehabilitation is shown on Figures 5-54 and 5-55. Before and after photographs are shown on Figures 5-56 and 5-57. A predesign study showed that the firm capacity of the pumping station (capacity with largest pump out of service) needed to be increased from 5.7 to 9.0 mgd to stop bypasses to receiving waters. The study also showed that the existing structure could be used to house the expanded pumping station. Certain deficiencies needed to be eliminated to bring the station up to modern day standards. Improvements were to:

- Install larger pumps for more capacity.
- Locate motors above maximum water level in wet well.
- Eliminate direct connection between wet well and dry well. An encased spiral staircase was added to replace the manhole cover on the wet well ceiling.
- Improve pump hydraulics.
- Improve wet well ventilation and exhaust to the outside instead of the dry well.
- Add odor control.
- Improve safety of stairwell.
- Add standby power by installing engine generator in an enlarged aboveground structure.
- Add landscaping and give architectural treatment to aboveground structure. Construction cost in 1970 for this project was approximately $500,000. This was considerably cheaper than building an entirely new station.

Table 5-20 Advantages and Disadvantages of Manhole and Sump Rehabilitation Methods

Method	Advantages	Disadvantages
Frame and cover		
Stainless steel, neoprene washers or corks in holes in covers	Simple to install.	Does not keep water from flowing through spaces around cover; does not allow venting.
Prefabricated cover insert	Simple to install; prevents surface water, sand, and grit from entering manhole through or around cover.	Requires perfect fit for success.
Joint sealing tape	Simple to install.	-
Hydraulic cement	Provides strong, waterproof seal to stop infiltration.	Labor-intensive; freeze-thaw cycles may reduce patch life.
Raise frame	Minimizes inflow through cover and frame.	Must be outside of street right-of-way.
Sidewalls and base		
Epoxy or polyurethane coatings on interior walls	Protects interior walls against corrosion; stops infiltration.	Requires structurally sound manhole or sump; surface must be very clean prior to application; surfaces must be dry prior to applying polyurethane coating.
Chemical grout	Can be very inexpensive method for stopping infiltration.	Requires structurally sound manhole or sump; cannot predict amount of grout required to eliminate infiltration.
Structural liner	Repairs structurally damaged manholes or sumps; requires less disruption of traffic and utilities than replacement.	Complex installation.

Table 5-21 Methods to Upgrade Pumping Station

Type of station	Deficiency	Problem	Possible solutions
Water or wastewater	1. Inadequate capacity	Inadequate flows/low pressure (water); too frequent overflows or backups	Change/add pumps; improve pump inlet hydraulics
Water or wastewater	2. Pumps old, parts not available	High maintenance cost and down time	Replace pumps
Water or wastewater	3. No standby power; power outage frequency judged too high	Same as for inadequate capacity	Add standby engine generators
Water or wastewater	4. Station does not meet OSHA standards	Inadequate safety, high liability	Comply with requirements (such as adding guard rails)
Water or wastewater	5. Structure deteriorated, aged	Station may collapse due to earthquakes or other unusual event	Make structural improvements
Water or wastewater	6. External appearance undesirable	Poor aesthetics	Provide architectural treatment to exterior, relandscape
Wastewater	7. Pumps/motors located in wet well	Possibility of motors being flooded out	Move pumps/motors to dry well
Wastewater	8. Direct connection between wet well and dry well (toilets, doors, vent ducts, floor drains, etc., in dry well)	Possibiity of flooding dry well explosion hazard due to volatile gases in wet well	Close direct connection
Wastewater	9. Inadequate ventilation of wet well	Explosion hazard/toxic gas hazard	Add mechanical ventilation and odor control if necessary
Wastewater	10. Nonexplosionproof equipment (motors, lights)	Explosion hazard	Replace equipment
Wastewater	11. Leaking wet well	Wastewater seeps into dry well	Seal wet well with epoxy or other coating (see Rehabilitation of Manholes and Sumps)

Figure 5-54 Section of Rainer Avenue Pumping Station Before Rehabilitation, Seattle, Washington

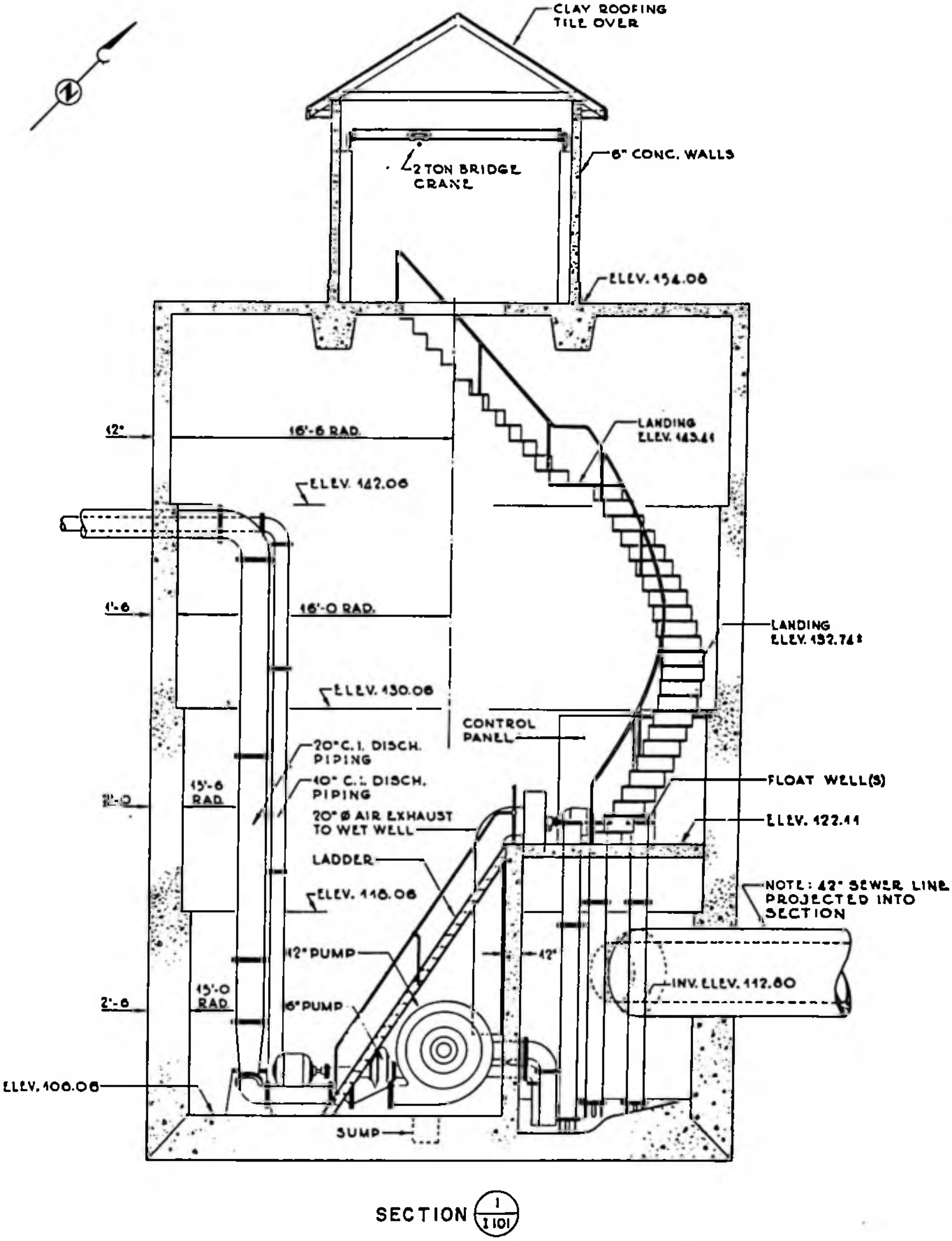


Figure 5-55 Section of Rainer Avenue Pumping Station After Rehabilitation, Seattle, Washington

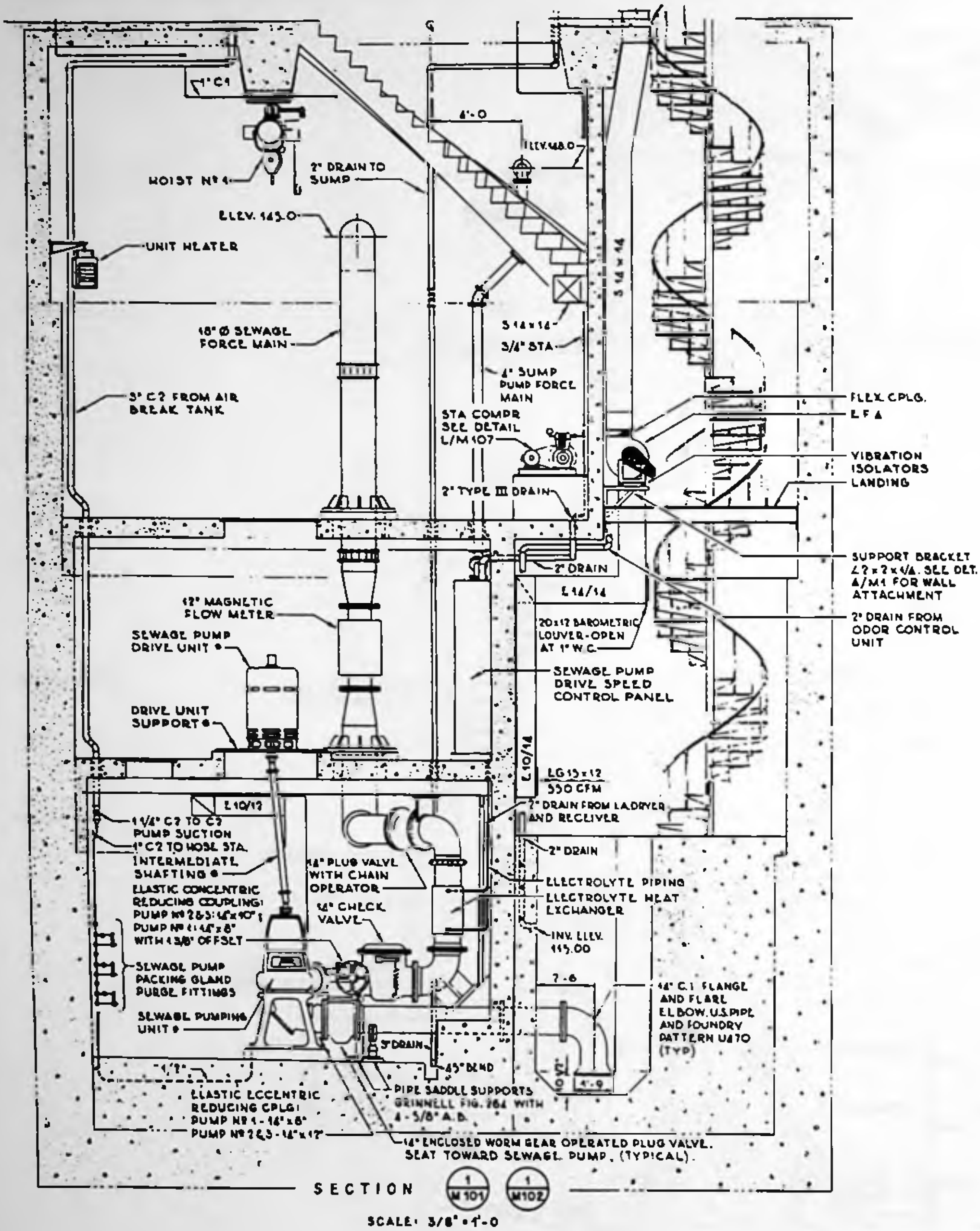


Figure 5-56 Rainer Avenue Pumping Station Before Rehabilitation, Seattle, Washington

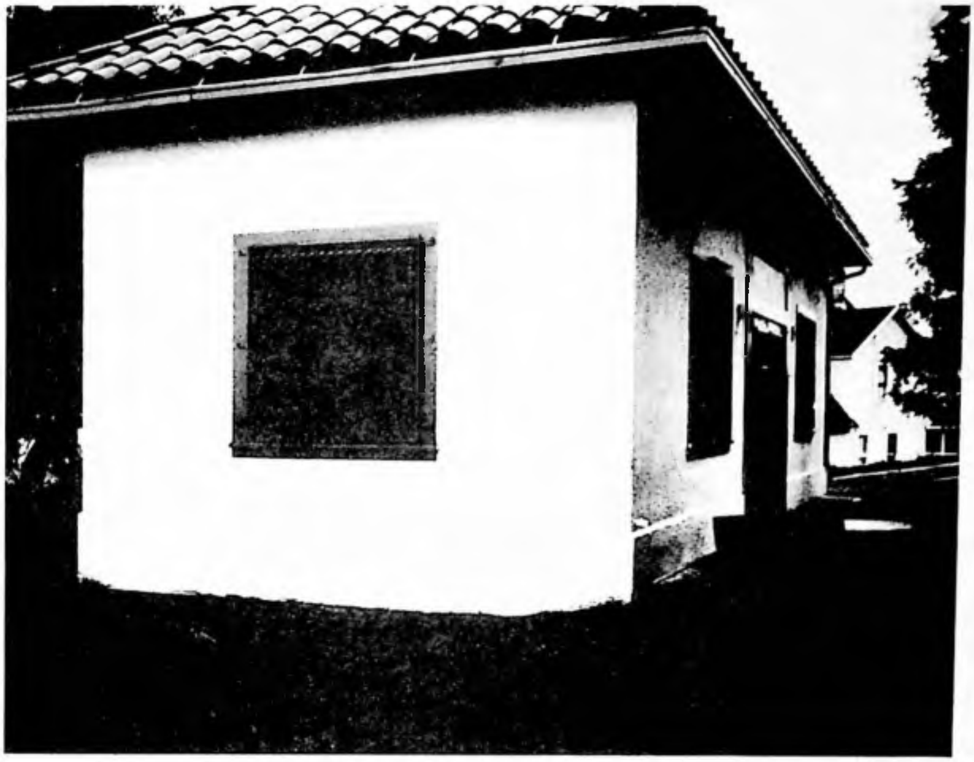


Figure 5-57 Rainer Avenue Pumping Station After Rehabilitation, Seattle, Washington

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CHAPTER 6

The purpose of this chapter is to inform city engineers and consultants about current power distribution practices and innovative techniques to rehabilitate electrical systems so that these people can work effectively with the local electric utility. Much of what is contained in this chapter is common knowledge and practice among the larger utilities. The city should understand that there are options for providing electricity to redevelopment projects that should be discussed, such as undergrounding on-site and nearby off-site distribution lines, which will improve aesthetics but may increase project costs. Substations can be designed to blend into the project environment by using landscaping and architectural treatment. Innovative undergrounding methods, if used on the project site, can save money over conventional methods.

This chapter is organized into four sections. The first is an introduction to overall systems and outlines the information a utility needs to plan improvements for redevelopment areas. The remaining three sections describe and outline the considerations involved for upgrading major elements of electrical systems--transmission systems, substations and distribution systems.

CURRENT POWER DISTRIBUTION PRACTICES

The principles involved in distributing electricity to customers has changed little since its first use. Today's technological advances, however, offer a wider variety of available electrical materials, and costs for those materials have come down in relationship to installation labor. Also, new mechanized methods are available for installing those materials, particularly for underground lines. This section will describe some of those materials and methods and discuss their application and economics. Tables 1-2 and 1-3 in Chapter 1 show the applications, advantages, and disadvantages of the various options.

Overview

Originally, power lines were installed overhead between poles. Air is a good, inexpensive insulator, and the only one available at the time, so conductors were generally bare and carried on glass or porcelain insulators. Later, as insulations such as paper, rubber, and plastics were developed, it became possible to place insulated conductors in conduits and in direct contact with the earth.

Starting in about the 1950s, some progressive cities converted their downtown distribution systems from overhead to underground for the following reasons:

- To improve downtown aesthetics.
- To replace aging poles and lines.
- To eliminate conflicts between poles and sidewalks and widening streets.
- To join other underground utilities in master plans.
- To reduce physical damage to poles and lines.
- To improve system reliability.

In general, utilities have good intercommunication through common associations and supply sources, so their methods and procedures are well standardized. Most utilities are progressive and receptive to new methods and changing economics. Because of the public's long-range dependency on electricity, utilities have committed themselves to serving that need. Most have good, comprehensive growth and modernization plans, as well as routine rehabilitation and maintenance programs.

Information Needed by Utility

To effectively plan improvements in the electric system with area redevelopment, electric utility management must understand the general nature of the project and must receive any information about the amount and nature of the load. They will also need a site plan of the project so that they can coordinate the installation of any new electric facilites services that may be required.

Future Load. Most electric utilities prepare and update future load projections for their existing customer areas on a yearly basis. To ensure that adequate capacity is available for a redevelopment project, it is necessary to inform them of the project at the onset and follow up as soon as possible with any anticipated changes in customer type, load, population density, or other factors affecting load.

Polls of typical electric utility companies show a small growth rate for future years--less than 2 percent per annum. Although small, the result is compounding, and projections must be regularly compared with available capacities to ensure adequate future service. Attempts to secure rights-of-way for transmission lines and to secure sites for substations must begin well in advance of need.

It is recommended that a close liaison be developed between the project design team and the utility company and that regular communications be exchanged with them. These communications should be in writing; or, if verbal, followed up with written confirmation. Someone on the design team (usually the project electrical engineer) should be given the responsibility for undertaking this effort. Someone with the utility also needs to be identified who will be their project manager, responsible for coordinating utility efforts: load projection, right-of-way and easement legalities, material acquisition (particularly long-lead items), installation crews, etc.

Space Requirements. If the electrical system within a redevelopment area is inadequate or in need of change, new distribution and transmission lines and substations may have to be installed. When these decisions are made, the plans for the project must be flexible enough to accommodate these new facilities.

Distribution System Configuration

A big decision facing utilities establishing an urban distribution system is whether to install a radial or a network system.

Radial System. A radial system is configured like the branches of a tree--a single branching path connects the serving substation with any customer. It is the least expensive system, but any problem between the substation and load will cause an outage for the customer(s).

Network System. In a network system, the secondaries of all of its distribution transformers are connected together, forming a "grid," or matrix. Additionally, those transformer primaries are fed by two or more feeders supplied by different substations. The result is redundancy--loss of any one substation, feeder, or distribution transformer will not cause an outage to a customer. Isolating switches remove the problem from the line and allow the utility to make the necessary repairs without shutting off the remaining network.

The network system can offer a very low probability of outage, which can be vital to customers which have critical need, such as health care facilities and certain industrial processes. However, the initial cost of a network system is considerably greater than a radial system because of the redundant transformers, feeders, interconnections, automatic controls, and instrumentation.

Conduit Versus Direct Burial

There is greater first cost to install conduits for distribution lines than to install those lines directly in the earth. However, future problems and customer outages can quickly erode those savings.

Primary Conductors. It is recommended that conductors for primary distribution voltages (above 600 volts) be installed in conduits for quicker replacement and avoidance of high future costs.

Secondary Conductors. Some cities have a policy that underground services located inside property lines be installed in conduit. Some utilities may install direct buried services where no other policy exists. It is recommended that conductors for secondary building services (up to 600 volts) be installed in conduits for commercial and industrial facilities and multioccupancy residential facilities. Direct-buried cables are acceptable for single-family dwellings and duplexes.

Regulatory Agencies and Public Funding

Many state regulatory agencies, such as public utility commissions (PUC), have requirements for utilities regarding progressive conversion of overhead facilities to underground. Typically, utilities may have to pledge some annual percentage of revenue to this upgrading. The majority of the funds for this work may come from utility revenues.

Determine the PUC requirements in effect for the state, city, and electric utility where the redevelopment is located. Also, determine to what extent there are federal, state, or municipal funds available for upgrading. Some states will provide the majority of the funding for qualified projects.

Responsibility for Rehabilitation

Ultimate responsibility for upgrading and rehabilitating the electrical system lies with the electric utility. There will be more room for negotiating how this will be done if the utility is municipally owned. If the utility is investor owned, then the requirements of the PUC and the utility's own policies must be followed in these types of projects. However, the following decisions can be jointly made between redevelopment agency or city department and the electric utility:

1. Should only transmission lines that cross the project be underground?

2. Should distribution lines which serve the project be underground?

3. If yes to No. 2, then can any of the new innovative undergrounding methods be used to save the utility and/or city money?

4. If substations are to be sited on the project, how much space is required, where is it needed, what security provisions and architectural treatment should be provided?

UPGRADING TRANSMISSION SYSTEMS

Transmission line: A set of conductors over which large blocks of electrical energy are transmitted at high voltages for long distances from a transmission substation at a generating station to a transmission or distribution substation. A transmission line may be an overhead line or an underground cable line. The distinguishing characteristics of transmission lines are that they are operated at high voltages, transmit large blocks of electrical power, and extend over considerable distances. Voltages are generally between 69,000 and 765,000 volts. Overhead conductors are usually routed on tall steel towers (see Figure 6-1) or wood or prestressed concrete poles with large conductor spacings (see Figure 6-2).

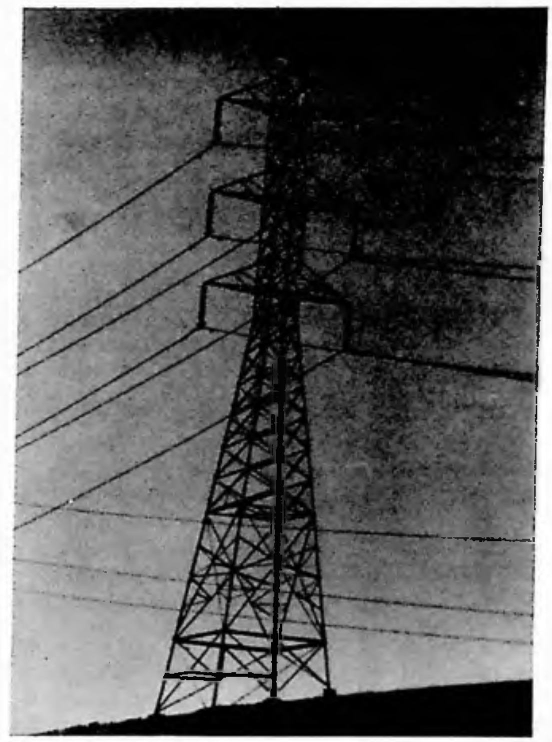
Many of the same considerations discussed for medium-voltage distribution lines discussed under "Distribution Lines" below apply equally well to high-voltage transmission lines.

Advantages of Using Underground Lines

Following are some additional factors which may affect the decision to retain overhead lines or convert them to underground.

Reduced Requirement for Open Space. When overhead transmission lines are used, an open space should be provided along its length as a buffered transmission corridor. This corridor must allow for access and service to the poles or towers and to the lines by maintenance crews and by vehicles such as trucks with man-lifts. Overhead wood pole transmission lines, particularly 69 to 115 kilovolts (kv), can be, and frequently are, run on city streets.

Figure 6-1 230 KV Double Circuit Transmission Line on Steel Tower



Reservation of Rights-of-Way for Future Needs

Existing rights-of-way for transmission lines through the redevelopment area should be maintained. If such a right-of-way interferes with redevelopment plans, and a long time period has elapsed since the grant, an inquiry can be made to determine whether the requirement is still appropriate. If the requirement is still valid, it may be possible to negotiate a comparable right-of-way in a more convenient location to accomplish the same result. If a new right-of-way is negotiated, consider the possible need to provide for higher voltage lines in the future.

Provision for Loop Around City

Where a transmission system is a radial design instead of a loop, it may be desirable to route that line in a complete loop, fed from either direction. Isolating switches should be located at convenient intervals around the loop with one of them (usually the one farthest from the source) left in the open position. If a fault occurs, the isolating switches on either side of the fault are opened, and the rest of the loop kept in service while the repair is being made. Only the faulted section of the transmission line between the nearest isolating switches is without power until the problem is resolved.

Figure 6-2 230-KV Double Circuit Transmission Line With 115-KV Underbuild Transmission Line on Steel Pole

Capacitors

When the power factor of a load (the ratio of true power to apparent power, kw/kVA) is poor (typically, less than 90 percent), installing capacitors will improve the power factor, reducing the current in the lines. This can reduce costs of serving customers or releases capacity to serve additional load and is particularly important when the line is operating at or near full capacity. Generally, the electric utility provides and installs capacitors in "banks" at the substations and on overhead distribution poles.

Reduction in Electromagnetic Interference. Overhead high-voltage transmission lines radiate electromagnetic energy into space, which can cause interference with radios, televisions, computers, and other electronic equipment. Also known as radio frequency interference, it can be nearly eliminated by placing transmission lines underground because of the surrounding ground shield effect.

UPGRADING SUBSTATIONS

Substation: A facility which usually has switching, transformation, protective devices, and voltage regulation equipment. At an urban distribution location, transformers located here typically convert transmission voltage (69 to 138 kv) to primary distribution voltage levels (4 to 35 kv). These lower voltages can more economically be distributed to loads throughout a community. The cost of insulation and safety are principal issues in choice of voltage levels. Operating as high as 35 kv can seldom be justified. Most primary distribution systems now operate in the 12- to 25-kv range. Many old 4- and 6.9-kv systems are still in operation but are rapidly being converted to higher voltage to obtain increased load capacity improve voltage regulation and reduce line losses.

Need for Security

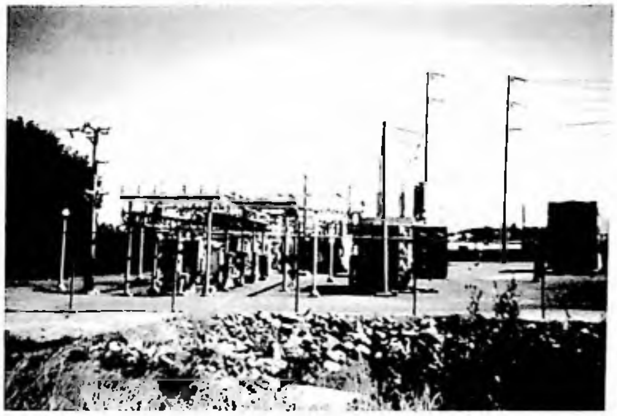
Substations must be well secured against outages that could be caused deliberately by vandals or accidentally by children or other persons. Traditionally, this has been accomplished with chain-link fencing around the perimeter, with splayed barbed-wire strands added along the top. Plenty of space between the fence and the contained equipment prevents reaching the equipment with conducting material and reduces the probability of damage done by throwing objects over the top.

A new threat has emerged in the last decade--that of terrorist activities. It is difficult to predict what political motivations may arise, or what forms they may take, but they are definitely a sign of our times. The security of a substation and the nature of any businesses or groups of people served by that substation should be reviewed in an attempt to predict any potential causes or results from deliberate outages. Alarms and other control devices are available to improve security.

Enclosure Type and Architectural Treatment

The chain-link and barbed-wire fences maintain good structural integrity over the years, and appearance has not been particularly objectionable where thay have been located in industrial or rural areas. However, in commercial and residential areas, this approach may lead to public objection. There are some good-looking alternatives that will blend into surrounding neighborhoods and almost completely mask their function. Another approach that has been used successfully is to make the substation attractive or interesting in its own right. Figure 6-3 is an example of two substations, one with and one without a visual barrier.

Figure 6-3 Examples of Electrical Substation--With and Without Visual Barrier. Courtesy Pacific Gas and Electric Company



Landscaping. One method to conceal substation equipment from direct view by the public, and still allow use of low-cost chain-link fencing, is to use planting materials around the exterior perimeter. Evergreen trees or shrubs which have foliage starting from the ground will grow together to form a dense "wall" and conceal the fence and starting from the ground will grow together to form a dense "wall" and conceal the fence and equipment behind. Climbing forms of ivy can be planted at the base of the chain-link and allowed to cover it completely. "Boston ivy" will turn to beautiful reds and golds in the autumn. A combination of both trees and ivy can provide interest and eye relief.

Architectural Walls. Although more expensive than chain-link fencing, a permanent structural wall can provide security, conceal the substation equipment, and have an attractive appearance. Such a structure can be designed to blend with the surrounding architecture or look like a building. Suggested materials would be masonry units such as common brick, textured brick or concrete block, or slump block, possessing long life with little maintenance. However, special care must be exercised in the design of such walls to ensure adequate security for the substation.

The finished appearance can be designed to match or blend with any surroundings. If, for instance, the surrounding motif were Spanish, the wall could be made of inexpensive concrete block and given a rough trowel coat of white cement stucco. Simple black wrought ironwork along the top could provide security. If the surrounding area was made up of modern commercial buildings, the same concrete block wall could be covered with "marblecrete"--a cement trowel coat blasted with aggregate. There are many choices of aggregates--smooth to rough, and many colors. Properly sealed, marblecrete walls are not easily defaced and are easily maintained.

The wall should be set on a continuous concrete footing and have a high or overhanging cap course to prevent climbing. Where security is a major concern, some form of barbed wire or proximity detection and alarm system could be gracefully added near the top.

Location and Space Requirements

There are two cost factors that have important bearing on the site selection:

- To minimize the secondary distribution costs, the substation should be located near the centroid of the load being served if possible. Geographically, this is about the center of the project, if the individual loads are uniformly distributed.

- To minimize the primary transmission costs, the substation should be located on the primary transmission line, if that line already passes through the project, or located on the perimeter of the project nearest the primary line if it does not.

To minimize the complete installation cost of both primary transmission and secondary distribution, a cost benefit study should be performed for each potential location. Usually cost of distribution lines and line losses outweigh transmission costs. In the final analysis, public acceptance at the site may be the major siting factor.

Sites for Future Use

Generally, a redevelopment area will not require additional siting for substations because existing load base facilities have already been developed. There are cases, however, when the existing facilities are overloaded or the redevelopment load will be larger. The serving electric utility should be asked to study the area, if they have not already done so, and determine if any reserve substation sites or rights-of-way are likely to be needed in the future. If so, those rights should be reserved for them.

UPGRADING DISTRIBUTION LINES

Primary distribution line: Feeder conductors usually extend in a radial fashion from a distribution substation to distribution transformers located near the customers' facilities. Voltages generally range between about 12 and 25 kv. These conductors may be located overhead on poles (see Figure 6-4), or underground.

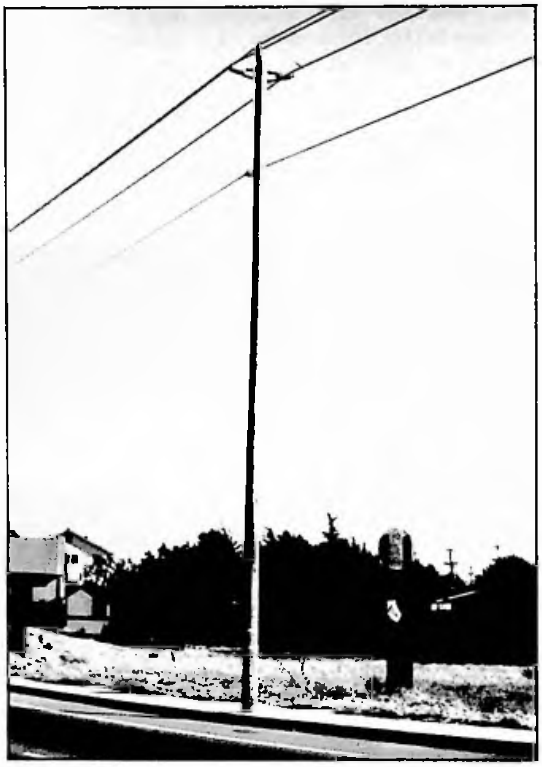
Typical costs of conventional distribution system upgrading projects are shown in Table 6-1. The costs for undergrounding are for cable placed in a trench. Costs are for 1984. Specific site conditions may cause costs to vary from those shown in the table and site-specific estimates should be made in every case. The costs are useful in comparing the innovative rehabilitation methods described below.

Conversion to Higher Voltages

A common practice among utilities has been to raise their distribution voltages. This serves several desirable purposes:

- Line losses are reduced.
- A new substation might be avoided or an occasional existing substation can be eliminated.
- Existing lines can carry larger loads, if they are insulated for and operated at the higher voltage.

Figure 6-4 21-KV Distribution Line



Reinsulating Existing Overhead Conductors. There are methods available for reinsulating conductors with new insulation when the existing insulation has deteriorated. The cost of reinsulating should be compared with the cost of new cable.

Provision for Future Conversion. If a line is to be reinsulated or replaced for any reason, the probability that the system line voltage may be increased should be explored. If that potential exists, it will probably be economically worthwhile to install insulation or conductors that are insulated for the higher future voltage so that they do not have to be replaced again later.

Advantages of Using Underground Lines

There are many factors which affect the decision to convert existing overhead facilities to underground, or to install new underground facilities in lieu of new overhead facilities.

Table 6-1 Distribution System Refurbishment Costs

Modification	Typical cost/unit, dollars
Remove overhead lines	2,300/city block
Upgrade overhead lines	16,000/city block
Install underground lines	130,000/city block
Reconductor existing lines	
13 and 34 kv	24,000/mile
Line conversion	
4 kv to 13 kv	150/kva
4 kv to 34 kv	200/kva

Aesthetics. The appearance of poles and overhead lines detracts from the beauty of "natural" surroundings that are usually the objective of present design practices that must be ecologically responsive. Placing the electric utilities underground, like the water and sewer lines, removes this unnecessary visual "noise" from view.

Reliability. The underground placement of transmission and distribution lines improves reliability for the following reasons:

- Line damage from wind and snow is eliminated.
- Pole damage, such as from being hit by automobiles, is eliminated.
- Outages caused by vandalism, such as destruction of insulators by the discharge of firearms, is eliminated.
- Relocation cost of moving an existing pole because of a change in roadway or sidewalk location is eliminated.

Increased Capacity. If an area is being served by an overhead line which is loaded to capacity, that line will need to be reconductored, or the voltage raised to provide additional power capacity. Considering the remaining life in the existing poles and other hardware, this may be the most economical time to provide the additional capacity with a new underground line.

Joint System Improvements. In addition to the obvious physical and economic considerations of an underground electrical system by itself, there may be additional benefits associated with combining installation costs and planning with other potential utilities:

- Joint underground trenching with other utilities such as public telephone; cable television; street lighting; municipal fire alarm; and natural gas, water, and sewer systems. The costs of trenching and backfilling are shared by each of the participating utilities. An additional intangible advantage is that an integrated utility scheme could be developed that might potentially reduce future damage, repair, and search time. See Reference 1 for additional details on joint trenching.
- Joint use of poles with other utilities that could be aerial, such as public telephone, cable television, and street lighting systems. The costs of pole installation and replacement are shared by each of the participating utilities, usually through leasing arrangements.[1]
- Underground utility tunnels or concrete-encased duct banks could be designed for joint use of utilities, with costs shared by all participants.
- Spare conduits should be included in any of the underground schemes to accommodate future expansion and additional systems.
- Street lighting. Street lighting is sometimes mounted on the same wood poles that carry the overhead distribution system lines. If the overhead power lines are eliminated, consideration should be given to the remaining life of those poles and lighting fixtures and to the adequacy of the present street lighting. If replacement of the poles is indicated, consider the use of prestressed, spun concrete poles--they have a very long life and require no maintenance. They are available in a variety of textures and aggregate/mortar colors that can complement any architectural design. Aluminum or steel poles should also be considered.

- If the lighting sources are incandescent, fluorescent, or mercury vapor, consideration should be given to replacing them with new fixtures using high pressure sodium (HPS) lamp sources which have higher efficiency and lower operating cost. These fixtures should use cutoff or semicutoff photometrics for optimal beam utilization and minimum glare. A key to successful roadway lighting is the brightness luminance of the roadway surface, and design should be predicated around the recently established set of reflectance coefficients and surface classes for various roadway materials as defined by the Illuminating Engineering Society and American National Standards Institute (IES/ANSI).

- Determine how street lighting is accomplished and paid for in the redevelopment area. If in an urban area, usually the city has the responsibility for providing and paying for street lighting, but it can be installed and maintained by several methods, sometimes the city does everything--designs the lighting, installs it, and maintains it. Other cities delegate everything to the local utility. In most cases, the city pays all costs--either actual costs as they occur, or monthly lease costs with amortization and energy included. In special cases assessment districts have been formed to pay for lighting.

- Tree maintenance costs. Trees are an important and desirable component of any development, but should be selected and located with care, to minimize future trimming costs associated with:

  1. Maintaining minimum clearances above sidewalks and roadways for clear pedestrian and vehicle passage and to comply with local codes.

  2. Maintaining clearances from overhead power and communication lines to avoid physical interference.

  3. Maintaining clearances around and below street lighting so that the lighting level and uniformity is not compromised.

  4. Maintaining shadow line clearances from properties whose owners may wish to take advantage of solar opportunities. Solar rights are often protected by local or state laws.

Innovative Undergrounding Methods

Many developments in equipment and wiring materials have taken place in the last decade which have helped reduce the installed cost of undergrounding electric utilities. Although still higher than equivalent overhead systems, there are offsetting, sometimes intangible benefits. The true life-cycle cost should be examined, not merely first cost, before long-term decisions are made.

The cost of conventional excavation of an 8-inch-wide, 3-foot-depth trench for electrical cable, with pavement sawing, backfill with new material and disposal of the old, plus repaving (asphalt) costs \$6 to \$7 per foot. Costs for the cable placed in a conduit and then encased in concrete are a function of the cable size. Means Electrical Cost Data, an annual publication, can be used to estimate costs. For example, in 1984, a 15 kv, 2 watt cable costs \$4.25 per foot, the conduit \$2.30 per foot, the concrete encasement, poured in-place \$1.85 per foot. To this must be added hand hole boxes that add about \$1.35 per foot. The total installed cost for this type of cable is thus the trenching and backfill costs, plus these costs, or about \$16 per foot. This cost can be used as a reference for the innovative methods described below.

Pavement Slitter/Trencher. This is a new combinational trenching process which removes a narrow strip of asphalt pavement and, at the same time, excavates a narrow trench beneath (see Figure 6-5). This method is more rapid and less expensive than previous methods, making undergrounding more economically attractive. It has application in any situation where asphalt pavement is encountered, particularly where traffic detours require minimizing the open trench time.

Cost for an installed cable using this system is about 60 percent less than using conventional trenching and backfill.

Cable Plowing. This technique uses a tractor to pull a narrow vertical plow shear through the ground to a depth down to about 4 feet. Simultaneously, a cable(s) is fed from a reel to the bottom of that trench through the hollow plow shear. The narrow trench closes immediately behind the plow, eliminating trenching and backfilling (See Figure 6-6). This system has application anytime that cables are located in native earth, and a joint trench with other utilities is not required. It works for individual cables, multiple cables, and cables in flexible conduit. It can install more than one cable at different levels simultaneously. It will not work in locations where there is pavement but will work in roadway areas once the pavement is removed or broken up.

Cost for an installed direct-buried cable is about 25 percent less than for conventional cable in rigid nonmetallic conduit.

Figure 6-5 Pavement Slitter/Trencher. Courtesy The Charles Machine Works, Inc.

Cost for an installed cable using this system is about 50 percent of the cost of using conventional trenching and backfill.

Direct-Buried Cables. Cables which are approved for use in direct contact with the earth (no conduit) have been available for some years. They are rated for submersible use and are available in most voltage classes. One common type that utilities have used regularly and successfully in residential areas has become known as URD (underground residential distribution). A single URD cable is made up of a phase conductor covered by insulation, semiconducting jacket, and surrounded by an exposed or jacketed, concentric neutral/ground conductor which offers some physical protection. One or two cables make a complete circuit.

Direct-buried cables have application whenever it is desirable to minimize first cost, and where outage downtime is not critical. They have the advantage of being less expensive than cables installed in conduits, with the savings coming primarily from a reduction in installation labor. One of the disadvantages of direct-buried cable is increased cost of maintenance and replacement.

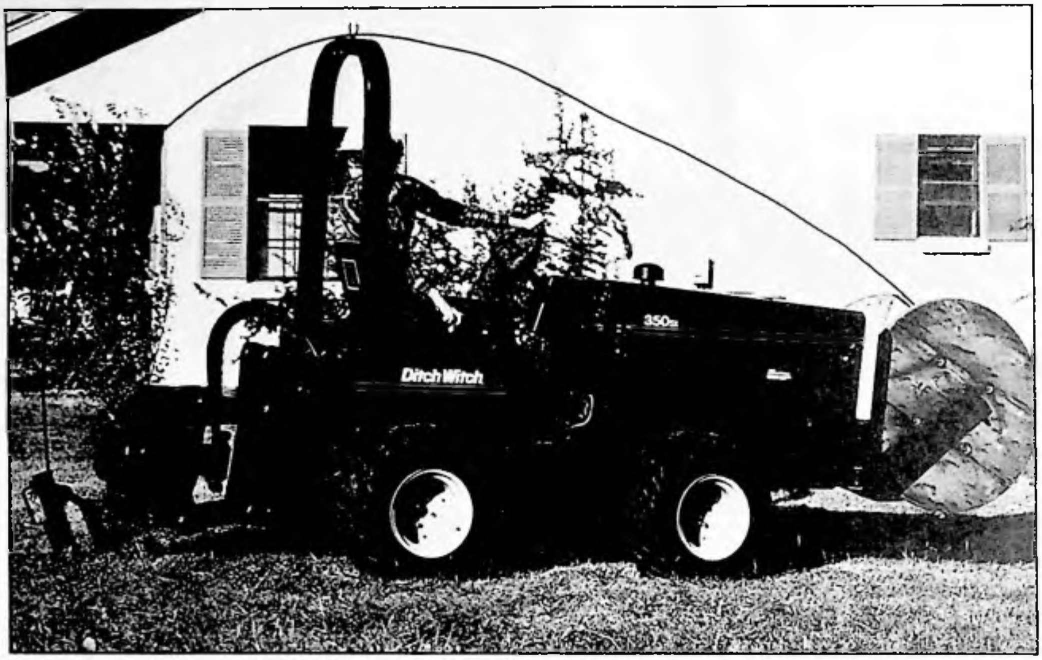
Cable-in-Conduit. Cable for primary voltages has recently become available preinstalled in a high-density polyethylene conduit. Cable-in-conduit (CIC) is flexible enough to be shipped on reels and then installed in the earth just like direct-buried cable. It has application for any potential underground project. It provides the advantage of the ability to remove a faulty cable from a buried conduit and replace it with new, as with a fixed conduit installation.

CIC has the disadvantages of being higher priced than direct-buried cable and not having as much physical protection as rigid conduit. It is estimated that CIC has an installed cost about 25 percent higher than direct-buried cable and about 50 to 75 percent lower than conventional cable installed in rigid nonmetallic conduit.

Polyethylene-Encased Residential Cable. Similar to type CIC, this new product is undergoing development and testing and should be released by manufacturers soon. It has a 600-volt rating, suitable for secondary services, such as 208Y/120-, 240/120-, or

480Y/277-volts. It has application for any potential underground service, and its advantages and disadvantages are the same as type CIC.

Figure 6-6 Cable Plow. Courtesy Charles Machine Works, Inc.



It is estimated that polyethylene-encased residential cable has an installed cost about 15 to 20 percent higher than direct-buried cable and about 50 to 75 percent lower than conventional cable installed in rigid nonmetallic conduit.

Guided Hole Boring and Conduit Pushing. Power-driven equipment is available which will drill a horizontal hole through the ground in which a conduit or cable may be pulled (See Figure 6-7). Known as "gophers" or "hole hogs", they may be pneumatically or hydraulically driven, sometimes with the help of water pressure at the penetrating end. Equipment is also available which will push a conduit or pipe horizontally through the ground, and once the head point is removed, cables can be pulled through.

Bored holes or pushed conduits have application wherever it is necessary to route a cable beneath an existing street, driveway, or railroad track, and it is undesirable to cut and patch the roadway surface or tract. Many utilities regularly use this method for water and gas piping and find it to be less expensive in certain areas than the traditional cutting, trenching, backfilling, and resurfacing. Advantages include minimal excavation of a roadway surface without patching and settling. About the only disadvantage might be the investment in purchasing or renting the boring or pushing equipment.

Overhead Considerations

Poles and lines used in an overhead distribution system within a rehabilitation area may be located such that they will not interfere with redevelopment plans. However, if there is interference, or if the poles have deterioration that must be remedied, there are several alternatives available in addition to placing those lines underground.

Moving Poles. If a street must be cleared or widened and the poles are sound, it may be feasible to simply move those poles and lines to a nearby location.

If a pole must be moved and is not sound, it should be physically removed from the ground and the remains disposed of, then, a new pole installed in an appropriate new location.

Figure 6-7 Hole Boring Devices. Courtesy Philadelphia Electric Company.

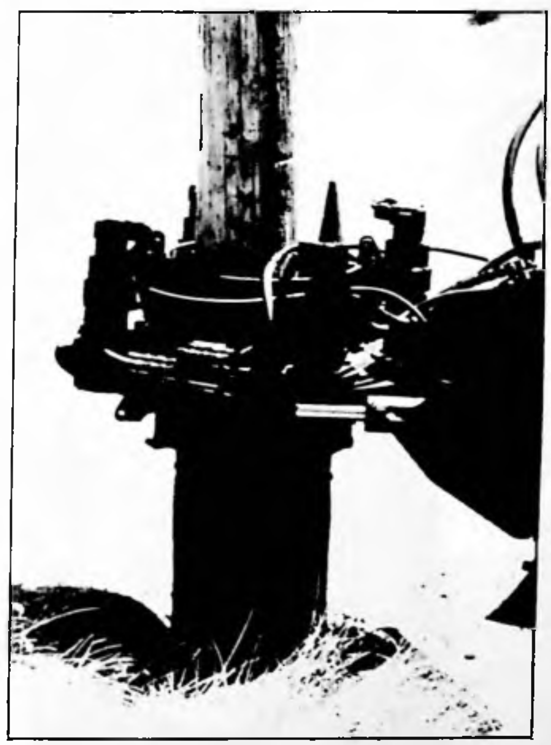
Butt Trenching. Butt trenching consists of digging a trench between the present and desired location of the pole and sliding the pole over to its new location. This method is less expensive than removal and replacement of an existing pole. The costs of typical one-pole butt trenching operation are on the order of 10 to 25 percent of the cost of a new pole.

Pole Reinforcement. Reinforcement of existing poles provides an economic alternative to complete replacement, yielding additional life at substantially less cost. One such system, including the equipment, was developed by the Electric Power Research Institute (EPRI) and is trademarked "REPOL." (See Figures 6-8 and 6-9).

REPOL involves screwing a two-piece section of steel tubing into the ground around a pole butt and filling the annulus between the pole and tubing with resin. The resin has a compression strength of 26,000 psi and a tensil strength of 15,000 pis, which is much stronger than concrete. Distribution poles are fitted with a 14- or 16-inch casing. The process requires about 1 hour per pole and 5 to 6 poles can be repaired in 1 day.

Figure 6-8 Completed REPOL Project. Courtesy of Utilitech, Inc.

Figure 6-9 REPOL Casing Driver. Courtesy Utilitech, Inc.



- Advantages

  1. Lower cost--no conductor or equipment transfer.

  2. No service interruption--lines need not be deenergized.

- Disadvantages

  1. Not applicable to tops of poles.

  2. New technique--few case histories.

The cost of the REPOL process is on the order of 10 to 30 percent of the cost of pole replacement, depending primarily on the cost to transfer conductors and other equipment to the new pole. The material cost is approximately $300 per pole.

Reference

1. Innovative Site Utility Installations, Building Technology Division, Office of Policy Development and Research, Department of Housing and Urban Development, HUD-PDR-753, November 1983.

CHAPTER 7

After evaluating the adequacy of the solid waste management system for the redevelopment area as described in Chapter 4, the next step is to identify ways to improve the system. Methods for improving solid waste storage, collection, litter control, recycling, and institutional arrangements are described in this chapter.

STORAGE

Storage is primarily the responsibility of the resident or landowner, as enforced by the city. Through its planning and permit process, the city can ensure that building design provides adequate solid waste storage facilities. In planning open space, the city will probably be directly responsible for designing storage facilities.

Some alternatives for improving existing solid waste storage practices and facilities include:

1. Review redevelopment planning and permitting procedures and require evaluation of solid waste storage.
2. Use larger containers that provide more volume per person or square foot of commercial space.
3. Place containers in screened areas (block walls or fences) to improve aesthetics and to discourage vandalism.
4. Provide more containers in open space areas, and use containers that are difficult for animals to tip over and get into. Also, use containers that have small enough openings to prevent people from putting in bags of household garbage. This reserves the volume for open space users. Figure 7-1 shows typical containers for open space areas.
5. Install drop chutes or vacuum collection pipes in buildings.
6. Increase enforcement of existing storage ordinances or improve the ordinances.

COLLECTION

The actual collection system is already established in a city so it is usually not practical to change it for a redevelopment area within the city. Because of the initial investment in collection equipment, it is not normally reasonable to change the equipment used unless the equipment is too large to pass through the streets and alleys. In this case, smaller vehicles should be used.

Figure 7-1 Typical Storage Container for Open Space Areas

Some practical improvements that can be made are:

1. Increase the collection frequency.
2. Change collection routes to increase efficiency and to reduce traffic congestion problems.
3. Use smaller "satellite" vehicles, shown on Figure 7-2, to collect wastes in interior areas so a larger "mother" vehicle can be parked outside the area.

Figure 7-2 Typical Satellite Collection Vehicle
Source: Solid Waste Management/ Resource Recovery Journal April 1981

4. Require mandatory collection. (This already exists in most large cities.)

5. Increase enforcement of existing ordinances and/or improve ordinances.

LITTER CONTROL

Litter control is necessary for maintaining an attractive redeveloped area and to protect public health. Some of the actions that can be taken to improve existing litter control are:

1. Increase street sweeping frequency.

    - For good litter control in major commercial areas, streets should be swept daily. This is best done at night to avoid traffic congestion.

    - Increased service can be financed by the city, by the commercial businesses, or by a cooperative effort between the city and the businesses. In the City of Oakland, California, businesses provided money to buy an additional sweeper so the city can sweep the downtown area 7 days per week.

    - Some cities contract out their street sweeping, as in Lynn, Massachusetts,[2] or charge user fees as in Austin, Texas.[3]

2. Monitor effectiveness of litter control.

    - One monitoring system used by the City of Memphis and other cities is a photometric index (PI) which is a scientific method that gives measurable results in litter reduction. It was developed in 1974 by the Research Foundation American Public Works Association, under contract to Keep America Beautiful, Inc. In this method, photographs are taken of randomly selected sites. The number of photographs taken in each category (e.g., streets, sidewalks, loading docks, vacant lots, and parking lots) is proportional to the land use percentage of each category. The photographs are projected over a grid of the study area, and the littered squares are counted. In Memphis, the PI is measured every 6 months. Although it does not measure the amount of litter, it does indicate a percent increase or decrease.[4]

3. Expand litter control programs.

    - Get involved agencies together in a task force or committee to increase cooperation.

    - Clarify responsibility of each involved agency.

    - Push for political support to increase litter control budgets, especially for street sweeping and manual cleanup.

    - Sponsor more public awareness campaigns.

    - Distribute more trash receptacles in public and open areas, especially bus stops and parks.

    - Solicit help with litter control from local service groups.

4. Improve and more-strictly enforce ordinances.

    - Increase enforcement of ordinances. One example is to post signs that prohibit street parking during street sweeping hours and tow any cars that are in noncompliance. Figure 7-3 shows a typical sign. Fines can be set high enough to cover the cost of increased enforcement.

Figure 7-3 Typical Sign Prohibiting Parking During Street Sweeping Hours

- An example of a way to make ordinances more effective is

San Diego's enforcement in public housing areas. All curbs are painted red in public housing areas to reduce loitering, thereby reducing litter. Also, residents are given only one chance before eviction if they are caught littering or being careless with their trash.

- Increased enforcement and/or ordinance changes requires strong political and judicial support. Often, litter offenses are near the bottom of the priority list for enforcement in a city's judicial system.

5. Carefully plan redevelopment area to minimize littering opportunities.

   - Plan carefully for adequate storage and collection as described in the previous sections of this chapter. Landscape any vacant open space including those planned for future development. Studies show that planting flowers and shrubs in vacant lots quite effectively prevents them from becoming dumping areas for trash.[1]

RECYCLING

Paper recycling by commercial businesses is probably the best opportunity for recycling in a redevelopment area. Cardboard, computer paper, and white office paper are commonly recycled. Usually this type of recycling system is operated by a private company, especially for computer and office paper. Commercial businesses (such as grocery stores and furniture stores) that have large quantities of cardboard often flatten, bale, and truck their cardboard to a buyer themselves. Cities can publicize and encourage this type of recycling.

Providing curbside pickup of recyclables and neighborhood drop-off and buy-back centers in a redevelopment area are options applicable to residential recycling. These services require much more effort and high participation and cooperation rates by the residents for success. Such services can be provided by the city, the private solid waste collection company, or a private recycling company. Before a city undertakes or requires recycling, a detailed cost-benefit study should be made.

COST FACTORS

A solid waste collection system is usually established and will not be changed for a redevelopment area, and storage is the responsibility of the landowners. Therefore, litter control, primarily street sweeping, is probably the solid waste management factor that can be the most easily improved in a redevelopment area. Some cost information on street sweeping is presented below. Cost considerations for recycling programs are also discussed briefly.

Street Sweeping Costs

Street sweeping costs vary significantly with factors such as:

- Street surface type.
- Accessibility for machines which determines whether it must be hand-swept or machine-swept.
- Type of litter (e.g., trash, leaves, or dirt) and quantity.
- Traffic congestion.
- Sweeping frequency.
- Travel distance and road type (surface street or freeway) between the machine storage yard and the work site, between the the work site and the disposal site, and between the disposal site and the storage yard. (These factors determine type of machine required, travel time, and fuel mileage.)

Therefore, costs shown below are only sample costs to be used as a guide and are not directly applicable to another city's program.

Sample Unit Costs. Labor comprises by far the most significant portion of street sweeping costs. Equipment costs and depreciation, operating and maintenance supplies, and debris transfer and disposal are other cost items. Sample costs, based on 1976/77 costs from the City of San Jose, California, are presented in Table 7-1.[5] These costs are adjusted to December 1983 costs using the Engineering News Record, 20 Cities, average Construction Cost Index Factor of 1.32. These costs do not include equipment amortization and do include equipment depreciation. Costs are in dollars per curb-mile (c-m), meaning the cost to make one pass on a 1-mile length of street.

Table 7-1 Sample Street Sweeping Costs

Item	Cost, dollars per cm	Cost, percent of total
Operating labor[a]	9.50	51
Maintenance[b]	6.34	34
Operating supplies	0.63	3
Debris transfer and disposal	1.54	8
Equipment depreciation	0.63	3
Total	18.64	99[c]

[a]Equipment operation and supervision.

[b]Labor and materials.

[c]Error due to rounding.

A street sweeper costs between $70,000 and $90,000, depending on the type and number of "extras."[6] Assuming a midrange cost of $80,000, and 12 percent interest for 10 years, the annual cost of a street sweeper is about $14,000. An estimated unit annual capital cost for the street sweeper is $1.25/c-m based on the following assumptions:

- 20 c-m/shift for a downtown route.[6]
- Two shifts/day.
- 30 percent downtime for maintenance.[6]
- 7-day-per-week operation.

Adding this cost to the cost in Table 7-1, a total street sweeping cost of $19.89/c-m is reached.

Recycling Costs

Recycling program costs are highly variable according to the type of program and the materials markets' fluctuations. Also, there is not a lot of cost information published. Therefore, it is very difficult to give general cost data. There are, however, some important points that should be addressed when a city or private company is evaluating the economic feasibility of a recycling program. Some of these considerations are listed below.

Materials Markets. Materials markets must be available within an economical haul distance. Also, materials markets fluctuate drastically and unpredictably. A recycling program operator must be prepared to store materials until prices are high enough to make a profit or must take a loss. The city must be ready to dispose of waste materials that are not sold.

Participation. Cooperation and participation of waste generators must be adequate to provide a large enough volume of materials at a high enough quality to support a program or the operator must subsidize the program. This participation is especially crucial in a curbside program, since curbside collection is very expensive. Incentives can be offered, such as a reduced garbage fee for participation in a curbside program. Recycling centers can be operated as buyback centers for some or all materials. This means that people are paid a fraction of the market value for the materials they bring. Programs can be mandatory, but enforcement is difficult and expensive.

Equipment. Any recycling center requires equipment to handle and prepare materials for sale. Some equipment includes forklifts, can crushers, can sorters, paper and metal balers, paper shredders, and trucks. Storage bins must also be purchased. Curbside programs must have vehicles to pick up materials. These can range from pickup trucks to compartmentalized trucks made especially for curbside collection of recyclables.

Labor. Labor is another significant cost to a recycling program. People are required to collect materials (in curbside programs), receive materials (at many recycling centers), operate processing equipment, and supervise operations.

INSTITUTIONAL ARRANGEMENTS

Since institutional arrangements for solid waste management are already established, it is unlikely that they can, or will be changed, for, or because of, a redevelopment area. However, a city may choose to change the institutional arrangements if the current ones are not adequate to maintain high visual aesthetics in the area.

- A city may take more control of collection by collecting the wastes itself or by signing a franchise agreement with a private collector rather than allowing each resident or landowner to contract individually with a private collector.
- A city may enter into a partnership with the businesses to provide street

sweeping and manual cleanup services if the city budget does not allow adequate service.

- A city may increase funding for added collection and/or litter control services. Increased rates or general fund allowance would affect the city as a whole.

References

1. City of Oakland Clean Community System.

2. "Street Sweeping Blues? Try Contracting the Service Out." American City & County. September 1981.

3. Ridings, R.L. "User Fee Pays for Clean Streets." American City & County. February 1981.

4. Memphis City Beautiful Commission.

5. Pitt, R. "Why Street Cleaning is Worth the Effort." American City & County. April 1980.

6. City of San Francisco Street Sweeping Department.

APPENDIX A

PIPELINE REHABILITATION COST ESTIMATION EXAMPLE

This cost estimation example has been prepared to illustrate the use of the unit cost curves and added cost tables presented in the manual. The example begins with a tabular description of the existing sewer and an identification of the rehabilitation and/or replacement alternatives for which cost estimates are to be prepared.

DESCRIPTION OF EXISTING SEWER

Ten reaches of trunk sewer require work. These ten sewer reaches total 8,000 linear feet and are all located within the same trunk sewer. The sizes, shapes, lengths, materials, depths, and numbers of service connections for the existing sewer are shown in Table A-1.

Table A-1. Description of Existing Sewer

Reach	Size, inches	Sewer shape	Length, feet	Type	Invert depth, feet	Service connections	Number of manholes	Required action[a]
a	10	Round	250	VCP	3.5	1	1	None
b	12	Round	1,050	VCP	4.5	20	2	Rep/Rehab
c	14	Round	1,200	VCP	4.5	10	2	Rep/Rehab
d	16	Round	1,100	VCP	5.5	18	3	Rep/Rehab
e	20	Round	1,200	Brick	7.5	17	3	Rep/Rehab
f	22	Round	700	Brick	7.5	4	1	Rep/Rehab
g	27	Round	250	Brick	7.5	7	0	Rep
h	36	Round	400	Brick	8.0	3	1	Rep/Rehab
i	44	Round	1,425	Brick	10.0	12	3	Rep/Rehab
j	54	Round	1,425	Concrete	15.0	18	3	Rep/Rehab

[a]Rep = replace; rep/rehab = either replace or rehabilitate. In all cases, required action includes replacement of manholes.

ACTION ALTERNATIVES

An investigation of sewer structural and hydraulic conditions has identified the workable action alternatives for each reach. These are shown in Table A-2. It is assumed that all alternatives are acceptable to the utility owner and would be specified and bid. Allowing more than one alternative to be bid will increase bidding competition.

Table A-2. Recommended Action Alternatives

Reach	Alternatives
a	None required.
b	Replace with 15-inch VCP or rehabilitate with resin-impregnated fabric.
c	Replace with 15-inch VCP or rehabilitate with polyethylene insertion.
d	Replace with 15-inch VCP or rehabilitate with resin-impregnated fabric.
e	Replace with 18-inch VCP or RCP or rehabilitate with: (1) resin-impregnated fabric or (2) polyethylene insertion.
f	Replace with 21-inch VCP or RCP or rehabilitate with: (1) resin-impregnated fabric or (2) polyethylene insertion
g and h	Replace with 30-inch VCP or RCP.
i	Replace with 36-inch VCP or RCP or rehabilitate with: (1) resin-impregnated fabric, (2) polyethylene insertion, or (3) reinforced plastic mortar pipe insertion.
j	Replace with 42-inch RCP or rehabilitate with: (1) resin-impregnated fabric, (2) polyethylene insertion, or (3) reinforced plastic mortar pipe insertion.

COST ESTIMATES

Cost estimates for the alternatives specified for Reaches b and c, d, and j are developed in the following examples. A cost contingency of 20 percent is added to the excavation and replacement alternative and, because of more uncertainties, 30 percent is used for rehabilitation alternatives.

Reach b--Replacement Alternative

- Replace existing 12-inch VCP with 1,050 feet of 15-inch VCP.
- Replace 2 existing manholes.
- Make 20 service connections (all 4-inch).

1. Estimate pipe removal and replacement basic cost using unit cost curve (Figure 5-4) for:
   - Replacement pipe diameter = 15-inch.
   - Average depth to bottom of trench = 5.5 feet (depth to invert plus pipe wall thickness plus thickness of pipe bedding).
     - a. Minimum trench depth shown on unit cost curve is 10 feet. Use the 10-foot depth curve for estimate. Unit cost from this curve is $52 per lineal foot.
     - b. Basic cost = 1,050 feet x $52 = $ 54,600
2. Estimate service connection cost using added cost table (Table 5-4):
   - a. 20 services x $800/connection = $ 16,000
3. Estimate street repaving cost using added cost table (Table 5-4):
   - a. Assume average width of pavement cut = 3 feet.

b. Area of repaving = 3 feet x 1,050 feet = 3,150 sq ft.

c. Use unit cost for repaving of $7/sq ft from cost table.

d. Repaving cost = 3,150 sq ft x $7 = $ 22,050

4. Estimate cost of general utilities interference based on added cost table (Table 5-4):

a. Use minimum unit cost of $20/lineal foot (there are no major utility interferences).

b. Utilities interference cost = $20 x 1,050 feet = $ 21,000

5. Estimate cost of manhole removal and replacement.

a. Manhole removal cost from added cost table (Table 5-4) = $600/manhole.

b. Cost for manhole replacement using full manhole constructed to 10-foot depth is shown in the added cost table (Table 5-4) to be $1,500 to $2,000/manhole with incremental cost of $150 to $200/foot for depths lesser or greater than 10 feet.

For 6-foot deep manholes, use replacement unit cost of $2,000 - (4 feet x $150) = $1,400/manhole.

c. Cost of manhole removal and replacement = 2 manholes x ($600 + $1,400) = $ 4,000

6. Traffic control cost is negligible due to block-by-block closure of street.

7. There is no wastewater bypassing.

8. Summary construction cost estimate without contingency:

a.	Pipe removal and replacement	$ 54,600
b.	Service connections	16,000
c.	Repaving	22,050
d.	Utilities interference	21,000
e.	Manhole removal and replacement	4,000
	Total	$117,650

9. Construction cost estimate with contingency:

a. Provide 20± percent cost contingency for conditions which are unknown at the time of the planning level estimate but which may arise during design and/or construction.

b. Estimated construction bid price with contingency = 1.2 (117,650) = $141,180 $141,000 (ENR 4109)

Reach b--Rehabilitation Alternative

- Rehabilitate existing 12-inch VCP with resin-impregnated fabric over entire 1,050-foot length.
- Replace 2 existing manholes.
- Make 20 service connections (all 4 inch).

1. Estimate cost for installing liner.

a. Unit cost from curve (Figure 5-38) is $60/lineal foot at low end of band for 12-inch existing pipe and $84/lineal foot at high end of band. Our pipe has no need for spot repair and we have no groundwater problem. Therefore, use unit cost of $60/foot.

b. Liner installation cost = 1,050 feet x 60 = $ 63,000

2. Estimate service connection cost.

a. Unit cost curve for liner includes up to 20 service connections. Therefore, there is no added cost.

3. Estimate cost of manhole removal and replacement.

a. Use the costs shown in the added cost table (Table 5-4) for pipeline removal and replacement (i.e., use the same cost per manhole as used for the pipe removal and replacement alternative for this same sewer reach.

b. Manhole removal and replacement cost = 2 manholes x $2,000/manhole = $ 4,000

4. Summary construction cost estimate.

Without contingency:

a. Liner installation	=	$ 63,000
b. Manhole removal and replacement	=	4,000
Total	=	$ 67,000

5. Construction cost estimate with contingency:

a. Provide a 30± percent contingency for conditions which are unknown at the planning level but which may arise during design and/or construction.

b. Estimated bid price = 1.3 (67,000) = $ 87,000 (ENR 4109)

Reach c--Replacement Alternative

- Replace existing 14-inch VCP with 1,200 feet of 15-inch VCP.
- Replace 2 existing manholes.
- Make 10 service connections (all 4 inch).

1. Estimate pipe removal and replacement basic cost using unit cost curve (Figure 5-4) for:

• Replacement pipe diameter = 15 inch.

• Average depth to bottom of trench = 5.5 feet (depth to invert plus pipe wall thickness plus thickness of pipe bedding.

a. Minimum trench depth shown on unit cost curve is 10 feet. Use the 10-foot depth curve for estimate. Unit cost from this curve is $52 per lineal foot.

b. Basic cost = 1,200 feet x $52 = $ 62,400

2. Estimate service connection cost using added cost table (Table 5-4):

a. 10 services x $800/connection = $ 8,000

3. Estimate street repaving cost using added cost table (Table 5-4):

a. Assume average width of pavement cut = 3 feet.
b. Area of repaving = 3 feet x 1,200 feet = 3,600 sq ft.
c. Use unit cost for repaving of $7/sq ft from cost table.
d. Repaving cost = 3,600 sq ft x $7 = $ 25,200

4. Estimate cost of general utilities interference based on added cost table (Table 5-4):

   a. Use minimum unit cost of \$20/lineal foot (there are no major utility interferences).
   b. Utilities interference cost = \$20 x 1,200 feet = \$ 24,000

5. Estimate cost of manhole removal and replacement.

   a. Manhole removal cost from added cost table (Table 5-4) = \$600/manhole.

   b. Cost for manhole replacement using full manhole constructed to a 10-foot depth is shown in the added cost table (Table 5-4) to be \$1,500 to \$2,000/manhole with incremental cost of \$150 to \$200/foot for depths lesser or greater than 10 feet.

      For 6-foot-deep manholes, use replacement unit cost of \$2,000 - (4 feet x \$150) = \$1,400/manhole.

   c. Cost of manhole removal and replacement = 2 manholes x (\$600 + \$1,400) = \$ 4,000

6. Traffic control cost is negligible due to block-by-block closure of street.

7. There is no wastewater bypassing.

8. Summary of construction cost estimate without contingency:

a. Pipe removal and replacement	\$ 62,400
b. Service connections	8,000
c. Repaving	25,200
d. Utilities interference	24,000
e. Manhole removal and replacement	4,000
Total	\$123,600

9. Construction cost estimate with contingency:

   a. Provide a 20± percent cost contingency for conditions which are unknown at the time of the planning level estimate but which may arise during design and/or construction.

   b. Estimated bid price with contingency = 1.2 (\$123,600) = \$148,320 = \$148,000 (ENR 4109)

Reach c--Rehabilitation Alternative

- Rehabilitate existing 14-inch VCP with high-density extruded polyethylene liner insertion over entire 1,200-foot length.

- Replace 2 existing manholes.

- Make 10 service connections (all 4 inch).

1. Estimate cost for inserting liner.

   a. The largest extruded polyethylene pipe size available to fit the old 14-inch is a 12-inch (nominal IPS) diameter. (Note: 14-inch-outside-diameter polyethylene pipe is available but some allowance must be made between inside of old pipe and outside of new pipe to ensure that liner can be inserted). The outside diameter of the 12-inch liner pipe is 12.75 inches. The liner insertion unit cost for 12-inch polyethylene pipe is shown on the unit cost curve (Figure 5-30) to lie in the range of \$18.50 to \$38/lineal foot. Our pipe has no seriously misaligned joints and is on a straight alignment. There are no locations requiring spot repair (structural damage consists of severe radial cracking and slightly pulled, leaking joints). Because of the minimal space between our 12-inch liner and the inside diameter of the old pipe, we will use a unit cost higher than the minimum ($18.50) cost from the curves. Our selected unit cost is $23/lineal foot (25± percent above the minimum value. This cost adjustment is a judgment based on our previous experience with liner insertion and the results of our video examination of this pipeline.

Liner insertion cost = 1,200 feet x $23 = $ 27,600

b. Estimate access pit cost:

- 1,200-foot liner can be pulled from single access pit 600+ feet in each direction.
- Pulling will occur from upstream and downstream manholes (i.e., no pulling pit is required).
- Access pit depth will be approximately 5 feet.
- Pit unit cost is $1,000/foot of pit depth (Table 5-12).
- Access pit cost = 5 ft x $1,000/ft = $ 5,000

2. Estimate cost for manhole removal and replacement.

a. Use same cost as for sewer removal and replacement alternative.
b. Manhole removal and replacement cost = 4,000

3. Estimate service connection cost.

a. Ten service connections at 4-inch size.

b. Service connections all at approximately 4-foot depth.

c. Unit cost for 4-inch service connections at 4- to 8-foot depth is $400 per connection plus $50 per connection for repaving (Table 5-12).

d. Service connection cost = 10 connections x ($400 + $50) = $ 4,500

e. Snug fit of liner in existing pipe makes full length grouting of annular space unnecessary.

f. Traffic control cost is negligible.

g. Wastewater bypassing is not necessary (liner can be pulled in flowing water).

h. Summary of construction cost without contingency:

a. Liner installation	$ 27,600
b. Access pit	5,000
c. Manhole removal and replacement	4,000
d. Service connections	4,500
Total	$ 41,100

i. Construction cost estimate with contingency:

- Provide a 30± percent cost contingency for conditions which are unknown at the planning level but which may arise during design and/or construction.
- Polyethylene insertion (slip line) estimated bid price = 1.3 x 41,100 = $ 53,000 (ENR 4109)

Reach d--Replacement Alternative

- Replace existing 16-inch VCP with 1,100 feet of 15-inch VCP.
- Replace 3 existing manholes.
- Make 18 service connections (all 4-inch).

1. Estimate pipe removal and replacement basic cost using the same unit cost as for Reaches b and c (i.e., $52/linal foot).

   Therefore, basic cost = 1,100 feet x $52 = $ 57,200

2. Estimate service connection cost using added cost table (Table 5-4):

   a. 18 services x $800/connection = $ 14,400

3. Estimate street repaving cost using the same assumptions and unit costs as for Reaches b and c.

   a. Area of repaving = 3 feet x 1,100 feet = 3,300 sq ft

   b. Repaving cost = 3,300 ($7/sq ft) = $ 23,100

4. Estimate cost of general utilities interference based on added cost table (Table 5-4):

   a. Use unit cost of $20/lineal foot.

   b. Utilities interference cost = $20 x 1,100 feet = $ 22,000

5. Estimate cost of manhole removal and replacement using same assumptions and unit cost as for Reaches b and c (i.e., removal cost = $600/manhole and replacement cost = $1,400/manhole).

   a. Cost of manhole removal and replacement = 3 manholes x $2,000/ manhole. = $ 6,000

6. Traffic control cost is negligible due to block-by-block closure of street.

7. There is no wastewater bypassing.

8. Summary construction cost estimate without contingency.

a. Pipe removal and replacement	$ 57,200
b. Service connections	14,400
c. Repaving	23,100
d. Utilities interference	22,000
e. Manhole removal and replacement	6,000
Total	$122,700

9. Construction cost estimate with contingency:

   a. Provide a 20± percent cost contingency for conditions which are unknown at the planning level but which may arise during design and/or construction.

   b. Estimated construction bid price with 20± percent contingency = 1.2 (122.700) = $147,000 (ENR 4109)

Reach d--Rehabilitation Alternative

- Rehabilitate existing 16-inch VCP pipe with Resin-Impregnated Fabric over entire 1,100-foot length.
- Replace 3 existing manholes.
- Make 18 service connections (all 4-inch).

1. Estimate cost for installing liner.

   a. Unit cost from curve (Figure 5-38) is $70/lineal foot at low end of band for 16-inch existing pipe and $110/ lineal foot at high end of band. Our pipe has no need for spot repair, and we have no groundwater problem. Therefore, use unit cost of $70/foot.

   b. Liner installation cost = 1,500 feet x 70 = $ 77,000

2. Estimate service connection cost.

   a. Unit cost curve for liner includes up to 20 service connections. Therefore there is no added cost.

3. Estimate cost of manhole removal and replacement.

   a. Use the costs shown in the added cost table (Table 5-4) for pipeline removal and replacement (i.e., use the same cost per manhole as used for the pipe removal and replacement alternative for this sewer reach.)

   b. Manhole removal and replacement cost = 3 manholes x $2,000/manhole = $ 6,000

4. Summary of construction cost without contingency.

a. Liner installation	$ 77,000
b. Manhole removal and replacement	6,000
Total	$ 83,000

5. Construction cost estimate with contingency.

   a. Provide a 30± percent cost contingency for conditions which are unknown at the planning level but which may arise during design and/or construction.

   b. Estimated bid price = 1.3 (83,000) = $108,000 (ENR 4109)

Reach j--Replacement Alternative

- Replace with 54-inch concrete pipe with 1,425 feet of 42-inch RCP.
- Replace 3 existing manholes.
- Make 18 service connections (all in 4- to 6-inch range).

1. Estimate pipe removal and replacement basic cost using unit cost curve (Figure 5-4) for:

   - Replacement pipe diameter = 42 inches.

- Average depth to bottom of trench is 16.8 feet (pipe invert depth plus pipe wall and bedding thickness).

   a. Unit cost curve shows $177/foot for 42-inch pipe at 15-foot trench depth and $210/foot for 42-inch pipe at 20-foot trench depth. Interpolate between these two values to get $189/foot for 16.8-foot trench depth.

   b. Basic cost = 1,425 feet x 189 = $269,000

2. Estimate service connection cost using added cost table (Table 5-4):

   a. 18 services x $800/connection = $ 14,400

3. Estimate street repaving cost using added cost table (Table 5-4):

   - Assume average width of pavement cut = 8 feet.

   a. Area of repaving = 8 feet x 1,425 feet = 11,400 sq ft

   b. Use unit cost for repaving of $7/sq ft from added cost table (Table 5-4).

   c. Repaving cost = 11,400 feet x 7 = $ 79,800

4. Estimate cost of general utilities interference based on added cost table (Table 5-4):

   a. Use unit cost of $20/lineal foot (minimum value reflecting no major utility problems).

   b. Utilities interference cost = 20 x 1,425 feet = $ 15,675

5. Estimate cost of manhole removal and replacement.

   a. Manhole removal cost from added cost table (Table 5-4) = $600/manhole.

   b. Cost for manhole replacement using saddle-type manhole constructed to 10-foot depth is shown in added cost table (Table 5-4) to be $2,400/ manhole. Use this unit value.

   c. Cost for manhole removal and replacement = 3 manholes x ($600 + $2,400) = $ 9,000

6. Traffic control cost is negligible due to block-by-block closure of street.

7. There is no wastewater bypassing.

8. Summary construction cost estimate without contingency.

a. Pipe removal and replacement	$269,000
b. Service connections	14,400
c. Repaving	79,800
d. Utilities interference	15,675
e. Manhole removal and replacement	9,000
Total	$387,875

9. Construction cost estimate with contingency:

   a. Provide a 20± percent cost contingency for conditions which are unknown and the planning level but which may arise during design and/or construction.

   b. Estimated construction bid price with 20± percent contingency = 1.2 (387,875) = $465,000 (ENR 4109)

Reach j--Rehabilitation Alternatives

- Rehabilitate existing 54-inch concrete pipe over entire 1,425-foot length using:
  - Resin-impregnated fabric, or
  - Polyethylene insertion, or
  - Reinforced plastic mortar pipe insertion.
- Replace 3 existing manholes.
- Make 18 service connections (all in the 4- to 6-inch range).

1. Resin-Impregnated Fabric Rehabilitation:

   a. Liner installation cost from unit cost curve (Figure 5-38) for 54-inch existing pipe size is $180/lineal foot at low end of band and $340/lineal foot at high end of cost band. Our pipe has no need for spot repair, and we have no groundwater problem. Therefore, use the unit cost of $180/lineal foot.

   b. Liner installation cost = $180 x 1,425 feet = $265,500

   c. Service connection cost for up to 20 services is included in cost from unit-cost curve. Therefore, there is no added cost for service connections.

   d. Use manhole replacement cost from added cost table (Table 5-4) for pipe removal and replacement. Unit cost is $1,500 to $2,000/manhole for full manhole constructed to 10-foot depth plus incremental cost of $150 to $200/foot for each added foot of depth. Our manholes will be constructed to 17-foot depth. Therefore, use unit cost of $2,000 + (150) x 7 = $3,050/manhole for replacement. Cost for removal of existing manholes is $600/manhole from the added cost table. Therefore, the total unit cost for manhole removal and replacement = $3,050 + 600 = $3,650/manhole.

   Manhole removal and replacement cost = $3,650/manhole x 3 manholes = $9,000.

   e. Summary of construction cost without contingency:

• Liner installation	=	$265,000
• Manhole replacement	=	$ 10,950
Total		$274,500

   f. Construction cost estimate with contingency.

   - Provide a 30+ percent cost contingency for conditions which are unknown at the planning level but which may arise during construction.
   - Resin-impregnated fabric estimated bid price = 1.3 x $275,950 = $357,000 (ENR 4109)

2. Polyethylene Insertion Rehabilitation

   a. The largest extruded polyethylene pipe size available to fit the old 54-inch pipe is 48-inch outside diameter. The inside diameter of this liner is about 45.7 inches. The liner insertion unit cost for 48-inch polyethylene pipe is shown on the unit cost curve (Figure 5-31) to lie in the range of $98 to $196/lineal foot. Our pipeline has no seriously misaligned joints and is on a straight alignment. There are no locations requiring spot repair (structural damage is limited to severe radial cracking and corrosion), and there is no need for groundwater dewatering during liner insertion. Therefore, use the lower limit unit cost of $98/lineal foot.

   Liner insertion cost = 1,425 feet x $98 = $139,650.

b. Estimate access pit cost:

- 1,425-foot liner can be pulled from single access pit 700+ feet in each direction.
- Pulling will occur from upstream and downstream manholes (i.e., no pulling pit is required).
- Access pit depth will be approximately 16 feet.
- Pit unit cost is $800/foot of pit depth (Table 5-12).
- Access pit cost = 16 ft x $800/ft = $ 12,800

c. Estimate service connection cost:

- 18 service connections in 4- to 6-inch size range.
- Service connections are all at approximately 11-foot depth.
- Unit cost for service connections at 8- to 12-foot depth is $550/connection plus $50/connection for repaving (Table 5-12).
- Service connection cost = 18 connections x ($550 + $50) = $10,800.

d. Manhole removal and replacement cost in this alternative is the same as for the resin-impregnated fabric alternative cost = $10,800.

e. Snug fit of liner in existing pipe makes full length grouting of annular space unnecessary.

f. Traffic control cost is negligible.

g. Wastewater bypassing is not necessary (liner can be pulled in flowing water).

h. Summary of construction cost without contingency:

a. Liner installation	$139,650
b. Access pit	12,800
c. Manhole removal and replacement	10,950
d. Service connections	10,800
Total	$174,200

i. Construction cost estimate with contingency:

- Provide a 30± percent cost contingency for conditions which are unknown at the planning level but which may arise during design and/or construction.
- Polyethylene insertion (slip line) estimated bid price = 1.3 x $172,250 = $226,000 (ENR 4109)

3. Reinforced Plastic Mortar Pipe Insertion Rehabilitation

a. Largest RPM pipe size with standard bell and spigot joint which will fit existing 54-inch is a nominal inside diameter of 45 inches (nominal bell outside diameter of 50.5 inches). One RPM manufacturer (CorBan/Armco) makes an inverted bell joint pipe which has a nominal inside diameter of 48 inches and a maximum outside diameter of 49.7 inches. Assume the use of this 48-inch pipe for cost estimating.

The unit cost for RPM pipe insertion is obtained by reading the cost value for the same pipe diameter on the cost curve (Figure 5-32) for Reinforced Thermosetting Resin (RTR) pipe insertion and applying a cost adjustment factor from Table 5-13 of the manual.

The unit cost for insertion of 48-inch RTR pipe ranges from $145 to $172/lineal foot. Our pipeline has no seriously misaligned joints and is on a straight alignment. There are no locations requiring spot repair, and there is no need for groundwater dewatering during liner insertion. Therefore, use the lower limit unit cost.

The cost adjustment factor (Table 5-13) to obtain RPM cost from the RTR curve value at 48-inch-diameter is 0.85. Therefore, the unit cost for 48-inch RPM liner insertion is 0.85 ($142/foot) = $121/lineal foot.

Liner insertion cost = $121 x 1,425 feet = $172,425.

b. Estimated access pit cost is the same as for polyethylene insertion. Access Pit Cost = $12,800.

c. Estimated service connection cost is the same as for polyethylene insertion.

Service connection cost = $10,800.

d. Manhole removal and replacement cost in this alternative is the same as for polyethylene insertion.

Manhole removal and replacement cost = $10,950.

e. Snug fit of liner in existing pipe makes full length grouting of annular space unnecessary.

f. Traffic control cost is negligible.

g. Wastewater bypassing is not necessary (liner can be pushed in flowing water).

h. Summary of construction cost without contingency:

• Liner installation	$172,425
• Access pit	12,800
• Service connections	10,800
• Manhole removal and replacement	10,950
Total	$205,025

i. Construction cost estimate with contingency:

- Provide a 30± percent cost contingency for conditions which are unknown at the planning level but which may arise during design and/or construction.

- RPM Insertion. Estimated bid price = 1.3 x $206,975 = $269,000 (ENR 4109)

Summary of Estimates

Table A-3 lists the above cost estimates for Reaches b, c, d, and j. In general, it is good practice to specify all feasible and acceptable alternatives in bid documents to increase bidding competition.

Table A-3. Summary of Estimates

Reach	Alternative	Estimated bid price, dollars
b	Replace	141,000
	Resin-impregnated fabric	87,000
c	Replace	148,000
	Polyethylene insertion	53,000
d	Replace	147,000
	Resin-impregnated fabric	108,000
j	Replace	465,000
	Resin-impregnated fabric	357,000
	Polyethylene insertion	226,000
	Reinforced plastic mortar pipe insertion	269,000

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