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Title: Sewer System Rehabilitation and the Effectiveness of Chemical Grouting

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The City of Salem, Oregon has an active sewer main chemical grouting program for the control of groundwater infiltration into the sewer collection system. The effectiveness of this chemical grouting program is evaluated by a comparison to other effective chemical grouting programs for control of inflow/infiltration (I/I). The importance of I/I control is discussed as well as generally accepted methods of collection system rehabilitation. Key elements of successful rehabilitation programs are presented along with discussion of past rehabilitation studies conducted in the City of Salem. The need for service lateral rehabilitation is promoted as an integral component of comprehensive I/I control. The City of Salem's current grouting program is described in the context of its Public Works Department structure, I/I problems, and related rehabilitation efforts. Chemically grouted joints of non-rubber gasket, concrete pipe are evaluated

for longevity based on grouting records dating back to the early 1970's. It was concluded that the effective lifetime for these joints in City of Salem is 15.6 years ± 0.3 years for a 95% confidence level. Conclusions and recommendations are presented that are intended to enhance the effectiveness of the grouting program and the overall I/I abatement program in the future.

Sewer System Rehabilitation and the Effectiveness of Chemical Grouting

by

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CHAPTER ONE

INTRODUCTION

When raw sewage enters a body of water, the depletion of oxygen by microbial activity can cause the death of fish and other sensitive organisms, create odor problems, present a public health hazard, and contribute to unsightly debris deposition on the water's edge.

Since the evolution of the National Pollution Discharge Elimination System (NPDES) in 1972, the overflow and subsequent discharge of raw sewage to streams and rivers has been the object of federal government attention. The objective of NPDES regulation is to eliminate raw sewage overflows. Compliance permits are issued to municipalities that include schedules for elimination of sewage bypasses into streams and rivers.

Most often, sewage overflows occur during periods of heavy rain when surface and groundwater enter the sewage collection system and exceed its hydraulic capacity. When this occurs, sewage is allowed to overflow at controlled sites to prevent flooding of basements and pumping stations.

Infiltration of groundwater into the collection system requires comprehensive rehabilitation of those areas within the system that allow significant quantities of extraneous water to enter.

In addition to protecting environmental quality, elimination of infiltration can result in substantial cost savings by publicly owned sewage treatment plants if infiltration flow reductions are large.

One method of preventing groundwater infiltration is to chemically grout leaking joints in sewer pipes. By injecting chemical grout into the soil surrounding leaking pipes, an impermeable barrier to water is formed.

The City of Salem, Oregon has an ongoing chemical grouting program that has been in existence for nearly 20 years. Concern over the effectiveness of the chemical grouting program in eliminating excessive infiltration has prompted an effort by the Facilities Engineering Division of the Department of Public Works to develop a methodology for effective infiltration control with chemical grout. Oregon State University was contracted to independently assess the effectiveness of and to recommend improvements in the chemical grouting program for I/I control.

The purpose of this report is thus to evaluate the effectiveness of the current chemical grouting program at the City of Salem and to recommend changes, where appropriate, that will enhance the performance of the program while facilitating continuous in-house evaluation of the program's effectiveness in the future. The report includes a summary of previous experience with sewer system rehabilitation methods including chemical grouting, recommended elements of a comprehensive sewer system rehabilitation program, and an analysis of the grouting program currently in effect at the City of Salem.

CHAPTER TWO

SEWER REHABILITATION METHODS AND CHEMICAL GROUTING

2.1 Introduction

Before the evolution of the National Pollution Discharge Elimination System (NPDES), the periodic discharge of raw sewage into the nation's rivers and streams was not regulated at the federal level. A product of the Federal Water Quality Act of 1972, (Greenwood and Kingsbury, 1979) the NPDES has the long term objectives of eliminating raw sewage overflows by establishing a permit system to regulate and monitor sewage overflow sites.

Raw sewage overflows occur when the municipal wastewater treatment plant capacity is exceeded or when the sewer collection system capacity is exceeded and there is danger of flooding houses and businesses.

One major contributing factor in the overloading of sewer collection systems and treatment plants is the infiltration/inflow (I/I) of water into the collection system.

Chemical grouting is one of several methods that has received widespread acceptance in the sewer industry as being effective in controlling excessive I/I flows in sewer collection systems.

2.2 Condition of the Nation's Sewer Systems

Besides the fact that federal regulations exist that establish a need to reduce I/I flows, there exist economic reasons that establish the same need. Many municipalities in the U.S. are faced with the decision of either rehabilitating their collection system to control I/I or expanding their treatment plant to accommodate the excessive wet weather flows.

Infiltration and Inflow are defined by the American Public Works Association as follows: (Sullivan and Ewing, 1985)

Infiltration - the volume of groundwater entering sewers and building sewer connections from the soil, through defective joints, broken or cracked pipes, improper connections, manhole walls, etc.

Inflow - the volume of any kind of water discharged into sewer lines from such sources as roof leaders, cellar and yard area drains, foundation drains, commercial and industrial "clean water" discharges, drains from springs and swampy areas, etc.

America's sewer systems are relatively new (National Council on Public Works Improvement, 1986) when compared to other countries. This characteristic has advantages and disadvantages. The advantage is that we have operated for many years with a relatively low-maintenance infrastructure. The disadvantage is that as this infrastructure begins to deteriorate, it becomes necessary to employ new technologies and more people to maintain the working condition of the sewers, but this requires additional money. A sudden acceleration in sewer usage rates and tax increases is observed by the citizenry and the cause of it is not fully understood. Consequently, public outcry over higher taxes and usage fees causes public officials to be reluctant to approve additional spending on sewer rehabilitation (McDonald, 1990). As a result, the condition of the collection system deteriorates at an even faster rate.

In a report to the President and the Congress, the National Council on Public Works Improvement in 1986 identified the need of maintaining the nation's infrastructure. (National Council on Public Works Improvement, 1986) This report, entitled "The Nation's Public Works - Defining the Issues", identifies the importance of infrastructure to the economy.

With the recent trends in environmental awareness and the increased federal regulation on raw sewage discharges, we can no longer avoid the subject of sewer system rehabilitation. Several municipalities recognized this reality some years ago and have established very progressive preventive maintenance programs (Sullivan and Ewing, 1985; RJN Environmental Associates, 1988). It is not only environmental awareness and regulatory increases that dictate more effort be expended on the elimination of I/I, in those municipalities that have adopted the progressive collection system maintenance management styles, it has been shown that the abatement of I/I can be cost effective (Cues, Inc., 1983). With this in mind, it appears that effective future collection system management strategies will almost certainly have a more "proactive" approach in comparison to the "reactive" approach observed over past decades.

2.3 Methods of Sewer System Rehabilitation

A variety of options for rehabilitation methods are available to the collections system maintenance engineer/manager. Each option has its advantages, disadvantages, and most effective uses. Generally accepted methods for collection system rehabilitation are discussed below.

1.) Replacement - three methods of replacing the existing sewer line exist (Sullivan and Ewing, 1985). They are:

   A) Spot Repairs - only a portion of a line is replaced.

   B) In-Situ Replacement - replacement of an entire run of line from one manhole to the next.

   C) Alternate Location Replacement - a new line is constructed in a location different from the original one.

   Replacement of sewer line is required when structural failure of the existing line has either occurred or is imminent. It is the alternative for those portions of the collection system that have suffered irreparable damage. The cost of replacement will vary depending on the location, size, and the depth of the sewer line.

2.) Slip-Line (Sullivan and Ewing, 1985; Municipal Construction Division, EPA, 1975; Joint Task Force, 1983) - sliplining is a method in which the sewer line is rehabilitated by placing a rigid liner inside the existing pipe. These liners are most often made of plastic or fiberglass and are flexible enough to accommodate small angle changes in the existing pipe. There are several criteria that must be met when considering slip-lining as an option. These include:

- The smaller diameter liner must accommodate the hydraulic loading of the enclosing line being repaired.
- Service lateral connections must be exposed and reconnected after sliplining is completed.
- Significant low or high areas in the line that will contribute to sedimentation and line blockage that slip-lining will not correct must be identified.
- Protruding taps or collapsed pipe sections that will prevent passage of a liner must be located and corrected before sliplining the pipe.
- The void space between the outside of the liner and the inside of the existing pipe needs to be filled with a supportive grout.
- Adequate room must exist at one end of the sewer line for the liner installation pit.

APWA (Sullivan and Ewing, 1985) has suggested that slip-lining technique is most effective when there is minimal structural instability and few service lateral connections to contend with. It is applicable where confined work space exists above or below ground.

3.) Inversion Lining (Sullivan and Ewing, 1985; Joint Task Force, 1983; Olson, 1985; Steketee, 1985) - this relatively recent development has gained acceptance in the sewer rehabilitation industry but like most other methods has situations where it is best suited and situations where it is not. Inversion lining, commonly called "Insitu-form", is a technique which uses a felt sleeve soaked with a temperature sensitive resin. The sleeve arrives at the site either refrigerated or packed in ice to prevent the catalyzing of the resin. Initially inside-out, the leading edge of the sleeve is attached to one end of the pipe or to a tower that extends above the manhole. As the rest of the sleeve is passed through the leading edge, cold water or air is introduced into the area between the sleeve which is inside out and the return part which is right side out. This process is illustrated in Figure 1. After the sleeve has passed through the entire length of pipe, it is attached to the other end and cut off. Hot water is then circulated through the line to cure the resin-felt combination. The result is a solid liner that is bonded to the inside of the pipe.

Some of the key points that must be addressed when considering inversion lining are:

- connection of service laterals,
- proper cleaning of line prior to lining to ensure adequate bond to the existing pipe walls, and
- structural instabilities.

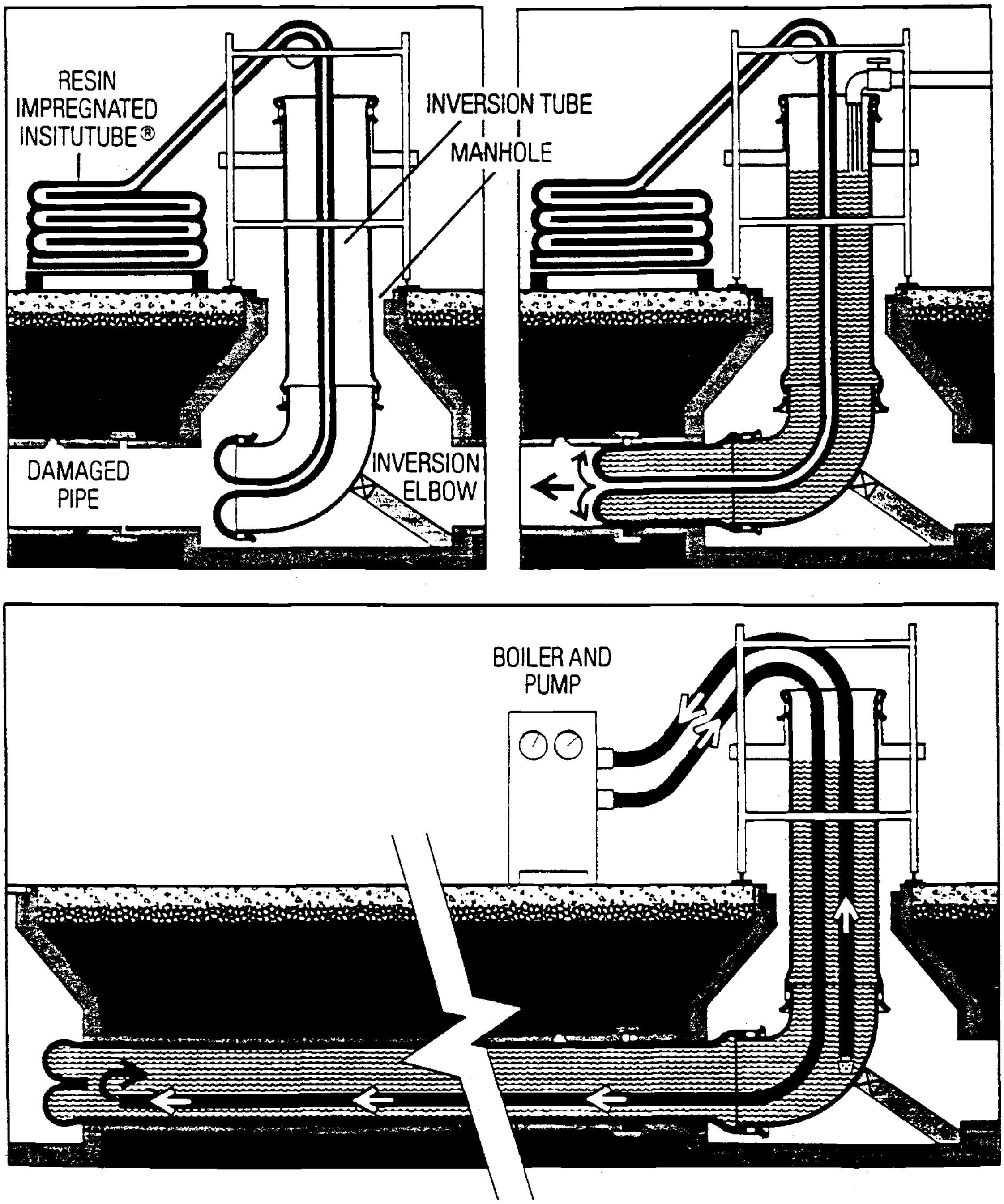


Figure 1 - Inversion Tube Lining Process

4.) Chemical Grouting - this is the most common of all the specialized methods of pipe rehabilitation (Sullivan and Ewing, 1985; Joint Task Force, 1983). This process will be explained in more detail in later sections but the basic process involves injection of a two-part chemical into the soil surrounding radially cracked pipes or leaking joints. When the two part reaction is catalyzed, the chemical sets up into an impermeable flexible solid, most often a gel or foam that prevents ground water from reaching the defect or bad joint and entering the sewer system.

As more and more attention is given to I/I control, new technologies emerge and go through the trial-modification - trial-acceptance process.

2.4 Chemical Grouting and Equipment

As previously mentioned, chemical grouting is the most commonly used method of sealing leaky joints in sewer lines that are structurally sound. The reported advantages from the ASCE manual of practice (Joint Task Force, 1983) are:

1) Chemical grout may be less expensive over the short term or long term depending on the life-span that is achievable by the particular application.

2) Since chemical grout is applied to the sewer line from the

inside, there is less disruption of traffic and less interference with underground utilities than would be experienced by excavation to replace or re-line the pipe.

3) Chemical grout can be applied relatively quickly as compared to other forms of rehabilitation.

Nevertheless, like all other rehabilitation methods, chemical grouting has its limitations. These limitations include (Joint Task Force, 1983):

1) Chemical grout does not improve the strength of the sewer line so it should not be used where structural failure has occurred or is imminent.
2) Due to physical constraints, the chemical grouting equipment can only seal leaking joints and radial cracks on small diameter pipes. Longitudinal cracking can not be grouted effectively.
3) Dehydration shortens the service life of chemical grouts. Additives to control shrinkage should be used when applying grout in arid regions.
4) In some cases, joints and cracks are not sealable by chemical grout because of large external soil voids surrounding the joint.

The majority of chemical grouts used in practice are gel grouts rather than foams. The selection of a gel over a foam is usually based upon ease of handling and cleanup. Of the gels in use, nearly all are the acrylamide-based monomer type. The following section summarizes the properties of chemical grouts that are available for sealing of sewer mainline joints, with emphasis on gels since they are the standard of the industry. (Joint Task Force, 1983)

2.4.1 - Acrylamide Monomer Gels (Karol, 1983) - The first chemical grout to be used extensively for sewer grouting was AM-9, acrylamide gel, introduced in 1955 by American Cyanamid. (Clark, 1982) This product was used extensively throughout the country until its withdrawal from the market in 1978. This action prompted the United States Environmental Protection Agency (EPA) to initiate a search for a replacement to AM-9, that resulted in several chemical companies entering the chemical grout manufacturing business. Today there are several acrylamide monomer grouts available, each with nearly identical properties.

Acrylamide monomer grout is provided as a crystalline odorless powder. When mixed with water, the grout solution has a viscosity and density near that of water and these properties remain virtually constant during the period of application before gelation occurs (Karol, 1983). After gelation occurs, the grout forms a stiff, rubbery gel that has an extremely low permeability (on the order of 10^{-10} cm/s). The grout is a two part mixture of acrylamide and a cross linking agent, such as methylene-bis-acrylamide. The acrylamide polymerizes into long molecular chains held together by the cross-linking agent. The weight ratio of acrylamide to cross-linking agent is normally 95:5 and most grouts are sold with this ratio being fixed. Variance in this ratio effects the stiffness of the grout (Karol, 1983). The grout is catalyzed by a two component redox system. The first component, called the catalyst or initiator, is usually a peroxide or persalt such as ammonium persulfate or sodium persulfate with the former being the most common. The second component, called the activator or accelerator, is an organic such as nitrilo-tris-propionitrile (NTP), triethanolamine (TEA), or dimethyl-aminopropionitrile (DMAPN). In some cases, an inhibitor is used to obtain a specific gelation time, such as potassium ferricyanide ($KFe(CN)_6$, which is abbreviated as "KFe" in some trade journals. Gelation time is independent of grout concentration but is a function of temperature as well as catalyst, activator, and inhibitor concentrations (Karol, 1983). The long chains formed from polymerization of the acrylamide molecules are capable of entrapping large amounts of water. In the resultant gel, water molecules are fixed by chemical forces within the polymeric matrix, thus forming an impermeable barrier to hydraulic transfer.

The principal advantages of acrylamide-based grouts are low viscosity during application and controllable gel time. One reason that gel grouts are favored over foam grouts is their lower shear strengths. This allows the annular ring of grout remaining on the pipe after grouting to be dislodged easily with the packer or later by cleaning equipment.

The principle disadvantage of acrylamide gel grouts is their toxic properties. Acrylamide monomer is a neurotoxin. Skin contact can cause redness and peeling. Repeated exposure can cause problems with the central nervous system. However, these grouts pose a health hazard only during application. The final gelated product is not known to be a health hazard. Toxicity problems are avoided by careful handling during the application stage.

The acrylamide based grouts generally exhibit the following properties:

1) Controllable reaction time of from 5 to 500 seconds.

2) Viscosity that remains constant throughout the induction period.

3) Ability to tolerate some dilution and to react in moving water.

4) Production of a continuous, irreversible, impermeable gel in the final reaction.

5) Gel that is not rigid or brittle.

6) Base compounds that may be varied considerably by additives to increase the strength, adhesion, solution density, and viscosity.

2.4.2 - Acrylate Polymer Grouts (Joint Task Force, 1983) - Acrylate chemical grout consists of a mixture of water soluble acrylate monomers and a small amount of methylene-bis-acrylamide as a crosslinking agent. The gel is formed by the free radical polymerization of the monomers in a two component, equal volume system much the same as the acrylamide monomer system described previously. The properties of the acrylate polymer grout are nearly identical to those of acrylamide grout except in their toxicity. Acrylate polymer grout has only one-hundredth the toxicity of acrylamide based grout. As with acrylamide grout, shrinkage under arid conditions is a problem that can be corrected by the addition of a shrinkage control additive such as ethylene glycol.

2.4.3 - Polyurethane Gel (Joint Task Force, 1983) - Urethane gel differs from acrylamide gel in that water is the catalyst for the grout. The gel is designed to react with and absorb water into the reaction mass. The weight ratio of water to grout can be varied to obtain different gel strengths but the ratio most often found in sewer pipeline sealing is approximately 8:1, although the exact ratio depends on the application of the gel. The gel is resistant to degradation from biological means and to most chemicals and solvents. Gel shrinkage is controlled by using shrinkage control additives in the water component of the grout.

Urethane based gel should have the following properties:

1) Gel forming reaction with water,
2) Controllable gelation time,
3) Low viscosity, pumpable liquid prior to gelation.

2.4.4 - Urethane Foam (Joint Task Force, 1983) - This grout is a liquid urethane, water reactive prepolymer, which when mixed with water, foams and then cures to a flexible, tough, and cellular rubber. The reaction is a two stage reaction, comprised of the "foam time" and the "cure time". Both the foam and cure times are temperature dependent. In general, higher temperatures promote shorter reaction times. An accelerator, 2 dimethyl-aminoethanol, which is a water soluble amine, is usually added to reduce the reaction times. The foam exhibits an expansive nature during the curing reaction, thus, cyclic wet/dry conditions do not appreciably affect the grout. When left unconfined during the curing process, the foam expands to 10 to 12 times its original volume. After the reaction has taken place, the rubber-like elastomeric gel acts as a gasket to seal the joint or crack itself, rather than rendering the surrounding soil mass impermeable as do the acrylamide and acrylate grouts. The grout is substantially resistant to most organic solvents, mild acids, and alkalies.

Urethane foam grouts generally exhibit the following properties:

1) Controllable cure time from 15 minutes at 40°F (4°C) to 5 minutes at 100°F (38°C) when reacted with water,
2) Steadily increasing viscosity during injection due to foaming and expansion.

2.5 - Grout Application

Chemical grouts are available to serve a variety of functions. Chemical grouts have been used to successfully rehabilitate sewer mainlines, manholes, and service laterals.

The procedures involved in proper application of chemical grouts require qualified technicians. The procedures described herein are for the application of an acrylamide gel-type grout. While other chemicals have slightly different application techniques, the acrylamide gels are the most widely used and therefore have been chosen for discussion.

The chemicals necessary to form the gel are usually mixed in two separate tanks and pumped through separate hoses to the point of application. The solutions are mixed as they are pumped into the opening of the defect. A chemical reaction is initiated that transforms the two liquid chemicals into a gel. The time required to form the gel can be controlled from a few seconds to several minutes by varying the catalyst concentration. The result is an impermeable mixture of soil and grout that prevents the passage of groundwater.

A diagram of the chemical grouting process is shown in Figure 2. As shown, a t.v. camera and grout packer are placed in the sewer line. As the camera and packer progress down the sewer line, joint locations are revealed with the camera. When the packer is centered on the joint, the inflatable rubber ends are pneumatically inflated to form a seal against the inside wall of the pipe and to isolate the joint. Next, an air pressure test is conducted to determine whether the joint is adequately sealed. Air is pumped into the void space between the two inflated sleeves of the packer. The joint being tested is "... adequate when a pressure equal to or greater than the maximum expected groundwater static head pressure can be maintained for a period of several seconds" (Municipal Construction Division, EPA, 1975). Most grouting contractors and municipalities contacted during this investigation have established a single pressure

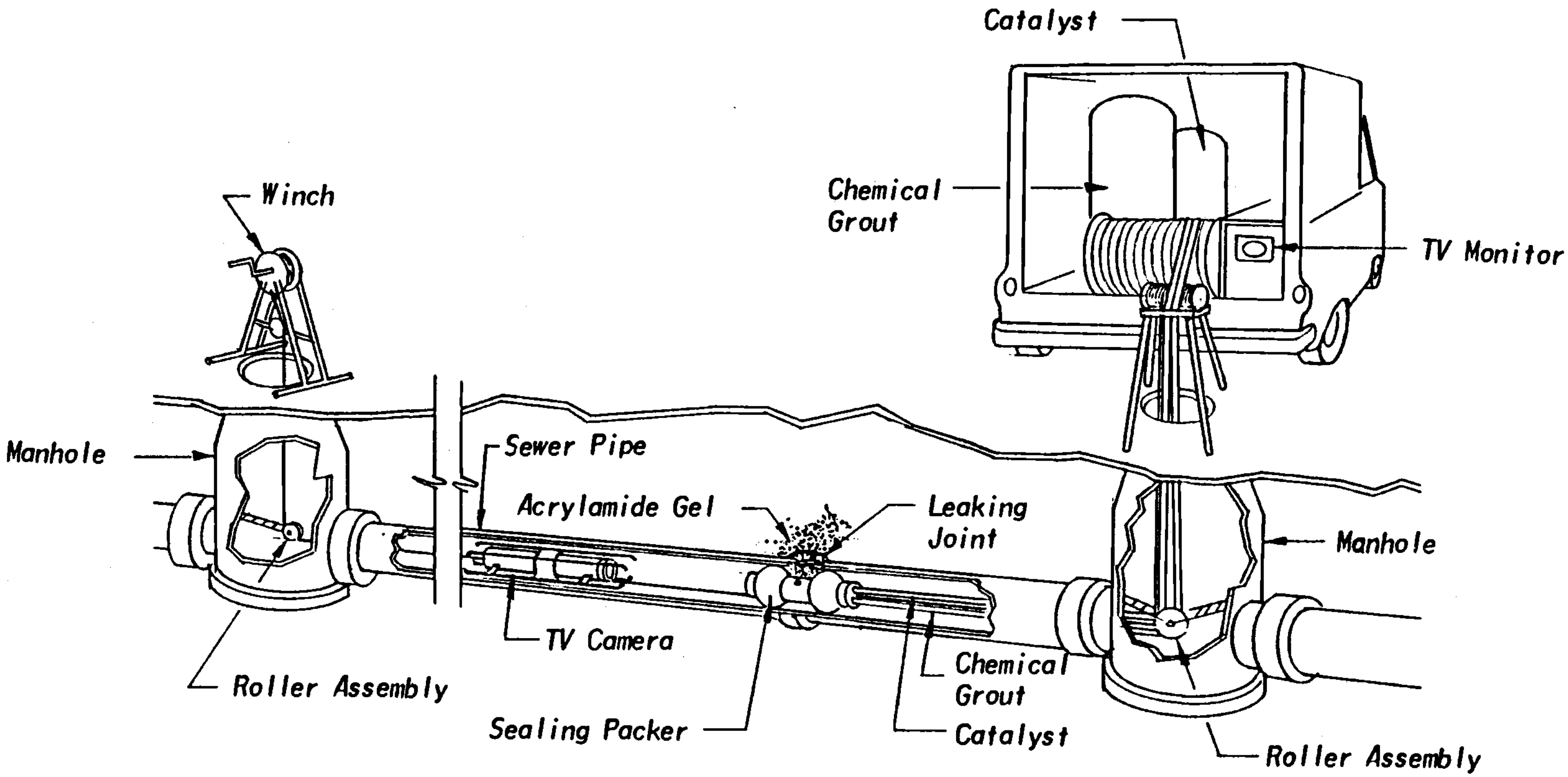


Figure 2 - Chemical grouting process

determined to sufficiently represent the maximum groundwater pressure over most of the system. This pressure varied between 5 psi (34.5 kPa) and 10 psi (68.9 kPa) gage, which represents static water levels above the sewer line of 11.5 ft (3.5 m) and 23 ft (7.0 m), respectively.

If a joint fails the air pressure test, then grout is pumped into the void space and forced out through the joint into the surrounding soil or trench material. After gelation occurs, another air test is conducted to verify that the joint has been sealed before moving the packer assembly to the next joint.

The movement and positioning of the camera and packer can be controlled remotely from within the mobile grouting van. Within this unit, a control panel containing all controls, pressure indicators, closed circuit T.V. monitor, and computer terminal can exist. Commercially manufactured grouting trucks have been available for several years.

As each joint is sealed, the information can be entered into the onboard computer and uploaded to the central data management system periodically. Pertinent information included in data management may include upstream and downstream manhole numbers, pipe length and type, date, footage of each tested and/or sealed joint, results of the air pressure test, and total gallons of grout pumped into each joint.

In recent years, the phenomenon of groundwater migration along the trenchline has been receiving more attention (see Groundwater Migration below). As a result, many grouting programs are applying the standard air pressure test to every joint in a line regardless of whether it shows evidence of visible leaking. In some pipetypes in Salem, Oregon that typically have a high percentage of leaking joints, a given amount of grout is pumped into every joint before an air test is conducted. If this procedure is used when grouting pipes that have been previously grouted, the ability of data analysis efforts to accurately determine the percentage of original seals that pass the air pressure test is eliminated. This can make accurate evaluation of past grouting effectiveness difficult.

2.6 - Effects of Subsurface Environment on Acrylamide Grout

The performance of the acrylamide grout is a function of several subsurface environmental factors including:

1) temperature,
2) pH,
3) sodium and calcium chlorides,
4) trench material,
5) soil moisture.

Temperature - The effects of temperature on grout performance are on the gel time. Recall from earlier discussion on acrylamide gels that gel time was a function of temperature and catalyst, activator, and inhibitor concentrations. Figure 3 and Figure 4 show the relationship between temperature and observed gel times for a 10% acrylamide based grout for

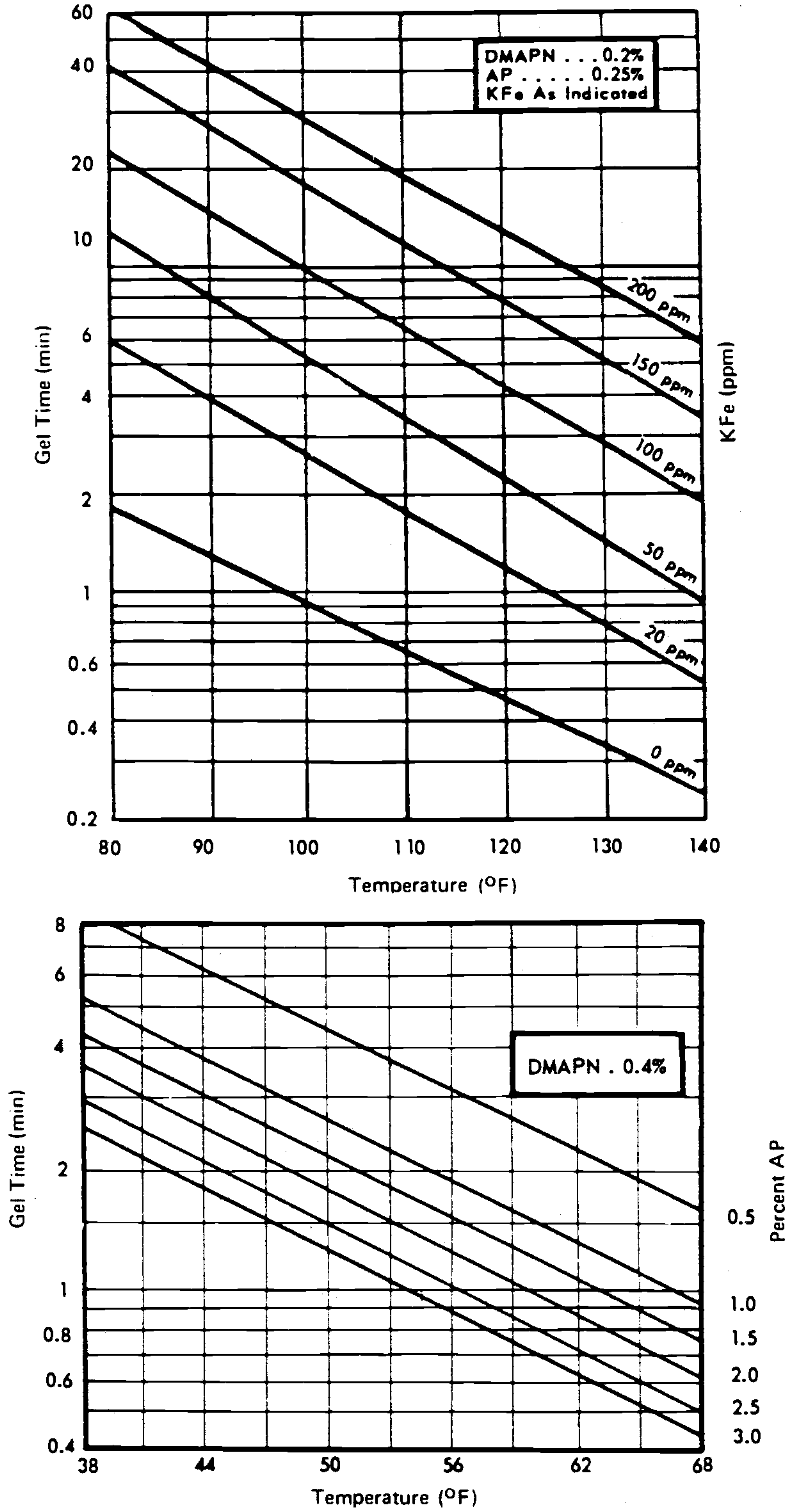


Figure 3 - Relationship between temperature and gel time for a 10% acrylamide based grout (Karol, 1983)

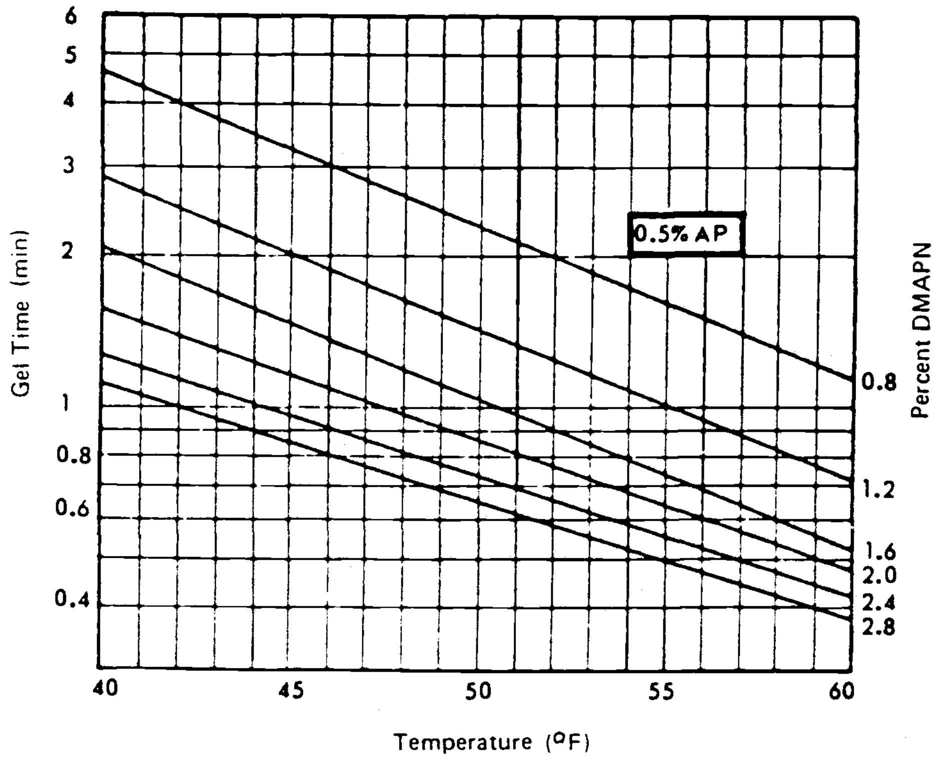


Figure 4 - Relationship between temperature and gel time for a 10% acrylamide based grout (Karol, 1983)

various concentrations of catalyst (Ammonium Persulfate, AP), activator (Dimethylaminopropionitrile, DMAPN), and inhibitor (potassium ferricyanide, KFe $(CN)_6$ or "KFe") (Karol, 1983). While temperature effects may be significant in lab scale tests, most soil temperatures range from 45°F to 55°F with very little seasonal fluctuation at the depth of most sewer lines (Thompson and Troeh, 1957).

pH - (Karol, 1983) Gel time control is achieved by maintaining the pH of the catalyzed grout solution between 8 and 11. While uncatalyzed grout solutions have a pH of 4.5 to 5.0, the average pH of catalyzed grout solutions is around 8.0. At higher pH values, the gel time is shortened while at lower pH values, the gel time is increased. If the pH of the soil environment is too low, gelation will be entirely prohibited. This is illustrated in Figure 5 (Karol, 1983). In most cases, ground water and ground formations do not cause a significant change in the pH of the grout solution. However, knowledge of the dependence of gel time on pH will aid in assessing the applicability of chemical grout to specific situations, such as pipe previously grouted with cement or pipe adjacent to chemical plant.

Sodium and Calcium Chlorides - In some cases, dissolved chemicals in the ground water may influence the gel time of a grout. This is especially true in the presence of sodium or calcium chlorides, which tend to shorten

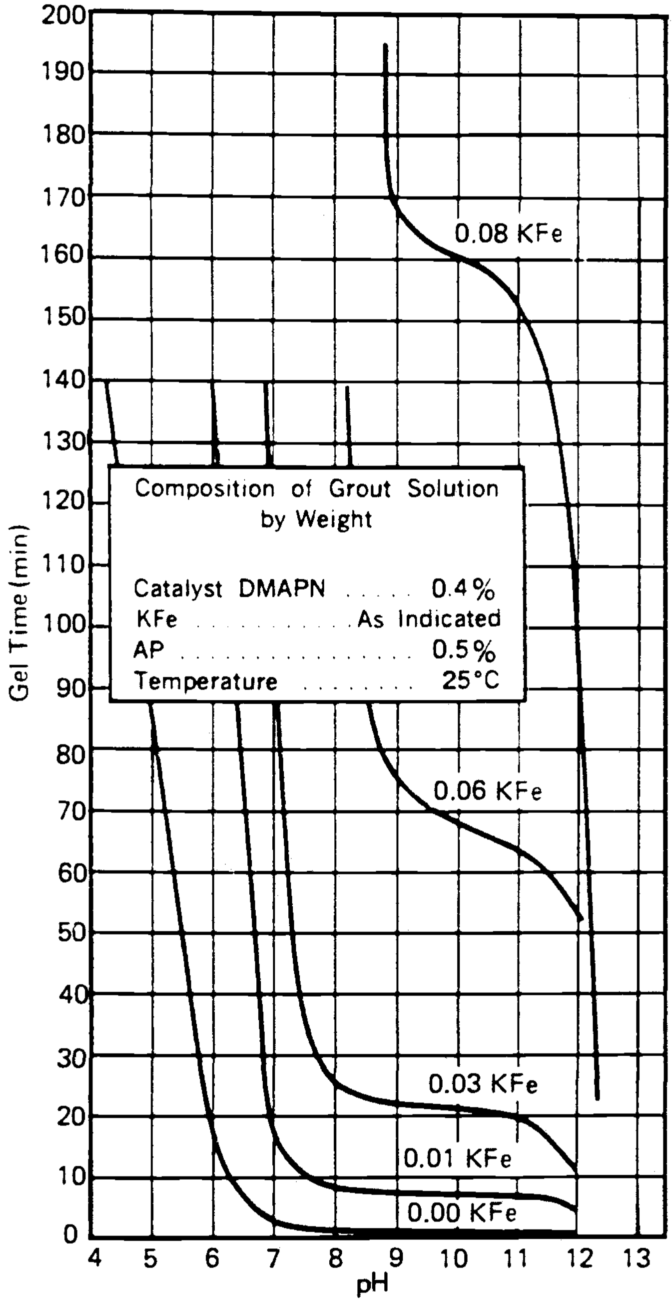


Figure 5 - Relationship between pH and gel time for a 10% acrylamide based grout (Karol, 1983)

gel times. In most cases, short gel times are acceptable, depending on the grain size of the medium to be grouted. The Water/Waste Water Division of Brevard County, Florida reported a poor success with acrylamide grout and noted that most of their sewer lines were under 18-20 ft (5.5-6.1 m) of salt-water. They experienced the grout showing up at the treatment plant as early as one year after placement. No conclusions were made as to what was causing this phenomena, but high chloride levels were suspected, as was high groundwater levels and application techniques. No documented research was found suggesting any dependence of grout longevity on chloride concentrations.

Trench Material - Considerable research has been done on the effects of grain size on the mechanics of chemical grouting by researchers at Rutgers University. In order to examine the effects of various grain sizes, it is important to understand the behavior of chemical grouts when they are injected into the soil.

When chemical grouting emerged, many of the practices were based on those practices that had previously been developed in the application of cement grout. Cement grouting is done in a batch process. When cement is mixed with water, a hydration reaction occurs and cement particles are bonded firmly together. Since it was required that the cement be mixed with water to facilitate its pumping, the hydration reaction was initiated in the mixing tank. Obviously, it was of paramount importance to pump all of the grout out of the tank before the set time elapsed. Because of the extreme consequences of not accomplishing this, a safety factor of usually 2 or 3 set times was allotted to the pumping of the mixed cement grout. The result of this was that the cement was in the ground and subject to the forces of moving ground water and gravity for quite some time before setting occurred.

After chemical grouts began to gain popularity, another factor began to play on the techniques of application. The grout was expensive and waste must be kept to a minimum, both above and below ground. Since any dilution and/or movement by groundwater or gravity would cause wasting of the grout, it became desirable to have the grout gel as soon as possible following injection into the soil. It soon became apparent that the old methods of batch mixing must be abandoned and mixture must occur at the point of injection so that gelation could be initiated as soon as possible. As the gel times became shorter than the pumping time, it was believed that at the instant of gelation, pumping would cease due to excessive pressures. However, it was found that this pressure refusal did not begin until several gel times had elapsed.

It was found through research (Karol, 1983) that as the grout penetrated the soil, it expanded in three dimensions so that the leading edges resembled a crude sphere. As the gel time was approached, the outside edge of the grout in contact with the groundwater would begin to set up, and, as it did so, rupture to allow the passage of the non-set grout in the interior of the sphere to pass through. This rupturing would occur in a finite number of places and several new spheres of grout would begin expanding from the original sphere. As the leading edges of these spheres approached their respective gel times, they would set and subsequently rupture and the process would start over.

Figure 6 shows a typical grout mass obtained by using a short gel time in fine sands; it illustrates the knobby shape resulting from the sequential spherical expansion process (Karol, 1983).

The development of gel times that were much shorter than the pumping time led to the observation that grain size of the grouted medium had a significant effect on the spherical expansion process and thus played an important role in the final shape of the stabilized mass. Figure 7 shows a vertical section through a stabilized coarse sand with a gel time longer than the pumping time. The lighter area is the location of the first half of grout, while the shaded area shows the location of the grout volume that was injected last. Figures 8 through 10 show the effects of grain size on the resultant shape of the grouted mass when the same grout is used but with a gelation time shorter than the pumping time. Figure 8 shows a vertical section in the same coarse sand as in Figure 7. Six flow channels can easily be seen. Figure 9 shows a vertical section through a stabilized fine sand; only two flow channels can be observed. The vertical section shown in Figure 10 is through a stabilized fine sand and silt. In this section only one flow channel was observed. Karol (1983) reported that laboratory

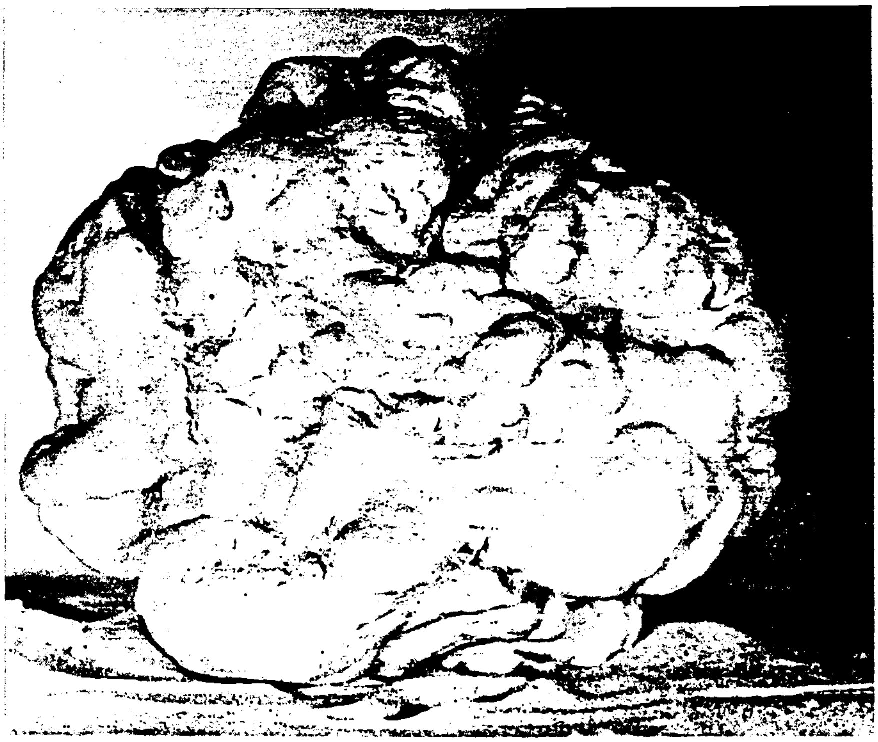


Figure 6 - Typical grout mass obtained using
a short gel time in fine sands (Karol, 1983)

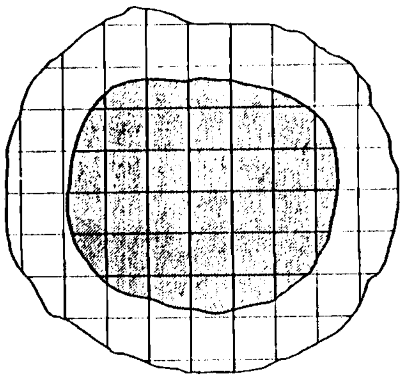


Figure 7 - Stabilized coarse sand with gel time longer than pumping time (Karol, 1983)

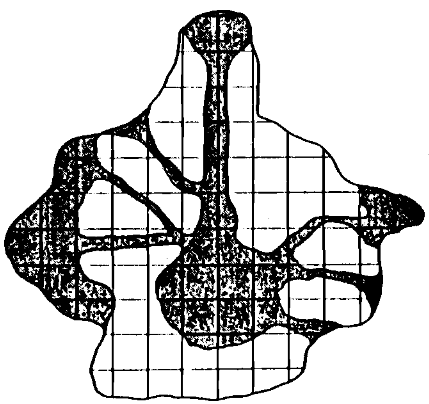


Figure 8 - Stablilized coarse sand with gel time shorter than pumping time (Karol, 1983)

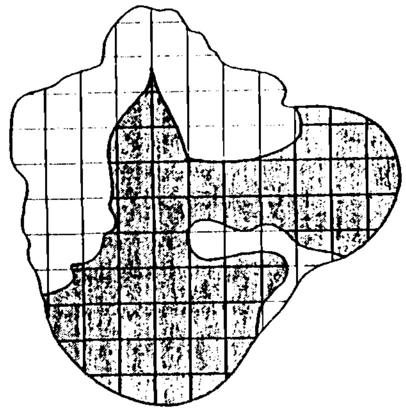


Figure 9 - Stabilized fine sand with gel time shorter than pumping time (Karol, 1983)

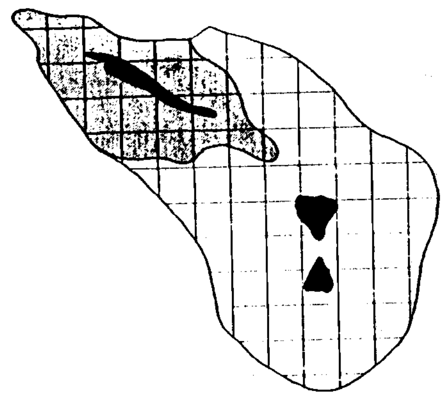


Figure 10 - Stabilized fine sand/silt with gel time shorter than pumping time (Karol, 1983)

evidence was conclusive and that there is a trend toward fewer breakthrough points as the grain size decreases. This implies that the shape of the stabilized mass will be more irregular in fine soils than in coarse ones. Since most sewer trenches are bedded with gravel, it is reasonable to assume that the grout will expand nearly uniform in all directions from its injection through leaking joints in sewer mains. When grouting in areas where it is suspected that fine soils have filled the voids of the gravel pipe bedding, or when grouting pipes in easements where granular backfill was not used, it may be helpful to realize that increasing the gel time will tend to result in a more ideal shape of the final grouted mass.

Soil Moisture - A critically important environmental factor that effects the performance of chemical grout is the soil moisture conditions. Since the grout is composed mostly of water (88% to 92% weight), the gel is subject to shrinkage under arid conditions (Karol, 1983). Shrinkage to less than 10% of the original volume is possible when the grout is exposed to long periods of dry conditions. Upon contact with water again, the grout will begin absorbing water and return to its original size (Karol, 1983). However, any shrinkage cracks that occurred during dehydration will reseal but not to be healed and the grout will be more permeable than before shrinkage occurred. As previously mentioned, additives are on the market to control water loss from the grout.

Seasonal variations in soil moisture and groundwater level can be measured by most municipal engineering divisions. When arid conditions may exist for long periods of time between wet, high groundwater periods, then a chemical additive to control shrinkage may be selected. In areas with periodic rainfall and low soil permeability, additives for shrinkage are most often unnecessary.

Adequate knowledge of the mechanics and chemistry of chemical grouting can be an asset to the successful chemical grouting program.

2.7 - Grout Longevity

A key consideration in rehabilitation of sewers by chemical grouting is the longevity of the grout seal. From a chemical and biological perspective, acrylamide gels are considered permanent. The gels are reported to be unaffected by exposure to chemicals, except for very strong acids and bases (Steketee and Beck, 1983). Tests on samples stored under saturated sands for 10 years were reported to have showed no loss in strength (Karol, 1983). Experience in the field has shown some variability in the physical integrity of grouted seals. Reported lifetimes for effective control of infiltration with chemical grout range from 1 year (Brevard County, Florida) to more than 20 years (Fort Meyers, Florida) in isolated repairs. Among the literature reviewed in this research project, no sources were found that presented average lifetimes for chemically grouted sewer main joints based on statistical analyses of large data bases. A statistical analysis was conducted during this research project on non-rubber gasket concrete pipes that had been grouted twice in the City of Salem, Oregon. Discussion of this analysis is presented in Chapter 4. The result of this analysis showed an average life for chemically grouted, non-rubber gasket pipe joints to be about 15.6 years ± 0.3 years for a 95% confidence interval.

2.8 - Measurement of Inflow and Infiltration (Municipal Construction Division, EPA, 1975; Sullivan and Ewing, 1985; Warburton, 1977)

Quantifying I/I flows is one of the most important steps in any program for the control of I/I into a sewer collection system. There are two methods to measure the I/I flows into a sewer system, direct and indirect.

Direct methods measure the pipe velocity at a given instant of time and use this together with an accurately determined area of the flow cross section to determine the pipe flow. Recent developments in electromagnetic and ultrasonic equipment have enabled convenient measurement of pipe velocity. Problems associated with this method of measurement include inaccurate measurement of depth of flow at high velocities, unrealistic estimates of sedimentation, and inaccurate estimates of average cross sectional area at high and low discharge. (Pisano, Watson, and Gerald, 1983)

Indirect methods normally include some method of measuring liquid level in the pipe and using a predictive formula such as the Chezy, Kutter's, or Manning's equation. All of these formulas require that parameters such as pipe slope, cross sectional dimensions, and roughness are known. Direct application of these formulas may lead to flow measurements that are substantially different than actual. This uncertainty can be reduced by using direct methods of flow measurements.

Pisano, Watson, and Gerald (1983) identified the value for flow calibration in decision making in I/I studies to increase the accuracy of recorded flow measurements.

One method of I/I measurement which is not included in the direct or indirect methods is measurement of wastewater characteristics, such as BOD. By this methodology, changes in the wastewater characteristics can be used to imply that dilution by I/I is occurring. If the value of the wastewater characteristic that is expected is accurately known, then a mass balance can be used to estimate the magnitude of I/I. This method is subject to error due to natural or industrial variations in wastewater characteristics, sampling procedures, etc.

2.9 - Flow Monitoring

The degree and location of I/I flows are best determined by establishing a flow monitoring program. This can range from low intensity flow monitoring where only flow data from the wastewater treatment plant is used, to high intensity flow monitoring where monitoring continues year round at key manholes throughout the sewer collection system. Instantaneous flow measurements in the sewer system can be made manually with weirs or dipsticks. Automatic monitoring for continuous measurement can be made with electronic equipment, either storing flow data on-site or electronically transmitting the data to a centralized location. The intensity of the flow monitoring program depends on the degree of detail desired. Monitoring the flow at the treatment plant reveals information about the collection system as a whole. Monitoring at key manholes within the system reveals information about specific areas.

The detail of information required from flow monitoring about specific areas depends on the purpose of the evaluation. If the program is in the initial evaluation stage to determine whether I/I is excessive or not, it may be sufficient to monitor flows at the treatment plant or a few selected manholes on large interceptors. However, if the purpose of flow monitoring is to determine the effectiveness of rehabilitation efforts it may be necessary to conduct a more intensive flow monitoring program, measuring flows at many key manholes throughout the system.

2.10 - Groundwater Migration

The success of sewer system rehabilitation has not always been as good as that projected by the sewer system evaluation survey (SSES). These shortcomings of the SSES were recognized in an in-house report by the Municipal Constructions Division of EPA in 1981 (Conklin and Lewis, 1981). The principal indication of the poor success was the difference between the projected post-rehabilitation sewer flows and those actually observed.

Less than projected flow decreases were at least partially attributed to ground water migration. Groundwater that was prevented by rehabilitation from infiltrating into the sewer system at one defect migrated to another non-rehabilitated defect that had previously shown no visual signs of leaking.

The Washington Suburban Sanitary Commission (WSSC) conducted a study in an attempt to quantify the effects of groundwater migration and develop a model to predict the extent to which groundwater migrates from rehabilitated sources to unrehabilitated sources (Greenwood and Kingsbury, 1979). A brief summary of the study is presented here.

Two representative, residential sites were selected suitable for monitoring sewer flows and groundwater levels. Flow data were taken during rehabilitation of the two areas in the spring of 1983. The data were analyzed to determine the effects of rehabilitation on flow reduction from individual sources, manhole to manhole sewer line sections, and mini-systems made up of several line sections. The conclusions of the study, presented here, are taken directly from the report (Greenwood and Kingsbury, 1979).

> "Migration of infiltration from rehabilitated to non-rehabilitated sources was documented at both sites. The extent of migration was primarily dependent on the number of rehabilitated sources and their location, and the differences in permeabilities between trench material and surrounding soil. Results of the migration study exhibit important implications for future cost-effectiveness analysis and for determining the susceptibility of an area to migration."

Systems identified in the report that are susceptible to significant groundwater migration include:

1) Systems constructed at or near the groundwater table where changes in hydraulic head due to rehabilitation are significant.
2) Systems located in topographically sloping areas where water movement is primarily in the trench.
3) Systems located in areas of low permeability where the permeability of the trench is substantially higher than the surrounding soils.

Since the susceptibility of groundwater migration effects the overall success of rehabilitation, careful consideration should be given to this area when determining the cost effectiveness of rehabilitation and choosing the rehabilitation methods to be used.

2.11 - Service Lateral Connections

In the past two decades, several sources have identified the contribution of I/I through service lateral connections as being of major importance (Rugaard, 1989; Steketee, 1985; Joint Task Force, 1983; Conklin and Lewis, 1981; The Eastshore Consultants, 1986). Reported estimates for percentage of service lateral contribution to total I/I range from 0 to 95 percent with a mean of 35%. Service laterals (also called building sewers) are those sections of pipe, usually on private property, that carry sewage from houses, businesses, and industries to the public sewer. A typical service lateral is shown in Figure 11.

Service laterals represent a substantial portion of the entire collection system. For the municipality to assume maintenance responsibilities of these lines would represent an increase in costs as well as an increased work load. For this reason, many municipalities have ordinances that require that either a portion of or the entire service lateral be maintained in proper working order by the property owner. Enforcement of these ordinances is often difficult or ineffective.

Another problem concerning the maintenance of service laterals is that effective inspection equipment has only recently been developed and repair equipment is still in the trial process. This leaves many property owners or municipalities with only one option: replacement. This cost can range from $500 (Steketee, 1983) to $2700 (The Eastshore Consultants, 1986) depending on the geographic location, depth of the line, proximity to underground utilities, and ground-surface conditions (asphalt, landscape, sidewalks, etc.).

The migration of groundwater following rehabilitation of the sewer mains in many cases causes more water to enter through defects in service laterals than was previously measured. A follow-up investigation of the SSES effectiveness in 12 cities around the United States showed service

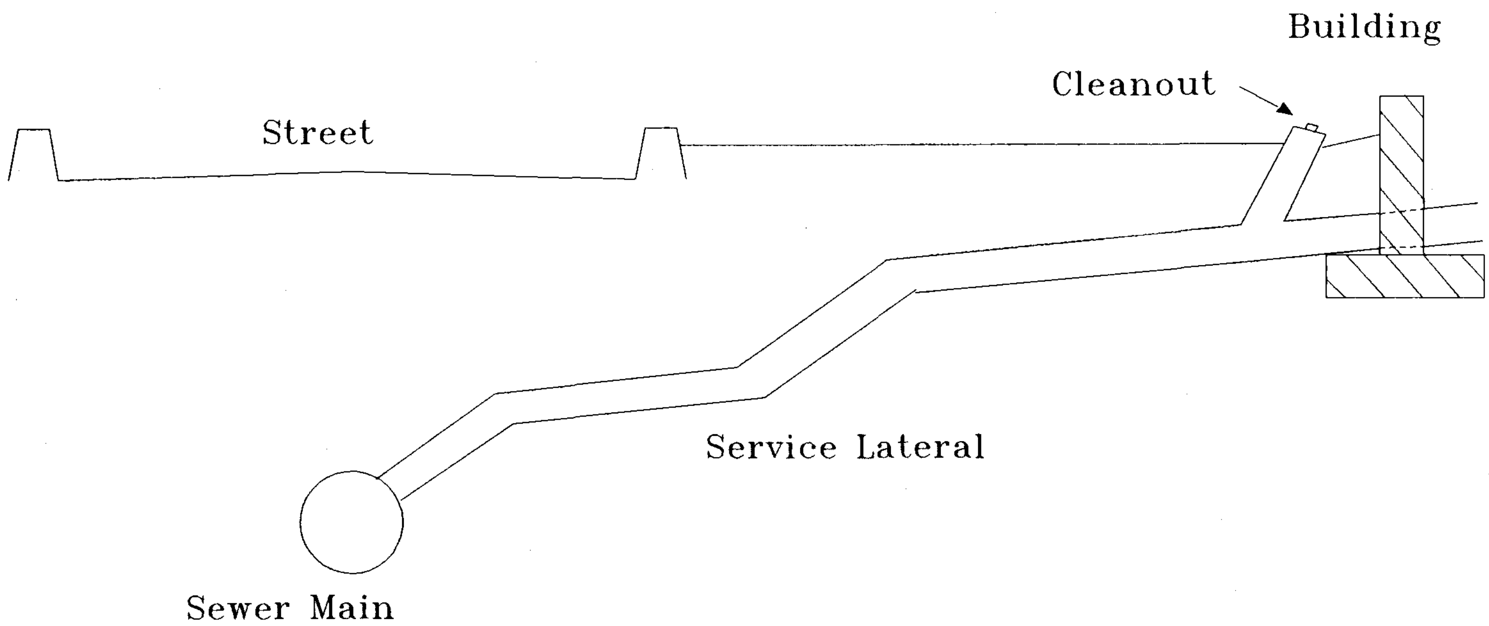


Figure 11 - Typical house service lateral configuration

lateral connections contributing 37% of the total I/I flows before mainline rehabilitation and 40% of the original total flows after rehabilitation. The study showed an increase of I/I through service laterals of 6% after rehabilitation of the sewer mainline (Conklin and Lewis, 1981). A study conducted in the City of Salem, Oregon by Westech Engineering in 1981-82 revealed that many service laterals leaked most within 3 to 5 feet (0.9 to 1.5 m) of the connection with the main sewer (Steketee, 1985).

Recent technological developments in testing, inspection, lining, and sealing equipment may reduce the potential costs for rehabilitating service laterals. Because of the significance of I/I through service laterals, it is becoming widely accepted among the sewer industry that this subject deserves attention when implementing a comprehensive I/I abatement program.

CHAPTER THREE

RECOMMENDED ELEMENTS OF A COMPREHENSIVE SEWER SYSTEM REHABILITATION PROGRAM

This chapter presents the recommended elements of a comprehensive sewer system rehabilitation program. It is based in a review of the literature pertinent to this subject (EPA reports, refereed journal articles, and other selected reports) but was also influenced by information gained in interviews with municipal public works employees in selected cities around the U.S.. Only those aspects of sewer system rehabilitation that are believed to result in a more effective approach to I/I control are presented.

3.1 - Establishing the Importance of I/I Control

Once the magnitude of the I/I problem has been quantified, it is essential to establish the importance of I/I control with public works personnel, the public, and governmental organizations which influence the financial and other resources available.

Establishing the importance of I/I control and informing all managers, engineers, technicians, contractors, and laborers of the full spectrum of the I/I problem can result in a more efficient, higher quality rehabilitation program (McDonald, 1990; Jellison, 1990).

Public support of sewer system rehabilitation can vary depending on how well the public is informed. Lack of an effective public relations program can decrease public awareness, interest, and support of the need to maintain the sewer collection system. In cases where the public has been kept well informed of the problem and the progress and decisions made in its solution, they have generally been more tolerable of the increased financial resources required to comprehensively rehabilitate the system (Rugaard, 1989).

Obtaining funds to effectively finance a comprehensive preventative maintenance and rehabilitation program is a major obstacle in many municipalities (McDonald, 1990). Those reporting that adequate funds have been provided by local government have also been successful in establishing the importance of I/I control with the funding entity, and the financial consequences of not controlling it. In Baton Rouge, Louisiana, such information has been reported to be the most "powerful tool" of the collection systems manager for obtaining funds for rehabilitation (Smith, 1990).

3.2 - Prioritizing Areas for Rehabilitation by Basin

Many municipalities that are just beginning to respond to the rehabilitative needs of their collection system are identifying the priority areas by reports of line blockages. Where frequent line blockages occur, interest is focused. Other municipalities that have advanced past this reactive stage of management use flow monitoring to determine areas where rehabilitative efforts should be focused.

A management strategy that has been proven effective is separation of the sewer collection system into discrete areas where limited flow paths exist across the area boundary (Sullivan and Ewing, 1985; RJN Environmental Associates, 1988; Steketee, 1985). These areas are most often referred to as basins. A sewer collection system basin is much the same as a river drainage basin. Several small service lines feed into fewer but larger mainlines which feed into still fewer but larger trunk lines. Basin boundaries can be established such that only one major line crosses the boundary which carries all flows generated within that boundary. Basins can be divided into smaller sub-basins, each with the same functional characteristics defining a basin. Furthermore, sub-basins can be divided into mini-systems. The exact size of basins, sub-basins, and mini-systems varies depending on labor and equipment resources, financial resources, topography, pipe type, subsurface soil conditions, and perhaps other factors. Reported sizes range from 3,000-6,000 lineal feet (914 - 1829 m) of sewer for mini-systems to 3-16 lineal miles (4.8-9.9 km) of sewer for basins (Sullivan and Ewing, 1985).

The effect of separating the collection system into these discrete basins and sub-basins is an increased ability to prioritize the entire system in terms of the degree of I/I which is being generated in each area. By identifying those key areas which are the largest contributors of I/I flows, it is possible to concentrate the rehabilitation efforts on the worst problem areas first.

An important factor in making the prioritization process reliable is the existence of an adequate flow monitoring program that can accurately determine areas of excessive I/I. An effective flow monitoring program allows engineers and technicians to determine the priority areas based on measured flows.

Another advantage of discretizing the system is that rehabilitation work can proceed incrementally in steps that match the available resources (budget and personnel). The process of separation, monitoring, and prioritizing is a prelude to a systematic, organized approach to collection system rehabilitation that proceeds through the entire system in a step-wise manner, beginning with those areas with the highest priority.

3.3 - Comprehensive Rehabilitation

Several studies have demonstrated that a comprehensive systematic approach to collection system rehabilitation is the most effective method of decreasing I/I flows (Sullivan and Ewing, 1985; RJN Environmental Associates, 1988; Steketee, 1985; The Eastshore Consultants, 1986; Conklin and Lewis, 1981). By implementing a comprehensive approach to rehabilitation, budgeted funds, equipment, and the labor force can be effectively utilized. Furthermore, public opinion has been favorable (Rugaard, 1989; RJN Environmental Associates, 1988) when the collection system was divided up so that total rehabilitation of each priority area could be completed in the shortest time possible.

From a review of the available literature on successful rehabilitation projects it was concluded that complete rehabilitation of smaller areas was more effective in controlling I/I than partial rehabilitation of large areas (Steketee, 1985; RJN Environmental Associates, 1988). A comprehensive rehabilitation program addresses all elements of the sewer collection system, including interceptors, trunk-lines, main lines, manholes, pump stations, and private (building) service laterals.

3.4 - Flow Monitoring

As previously mentioned, flow monitoring is the most effective method of quantitatively determining the effectiveness of collection system rehabilitation. However, the ability of a flow monitoring program to accomplish this goal is dependant upon the establishment of a systematic, step-wise approach. System change can not be quantified by a single descriptive examination of the system at one point in time. Change can only be determined by the comparison of descriptive parameters measured over a period of time. Total rehabilitation effectiveness is best determined by having a continuous flow monitoring record for a sufficient amount of time before and after rehabilitation. To compare the effectiveness of various methods of rehabilitation, it is also necessary to have continuous flow monitoring during rehabilitation.

The intensity of the flow monitoring program is important when attempting to evaluate rehabilitation effectiveness. Monitoring only the flow at the treatment plant may not reveal noticeable changes in I/I flows depending on the size of the system, the size of the area rehabilitated, and the magnitude of the I/I flows eliminated.

Flow monitoring can be too detailed or localized such that its reliability is reduced. Measured I/I flow reductions from individual sources does not necessarily indicate that the measured reduction was prevented from entering the system entirely. Concluding that the observed flow reduction was prevented from entering the system can lead to unrealistic predictions of effectiveness due to groundwater migration effects.

Successful flow monitoring programs are those that monitor the system by basin, sub-basin, and mini-system (Sullivan and Ewing, 1985). By conducting flow monitoring in this manner, the flow through key manholes draining an entire system can be used as a check for all flows measured within the system. Balancing flows in this manner verifies the accuracy of flow monitoring equipment as well as identifies the effects of groundwater migration. Sullivan and Ewing (1985) reported that while key manhole monitoring is initially much more expensive than single point flow monitoring, in most cases it will be the most economical approach because of the time saved in knowing where the intact areas of the system are located.

Another factor which affects the reliability and accuracy of flow monitoring data is calibration of the flow monitors. Pisano, Watson, and Gerald (1983) determined that the conventional use of Manning's equation (which assumes steady state, uniform, open channel flow) in relating stage records to discharge, without calibration of the flow monitor prior to data collection, could lead to gross estimation errors in the discharges over all flow regimes. This can result in erroneous cost estimates regarding sewage treatment and transportation, and subsequent rehabilitation recommendations. The added expense of calibrating flow monitors prior to implementation could save the government "valuable resources."

Sedimentation, surcharging conditions, non- standard flow cross-sections, and inaccurate estimates of pipe slope and roughness, can cause errors in calculating pipe discharges using Manning's equation.

Data management which preserves the descriptive integrity of the flow monitoring data should be utilized. By analyzing the long term change in sewage flows, the effective lifetimes of various rehabilitative efforts can be quantified and the most effective methods identified.

The flow monitoring program can prove useful in determining cost savings from measured flow reductions. By knowing the amount of I/I eliminated and the treatment costs for extraneous water entering the system, the cost savings for eliminating that portion of I/I can be compared to the costs of the rehabilitation. Savings are also realized in reduced system capacity required (i.e. It may not be necessary to expand sewage treatment plant to accommodate larger flows). These cost savings can be used to establish the economic value of sewer system rehabilitation with budget committees.

Sewer flow variations are an indicator of the collection system integrity and reporting the successes of I/I reduction to concerned parties (laborers, technicians, managers, engineers, local government, and the public), can create a feeling of optimism and increased support for the program (Smith, 1990).

3.5 - New Ideas in Successful I/I Control Programs

Conklin & Lewis (1981) assessed several sewer system evaluation and rehabilitation projects funded by EPA Construction Grants across the U.S., and found that several deficiencies existed in the standard EPA sewer system evaluation surveys. The findings of the report are listed below.

1) The EPA I/I program was implemented to eliminate excessive I/I - generally this has not been the case.
2) Post-rehabilitation infiltration/inflow are exceeding treatment plant design I/I flow components.
3) House service connections and non-rehabilitated pipe joints are the major sources of returning I/I from rehabilitated sewer reaches.
4) Removal of excessive inflow was apparently not any more successful than infiltration removal.
5) The major elements of the I/I methodology are imprecise.

The Washington Suburban Sanitary Commission (WSSC) recognized the shortcomings of the Sewer System Evaluation Surveys (SSES) and together with RJN Environmental Associates, Inc. developed what they called a National Alternative Methodology (NAM) to the traditional sewer system evaluation survey. The NAM resulted from experience and expertise gained in an innovative rehabilitation project on two priority areas in the WSSC system. A summary of the new alternative methodology is taken from the final report to WSSC by RJN Environmental Associates, Inc. (RJN Environmental Associates, 1988):

> This new methodology addresses every aspect of I/I, from evaluating its magnitude to deciding to start an investigation to monitor the system. The methodology recognizes the realities of limited budgets and the resulting necessity of prioritizing work. Finally, it is applicable to systems of all sizes, and may be implemented manually, although computerization is recommended for large systems.

This approach is based on the theory that each sewer system has its own unique "personality" that influences the effectiveness of rehabilitation methods and strategies. Similarly, within a single sewer system, smaller subsystems have their own unique "personalities." "Since certain system personalities behave similarly, personalities can generally be compared and defined where pipe type, joint material, and other accepted grantee requirements are similar." (Sullivan and Ewing, 1985). This National Alternative Methodology is considered by APWA to be an example of the recent trend toward a more progressive approach to sewer collection system maintenance and management.

3.6 - Data Management

Computerized data management systems are now available commercially that allow municipalities to create a management system which is tailored to their specific needs.

Recent developments in this area include: computerized field entry of data, computer mapping, and digital picture recording.

Computerized field entry of data eliminates the time consuming task of data transfer at the end of the day or week. With the time saved using this technology, more effort can be exerted to the actual collection system rehabilitation.

Computer mapping has immense potential to combine the precision and detail for sewer system layout required by engineering staff with the frequency and immediacy for location information required by maintenance staff. Conventional map books are typically bulky and damage easily. The advantage of computer mapping systems are their ability to be updated almost immediately when new information becomes available from field staff or when new subdivisions and main line extensions are constructed. The disadvantage of computer mapping systems is the initial high cost to convert the physical map information to computer memory.

The technology of digital picture recording systems allows the operator of a tele-inspection unit to record, in digitized computer memory, images of joints, service lateral connections, and pipe defects. When reviewing the condition of a particular line, the stored picture can be recalled for visual examination on the computer screen.

While advances in computer science have the ability to enhance the manageability of a collection system, care should be taken when selecting which system to implement. Systems that are not adaptable to specific needs of the municipality should be avoided. Systems that utilize standard hardware can be more cost effective when upgrading the system or when replacing components. It should be realized that some flexibility may have to be sacrificed for operational superiority. A computer management system should be selected for its ability to meet the current as well as future needs of the municipality and for its adaptability to specific tasks.

3.7 - Evaluation of Rehabilitation Techniques for Increased Program Effectiveness

Adequate data collection and management practices can lead to the establishment of reliable self-evaluation of various methods of rehabilitation. To accomplish this evaluation, key parameters must be selected <u>before</u> data collection begins. Selected parameters should be of two types which will be described herein as "dependent" and "independent" variables with examples given in the context of chemical grouting.

Dependent variables indicate the performance of the collection system or rehabilitation efforts and are the variables which should be continuously analyzed for changes over time. Examples of dependent variables in chemical grouting include:

- percentage of total joints passing the standard air pressure test
- percentage of previously grouted joints passing the standard air pressure test
- chemical grout usage per foot of pipe length
- chemical grout usage per joint
- lifetime of grouted joints
- sewage flow measurements

Independent variables are factors which influence the behavior of dependent variables. Two types of independent variables are presented here, referred to as "Type 1" and "Type 2" independent variables. Type 1 independent variables represent conditions that describe what has been previously referred to as the collection system "personality". Examples of Type 1 independent variables include:

- rainfall data
- groundwater levels
- service lateral conditions
- soil type
- depth of sewer line
- age of pipeline
- pipe/joint type

- years in service of chemically grouted joints

Type 2 independent variables represent factors that effect the collection system performance that are manageable by procedures used for rehabilitation. Examples of Type 2 independent variables include:

- equipment/chemicals/procedures used in grouting
- crews conducting grouting

Changes in the dependent variables over time are reflected in changes in the independent variables. By continuously monitoring the dependent variables and recording the independent variables, the relationships between the two can be determined. The independent variables should be adjusted, when possible, to enhance the program effectiveness. When the independent variables are fixed; such as soil type, pipe/joint type, depth of line, and age; an evaluation of the effectiveness of grouting under a specific set of conditions can be made.

The parameters selected as independent and dependent variables may vary between municipalities or areas within collection systems depending on the system "personality" and the rehabilitation methods.

3.8 - Effective Chemical Grouting

From a review of successful rehabilitation studies, a methodology was developed for successful I/I control through chemical grouting. This methodology contains important elements of a progressive rehabilitation program.

The first step in the methodology is problem identification. This is accomplished by adequate flow monitoring. Flow monitors are set up in key manholes throughout the system and those basins with excessive I/I are identified. The next step is problem isolation. After a basin with excessive I/I has been identified, the sub-basins within it are monitored to isolate only those areas within the basin that are contributing to the excessive I/I flows (this could range from 1 or 2 sub-basins up to the entire basin). Following problem isolation, the next step is prioritization of problem areas. A priority rating is given to each basin with excessive I/I that reflects the degree of I/I present as well as other factors such as accessibility, population served, work required to eliminate I/I, etc. The role of t.v. inspection data is important in all of the steps mentioned above.

The next step is to select the area to be rehabilitated. A cost estimate for total comprehensive rehabilitation for each area should be made, as well as an estimate for the length of time necessary for rehabilitation to be accomplished. Based on the financial and labor resources of the municipality, an area is selected for rehabilitation. This area may include a single sub-basin, several sub-basins, an entire basin, or several basins, depending on the degree of rehabilitation that is necessary, the operating budget, and the availability of labor and equipment.

After the areas for rehabilitation have been selected, a t.v. inspection of all lines within the area should be made (if recent inspection data do not exist) to determine the extent of repair necessary. Inspection of service laterals should be included in this step.

Following preliminary t.v. inspection, rehabilitation work should progress in stages. Replacements, linings, spot repairs, and service lateral repairs/replacements should be completed before grouting occurs. By grouting last, leaks due to groundwater migration can be detected and repaired during grouting, and internal t.v. inspection of service lateral connections and spot repairs can be accomplished simultaneously. The limiting size of an area to receive other rehabilitation methods before initiating chemical grouting is dependent upon the extent to which groundwater migration is estimated to occur. Another advantage of grouting after other repairs are completed is that grouted joints will not be disturbed by nearby excavation.

Continuous monitoring of flows should remain throughout the period of rehabilitation to evaluate the effectiveness of individual rehabilitation techniques and to identify the extent of groundwater migration. If groundwater migration is significant, then rehabilitation methods conducted first may appear to be the least successful and those conducted last may appear to be the most successful in reducing I/I flows. A final t.v. inspection and updating of data bases should be conducted following completion of rehabilitation. Remaining defects should be repaired. The final inspection is most effectively conducted during periods of high groundwater levels. However, it may be of greater importance to conduct the final t.v. inspection before resurfacing streets or relandscaping yards to avoid excavation of new pavement or new yards should further repairs be necessary. The entire rehabilitation of a single area may require several stages of repairing, inspecting, and monitoring.

Post rehabilitation flow monitoring is vital to program evaluation. Accurate assessment of overall or specific rehabilitation program effectiveness is precluded without this information. Long term, post rehabilitation flow monitoring is useful in determining effective longevities of various rehabilitation efforts and for determination, isolation, and prioritization of future work.

Well documented records of grouting data should be continuously collected, stored, and periodically analyzed so that changes can be made when necessary to continuously improve the program effectiveness.

CHAPTER FOUR

ANALYSIS OF CITY OF SALEM'S GROUTING PROGRAM

4.1 - Overview

The City of Salem, Oregon has a population of about 100,000. An additional 56,000 are contained within the city's urban growth boundary. The entire population has been served by Willow Lake Wastewater Treatment Plant since its construction in 1984 in Kiezer, a suburb of Salem.

The structure of the Salem's Public Works Agency is shown in Figure 12. The maintenance of the sewer collection system is the responsibility of the Wastewater Collection Division, which is one of five divisions of the Operations Unit. The Facilities Engineering Division acts as an in-house consulting service for the Customer Service, Street, Water, and Wastewater Collection Divisions. It is the responsibility of Facilities Engineering to conduct flow monitoring and make recommendations to Wastewater Collections as to which areas of the collection system exhibit high I/I flows and are in need of further investigation. Furthermore, Facilities Engineering is responsible for pollution control, utilities inspection, technical support, engineering support services, long range planning, capital improvement projects, and computer management support.

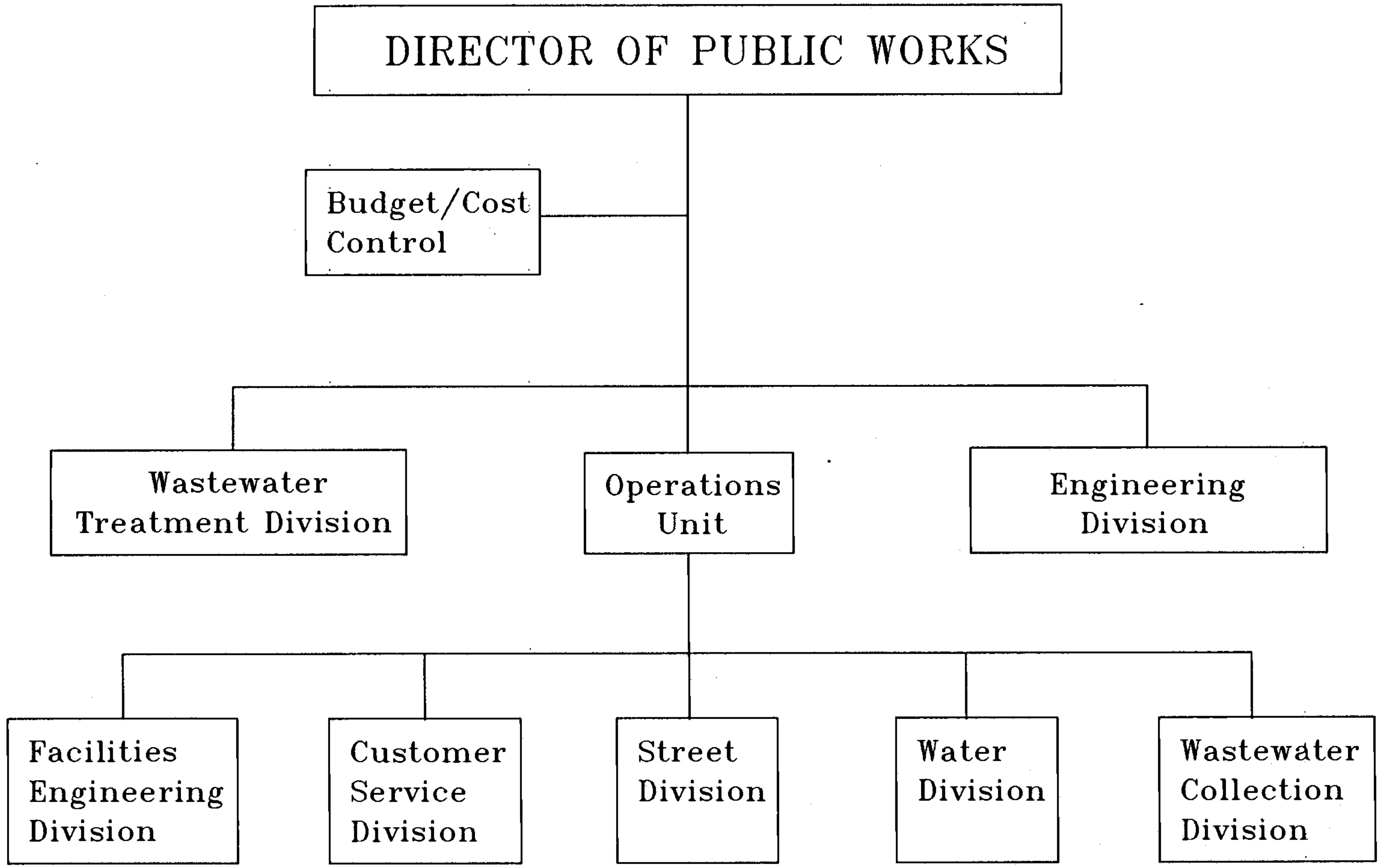


Figure 12 - Structure of Public Works Department, city of Salem, Oregon

Salem's wastewater collection system is mostly constructed of concrete pipe with vitrified clay pipe being about 3% of the system. The age of the collection system ranges from new to over 100 years, with the majority being around 50 years. Most flow is by gravity with about 30 pump stations providing lift where needed. There are about 600 miles (966 km) of sewer mains, 13,768 manholes, and nearly 49,000 service lateral connections. The wastewater collection system and the storm sewer system are separated, except for isolated locations.

Salem's I/I problem is not unlike most cities in the pacific northwest. During the wet months of the year, the groundwater levels rise above that of the sewer lines. A head of water develops, forcing water in through cracks and bad joints in pipes, manholes, and service laterals. A graph of the total monthly rainfall recorded at the Public Works Field Office and average monthly sewage flows recorded at Willow Lake Treatment Plant is shown in Figure 13. As can be seen, the flows peak during winter and spring months when rainfall is heaviest and groundwater levels are presumed highest.

Past rehabilitation studies in the City of Salem have shown that groundwater levels serve as a reliable indicator of the potential for infiltration to occur (Steketee, 1985). From a hydrologic perspective, groundwater level measurements provide a better indication of infiltration potential than do rainfall records since no consideration of storm intensity

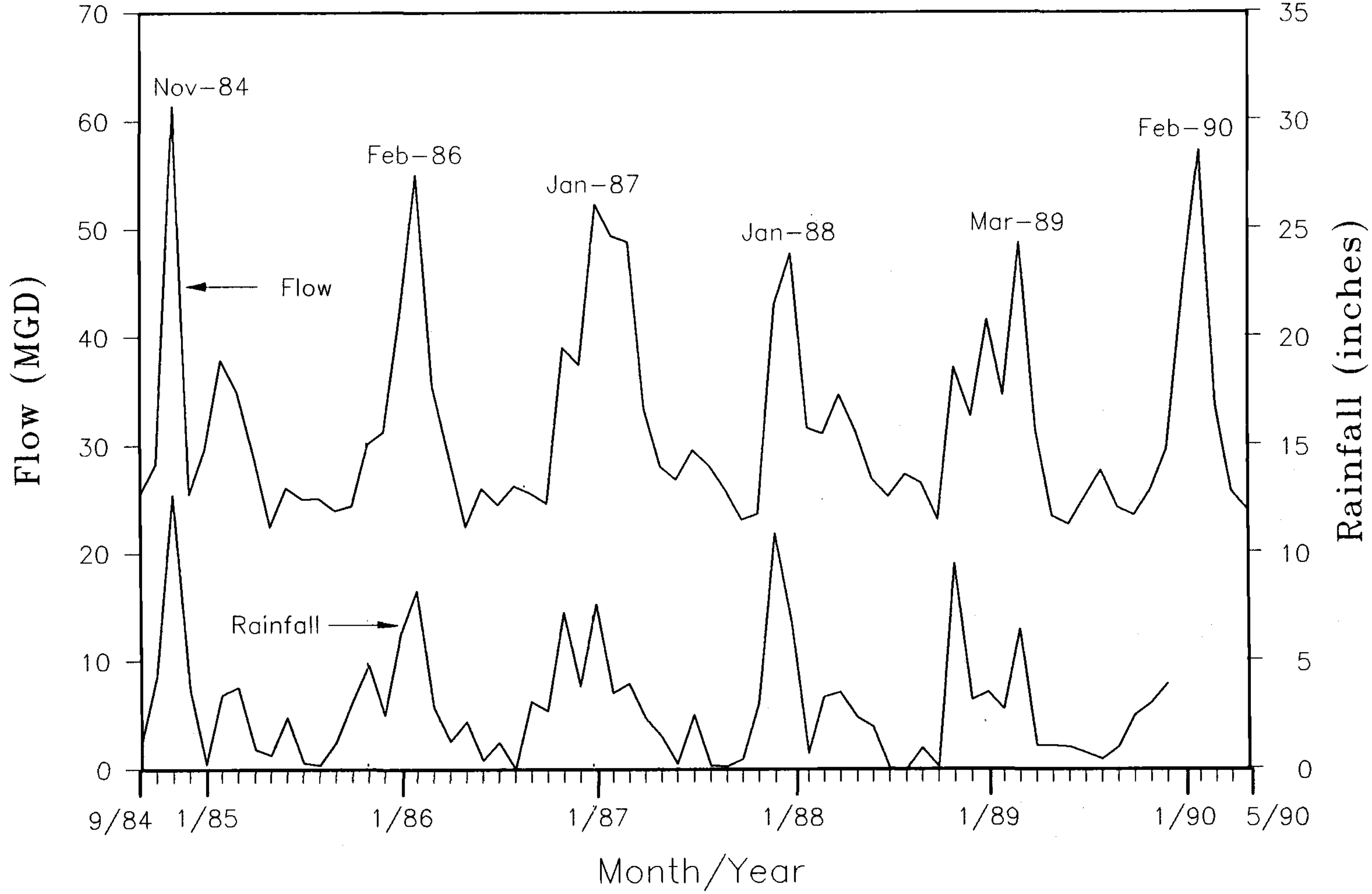


Figure 13 - Average daily flow at Willow Lake Wastewater Treatment Plant and total monthly rainfall measured at Public Works Field Office, City of Salem, Oregon

and duration is necessary, only the height of groundwater above the sewer line. Groundwater level measurements also include the effects of nearby water bodies that provide a source of groundwater for potential infiltration into the collection system that is nearly independent of rainfall (except in extreme flooding or drought conditions).

Willow Lake Treatment Plant has the capacity to treat about 90 MGD (341,000 m^3/d) of sewage flow. During heavy precipitation when ground water and surface runoff contribute the most to the flows, either the treatment plant or the collection system capacity, or both, are exceeded and raw sewage is discharged directly into the Willamette River or into one of several tributaries. In 1982, Salem had 117 bypass locations. Presently (1990), only 16 bypass locations still exist. During the 1988-89 year, the NPDES bypass events summary totaled 27.8 million gallons (105,303 m^3) of raw sewage discharged into the Willamette River or its tributaries.

Faced with the NPDES objectives, Salem has two options to eliminate sewage overflows: expand the collection system and treatment plant to accommodate I/I flows, or rehabilitate the collection system to reduce I/I flows. Currently the city has $2.3 million in proposed I/I improvement projects to correct leaky sewers and sewer bypasses, and for large diameter pipe sealing and repair, over the next two year period. Proposed Capital Improvement Projects that will increase the system capacity to accommodate large I/I flows total $1.7 million over the next five years.

4.2 - Current Rehabilitation Program for Collection System Infiltration Control

The collection system rehabilitation program in use by the City of Salem is reported to be among the most progressive in the nation (Sullivan and Ewing, 1985). Rehabilitation efforts include replacement, slip lining, inversion tube lining, and chemical grouting. Focus for infiltration control is on rehabilitation of mainlines, manholes, and large diameter pipelines. Recently, a new policy was adopted to replace service laterals up to the property line when new main lines are being replaced. A recent project included relocation of several mainlines from backyard easements to city streets. New services, with two-way clean-outs at the property line, were installed.

The current city policy on vitrified clay pipe is to replace it with concrete or plastic pipe. In addition to this, all 6-inch concrete pipe is being replaced with 8-inch plastic pipe.

The process for collection system rehabilitation in Salem is summarized below.

<u>4.2.1 - Basin Separation</u> - The city sewer system has been divided into 38 separate basins. These basins are occasionally divided into smaller sub-basins but these are not permanently recognized with a unique identification. Ideally, each basin is a closed system with one line draining

the basin. However, some basins have more than one output line, and may have some input lines as well, which makes monitoring the flow generated within the basin more difficult. This problem creates a larger demand for additional flow measuring equipment when it is desired to monitor only that flow generated inside the basin boundaries.

4.2.2 - Flow Monitoring - Facilities Engineering proceeds through the collection system systematically, identifying those basins or sub-basins that contribute significant I/I. This is done by monitoring flows at key manholes.

There are currently two flow monitoring systems in use by Facilities Engineering. Their primary uses include monitoring overflow sites, monitoring State of Oregon facilities for billing purposes, and identifying areas of high I/I. The most technologically advanced flow monitors in use by Salem are manufactured by American Digital System (ADS). Seventeen of these monitors remain permanently at given sites and are connected via phone line to a computer in the Facilities Engineering department. All data is automatically sent into the computer which loads the data into the ADS program software. An additional 4 ADS monitors are scheduled for placement in early 1990 bringing the total number of ADS monitors to 21. Each ADS monitor costs approximately $17,000 installed.

The second type of flow monitoring system is that manufactured by Montedoro/Whitney and is portable. Facilities Engineering operates and maintains 29 of these units. These monitors are not connected to a computer, rather the data is stored at the monitoring site and Facilities Engineering personnel are responsible for periodically going out in the field and recording data with a portable computer. Several weeks of data can be stored on-site by these monitors. Of the 29 monitors available, 6 are dedicated to monitoring overflow sites and 3 are dedicated to permanently monitoring State of Oregon facility sewer lines for billing purposes leaving 20 portable monitors available for investigative work to determine areas of high I/I. These monitors cost about $3400 each.

Salem is currently not using flow monitoring data to directly determine areas for grouting work or to check on areas that have been grouted previously. The principal use for I/I analyses with the flow monitors is to determine where areas of high I/I exist. After this, the most recent tele-inspection (t.v.) problem logs are reviewed to determine the extent of damage for lines within the problem areas. If no prior t.v report exists, if the previous report is over 10 years old, or if the problems reported by the last inspection are severe, a recommendation is given to re-inspect the line with t.v. and the problem log is updated to reflect the current condition of the line. Facilities Engineering routinely examines the problem log and makes recommendations to the Wastewater Collections Division as to which lines are in need of work and what rehabilitative method should be employed. The problem log is part of Hansen Software's Wastewater Collection Management System (WCMS).

4.2.3 - Television Inspection - All t.v. inspections are done with color cameras in a manner that is consistent with recommended procedures by manufacturers of the video equipment in use. The equipment in ownership by the City of Salem that is available for t.v. inspection and grouting work includes 2 Cues color cameras, 3 Aries color cameras, and 2 black and white cameras that are rarely used.

The t.v. inspection program of the City of Salem utilizes the sewer maps created by city personnel who systematically numbered each sewer system map with a unique 5 digit code (see Figure 14). The first two numbers indicate the east-west location of the map and the second three numbers indicate the north-south location of the map.

Manholes are identified by an eight digit number with the first five numbers identifying the map containing the manhole and the last three numbers identify the manhole on the particular map. For example, manhole #48-468039 in Fig 10 is located on map #48-468, with the last three digits indicating the specific location (at the intersection of S.E 24th Street and S.E. Hyde Street). Map numbers increment by three in the east-west direction and increment by two in the north south direction. Thus, map

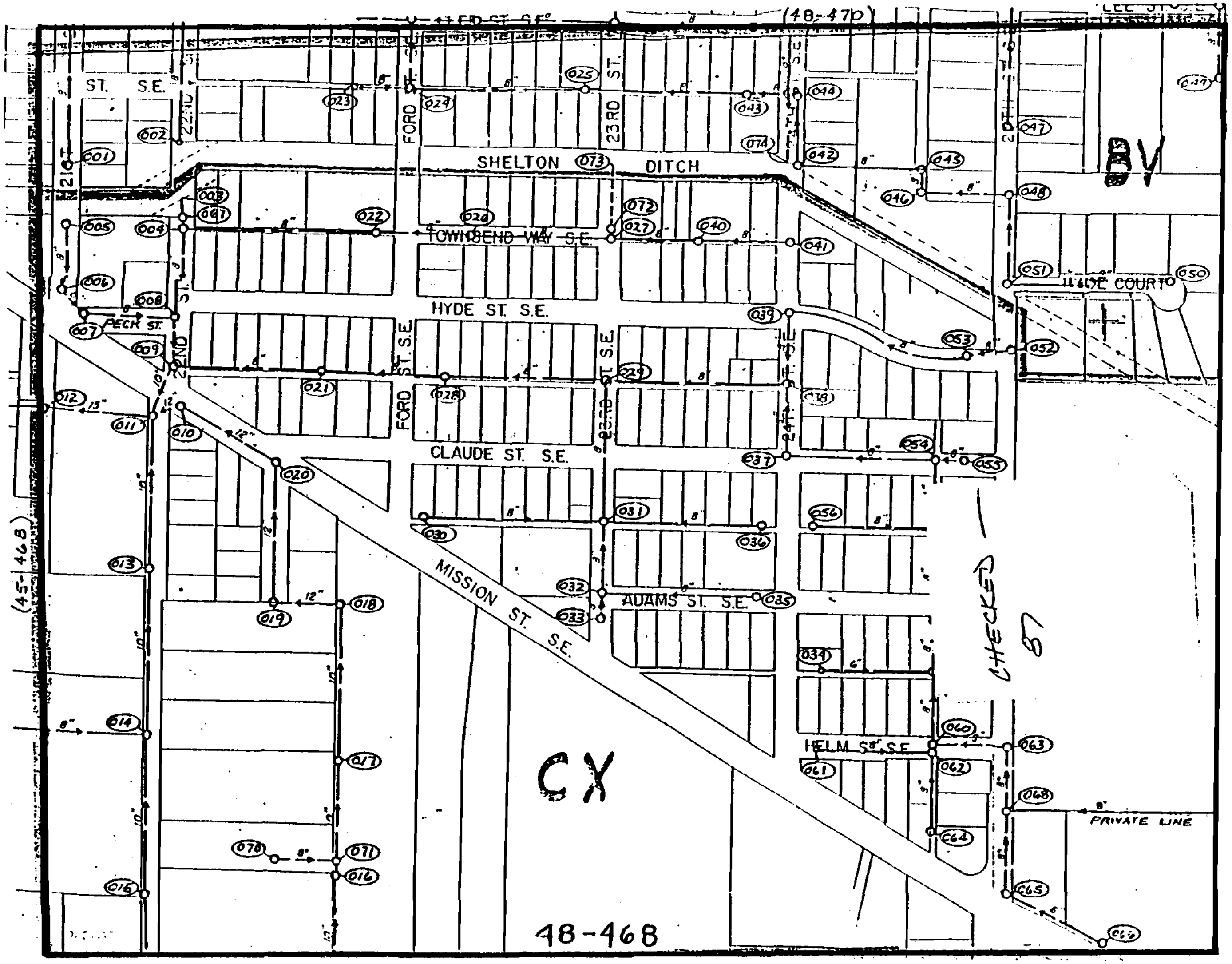


Figure 14 - City of Salem sewer map #48-468

#45-468 is the map directly to the west and map #48-470 is the map directly to the north of map #48-468. This manhole numbering system allows easy management of information pertaining to sewer lines contained between two manholes.

4.2.4 - Scheduling of Rehabilitation Work - When rehabilitation work is recommended by Facilities Engineering to Wastewater Collections, it is reviewed for approval by managers in that division. Differences of opinion are resolved by a joint meeting of both divisions. When the area and the type of work have been selected, the project is scheduled.

4.2.5 - Salem's Grouting Program - The objective of Salem's grouting program is to obtain effective control of groundwater infiltration into the sewer collection system by sealing leaking joints and radial cracks in sewer mainlines. Chemical grout is also used to control groundwater infiltration through joints and cracks in manhole walls.

The methods used by the City of Salem to obtain effective control of infiltration with chemical grout are as follows:

1) Proceed in a systematic basin-by-basin manner through the collection system beginning with those basins identified as having the most infiltration and ending with those basins having the least.

2) Test all joints in a line, and chemically grout joints that are visibly leaking or exhibit a potential for leaking as determined by a standardized air pressure test.

3) Seal manhole wall joints and cracks which show evidence of leaking.

The procedures for sealing mainlines and manholes differ somewhat. When sealing manholes, an entry hole is drilled through the manhole wall in the vicinity of the leak. A tapered fitting is either driven or screwed into the hole. Dye traced grout is pumped through the fitting into the hole until it begins entering the manhole through the defect. One or more entry holes may be required to effectively seal the defects in a manhole. Chemical grouting of manholes occurs when the leaks are active so that a follow-up inspection can be made to determine if groundwater has risen and is infiltrating through defects higher up the manhole wall. Approximately 15 to 30 manholes are grouted in this manner by the city grouting crews each year.

The procedures used by Salem's grouting crews are those recommended by ASCE (Joint Task Force, 1983) and the National Association of Sewer Service Companies (NASSCO) (National Association of Sewer Service Companies, 1989). The recommended procedure is summarized in Chapter 1. The City of Salem's specifications for chemical grouting are included in Appendix A. The equipment and chemicals in use are summarized below.

1 Grout Truck - 1978 model, manufactured by CUES, Inc.

A Leading Edge computer has been installed on-board for recording grouting data in the field.

2 CUES, Inc. Color Cameras

3 Aries Color Cameras

2 Black & white cameras - rarely used

CUES Grout Packers:

2 6-in packers

2 8-in packers

2 10-in packers

1 12-in packer

The equipment necessary to grout sewer lines larger than 12-inch is not owned by the City of Salem. Nearly all equipment used for chemical grouting in Salem is either manufactured by CUES, Inc. or is a prototype of CUES equipment.

Chemicals:

Grout - AV100 distributed by Avanti, International

Activator - AV101 - Catalyst T (triethanolamine)

Root inhibitor - Caseron; used only when grouting areas with root problems

NASSCO recommended specifications for chemical grouting are presented in Appendix B.

In recent years, chemical grouting has become a more comprehensive activity. Rather than grouting a few lines in one basin and then moving to high priority lines in another basin, the basin with highest priority receives chemical grout in all lines that require it before work commences on another basin.

At present, city crews do not repair service laterals with chemical grout. The technology to chemically grout leaking service laterals is available on a limited basis but will not be made available to all municipalities until the methods and equipment have been perfected by the manufacturer.

In the months of January through September of 1989, Salem's only grouting crew sealed 27,418 lineal feet (8,357 m) of mainlines. Assuming the same sealing rate could be maintained year-round, 36,000 lineal feet (10,973 m), or 6.8 miles/year (11 km/year) of mainline can be sealed annually. Using the effective lifetime of 15.6 years for non-rubber gasket pipe joint seals (see Section 4.3 below) and assuming that rubber gasket pipe joints exhibit a similar lifetime, nearly 106 miles (170 km) of defective mainline could be serviced by the grouting crew before those joints previously sealed are in need of re-sealing. This represents about 18% of the system. If chemical grouting is the most applicable rehabilitation technique for more than 18% of the collection system, then additional grouting technicians and equipment are needed to maintain that portion of the system.

The combined operating budget and capital costs for Salem's grouting operations totaled $146,353 for the 1989-90 fiscal year. Using the estimated annual mainline servicing figure of 36,000 lineal feet (10,972 m), a per foot cost of $4.06 ($13.34/m) results.

4.2.6 - Management of Grouting Data - Grouting crews record all grouting data in the field on computer files. Information entered for a line includes the date, basin, line identification by manhole numbers, pipe-type, length of line section, location of each joint, results of each air-pressure test, and amount of grout applied to each defect in the pipe. Additional information for use in the t.v. problem log can also be recorded.

Data collected in the field is transferred to two data bases in Facilities Engineering. The first data base is on R-Base software and has been maintained for about 3 years. In this system, a joint-by-joint record is kept of all grouting activity. This data base is primarily used for analysis and summarization of grouting data. Data can be analyzed by basin, pipe type, or manhole numbers when needed. This system has excellent potential for evaluating grout program effectiveness but currently does not contain enough data to yield statistically representative results.

The second data base in which grout activity is recorded is the Wastewater Collection Management System (WCMS) marketed by Hansen Software, Inc. In this data base, a line-by-line record is kept of all grouting activity. Statistical analysis of some recorded data is limited because numbers of total joints, tests, seals, and grout usage are entered as text in a combined "comments" column and are not available for mathematical manipulation. The principal function of this data base is to keep a record of past activity on each line in the system. As a management tool, it allows the user to quickly summarize information about the collection system, for example, which lines have not received grout for more than 10 years. Modifying the WCMS system is not as easy as modifying the R-Base system because it is marketed as application software that can not be modified by the user.

The two database management systems operate as a compliment to each other with the R-Base system having greater capability of effectiveness analysis and the WCMS system having greater management usefulness. The disadvantage of this 'two system' data management approach is that it requires duplication of effort. If it were possible to expand either of the two systems to include the functions of the other, a single data base would be capable of statistical analyses for use in effectiveness evaluations and qualitative summaries for use in management decisions.

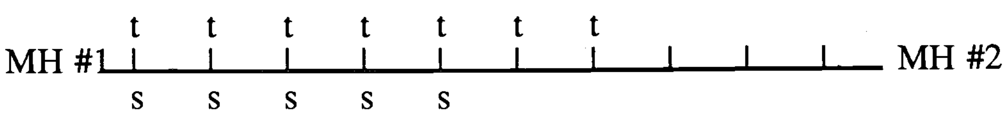
4.3 - Grout Longevity

A statistical analysis was performed to determine the effective lifetime of chemically grouted concrete pipe joints based on data from the City of Salem, Oregon. Only data from non-rubber gasket concrete pipes that had been grouted twice was used. An effective lifetime of chemically grouted rubber gasket concrete pipe joints was not determined because of insufficient data (an insufficient number of pipes that had a large percentage of joints sealed during their first grouting). The statistical analysis is based on the total number of joints in the line, the total number of air pressure tests conducted, and the total number of joints grouted.

Figures 15 and 16 show the yearly totals of joints, tests, and seals for first time grouting of both rubber and non-rubber gasket pipes. Since grouting data were summarized in a line-by-line manner rather than joint-by-joint, it was not possible to determine which joints sealed during the first grouting had failed the air test during the second grouting and were subsequently sealed by chemical grouting. This can be illustrated by the following simplified example.

<u>Example 1</u>

Consider the pipe section shown below with a total of 10 joints. During the first grouting, seven of the ten joints inspected with the T.V. camera were determined to be potentially faulty joints and were tested. Of these seven, five were determined by the air test to be faulty and were sealed with grout.

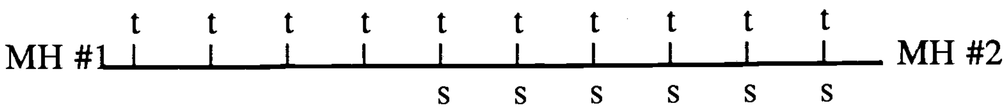


t = tested
s = sealed
| = joint

A summary of the first time grouting would appear as follows:

Upstream MH #	Downstream MH #	Total Joints	Total Tests	Total Seals	Fail Rate
1	2	10	7	5	50%

Now, after ten years, this same line is regrouted. This time, every joint is tested and six joints are found to be defective, only one of which was sealed during the first grouting.



The corresponding summary of the second grouting would appear as follows:

Upstream MH #	Downstream MH #	Total Joints	Total Tests	Total Seals	Fail Rate
1	2	10	10	6	60%

The line by line summary can give misleading results for two reasons. First, there is no proof of the watertight integrity of the untested joints during the first grouting except that there was no visible leakage or defect. Secondly, it is impossible to tell from the second grouting summary which joints sealed during the first grouting were resealed during the second grouting. Initial inspection of the change in pass rate would lead to a conclusion that the watertight integrity of the sealed joints had completely diminished, which would result in a 100% failure in ten years. Only one of the five joints initially sealed had actually failed, which results in a 20% failure in ten years. Nearly all rubber gasket pipes were eliminated from the final analysis because of the large difference between total joints tested and total joints sealed. However, since the difference between total tests

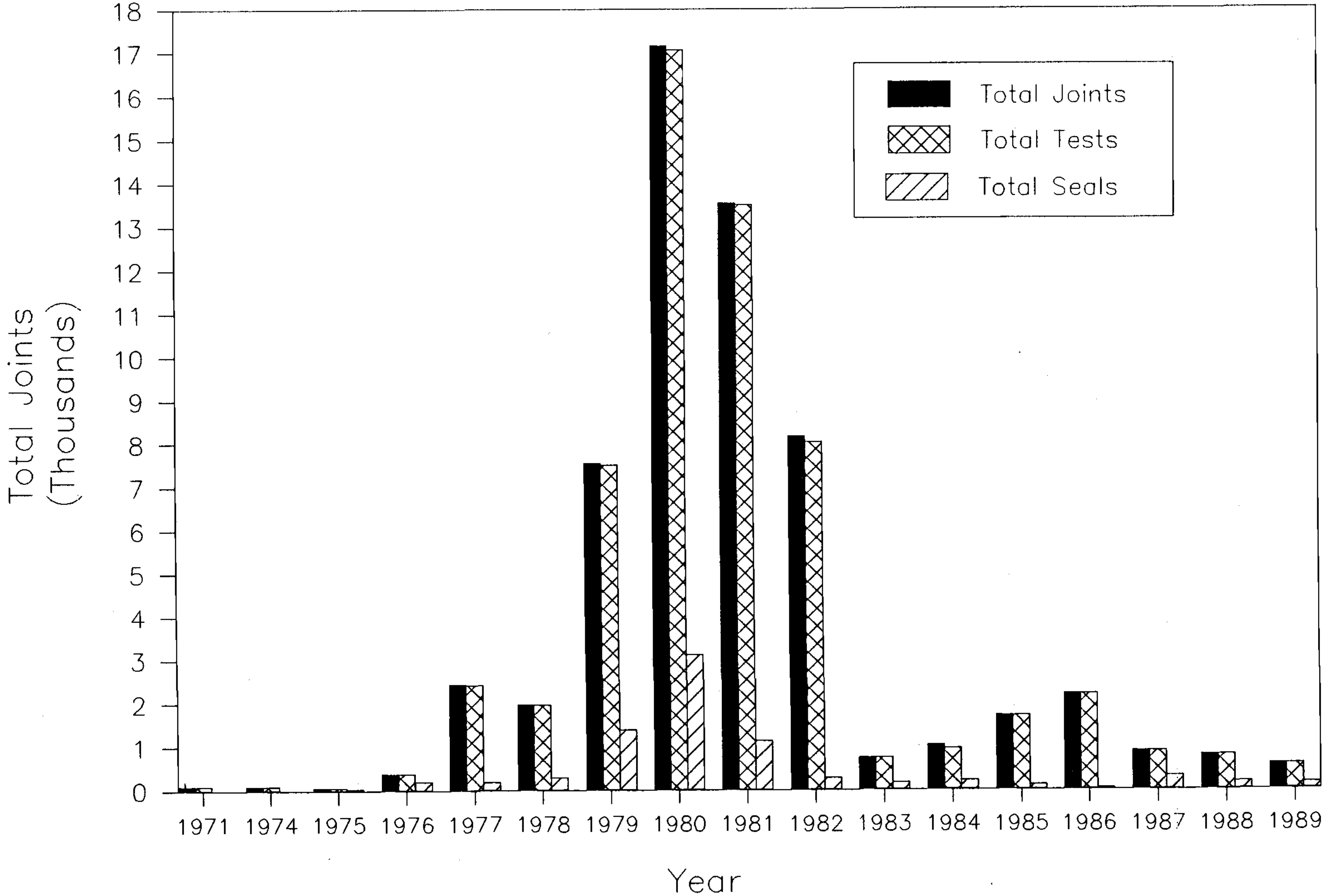


Figure 15 - Total joints inspected, tested, and sealed in the first time grouting of rubber gasket concrete pipes

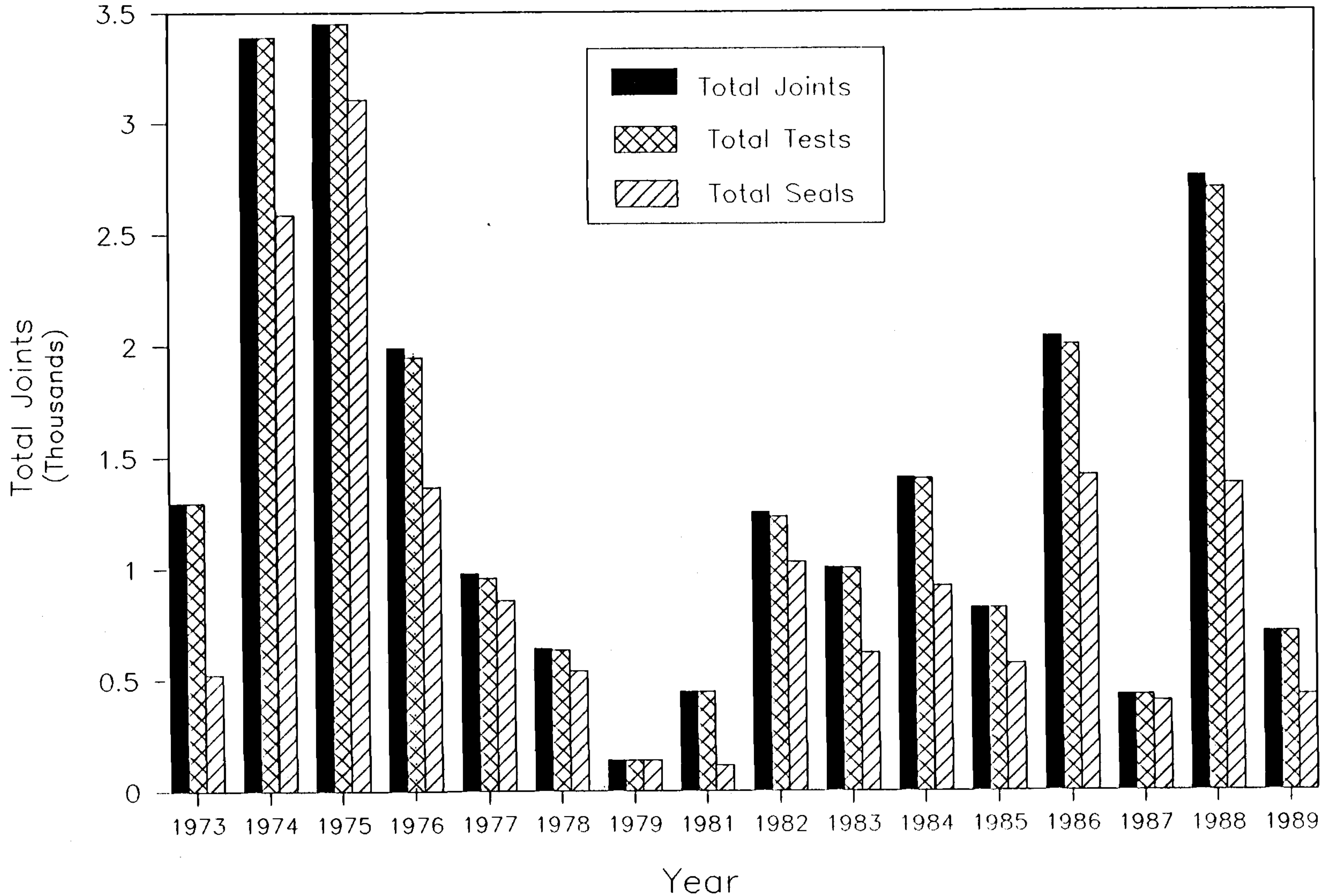


Figure 16 - Total joints inspected, tested, and sealed in the first time grouting of non-rubber gasket concrete pipes

and total seals for non-rubber gasket concrete pipes was small, it was assumed that the joints sealed during the second grouting were joints that had been sealed during the first grouting. Any error introduced by this assumption will be small and would yield a slightly shorter lifetime than actual. To avoid future problems associated with this situation, two recommendations for future air testing and data collection can be made.

1) When grouting sewer mains, air test every joint in the pipe section.
2) To evaluate grout longevity directly, and program effectiveness indirectly, record the performance of each joint.

Data management in a joint-by-joint manner is currently being practiced in Salem but has only been in effect for about two years, in which time a non-representative sample of joints has been tested, sealed, and then later retested and resealed. If joint-by-joint testing and data management continues, a statistically representative number of joints will be available for future analysis and should result in reliable estimates for the lifetimes of chemically grouted rubber and non-rubber gasket pipe joints.

Since the data for chemically grouted rubber gasket concrete pipes was insufficient to give reliable results, the analysis that follows was conducted on chemically grouted non-rubber gasket pipe joints only.

Approach

To determine the effective lifetime of chemically grouted joints, grouting records were analyzed to determine whether a correlation existed between the time rate of seal failure and the number of years in service.

The non-rubber gasket grouted joint data were examined and those lines which received grouting activity twice were selected for analysis. For each pipe grouted twice, the years in service and rate of failure were calculated. The rate of failure is defined as:

Equation (1)

$$\text{Rate of Failure} = \text{FR} = \frac{\text{percentage of original seals which failed the standard air pressure test during the second grouting}}{\text{number of years in service between grouting}}$$

If the relationship between the time rate of grouted seal failure (Equation 1) and number of years in service can be accurately determined, then a reliable prediction of the lifetime of grouted seals can be made.

Assumptions

The following assumptions were made in the determination of the effective lifetime by this approach.

1) The number of pipe wall cracks that were sealed with chemical grout is insignificant in comparison to the number of joints sealed.

2) Those joints sealed during the second grouting were joints that received grout during the first grouting.

3) The performance of those non-rubber gasket concrete pipe joints that were eventually grouted twice is representative of the performance of all grouted joints of the same pipe type.

4) The results of the standardized air pressure test are indicative of the water-tight integrity of the joint tested.

Procedure

The grouting data summary shown in Table 1 is for non-rubber gasket concrete pipe joints sealed with acrylamide gel chemical grout. Pipes that were grouted twice were selected for statistical analysis in the evaluation of the effective lifetime of chemically grouted joints. The selected pipes represent 18% of the non-rubber gasket concrete pipes which have been grouted once.

Since the population of non-rubber gasket concrete pipes used for analysis was not randomly selected, a comparison of certain parameters was made between the selected population (pipes that were grouted twice) and the entire population (pipes that were grouted at least once) to determine if the selected population was representative of the entire population. The average grout usage per seal during the first grouting was 2.93 gallons for the entire population compared with 2.66 gallons for the selected population. Similarly, the average grout usage per foot was 0.78 gallons for both the entire and the selected populations. The average air test pass rate for the entire and selected populations were 28% and 20%, respectively. The percent of total joints sealed for the entire and selected populations were 71% and 79%, respectively. Based on the close comparison of these four parameters, it was concluded that the selected population was representative of the entire population.

Table 1. Grouting data summary for all non-rubber gasket concrete pipes

	All Pipes - 1st Grouting	Selected* Pipes - 1st Grouting	Selected* Pipes - 2nd Grouting
Total Footage (ft)	62,101	11,278	11,278
Total Joints	23,305	4,155	4,170
Total Tests	23,077	4,128	4,020
Total Seals	16,511	3,303	1,897
Total Grout (gal)	48,372	8,773	3,291
Average Grout/Seal	2.93	2.66	1.73
Average Grout/Foot	0.78	0.78	0.29
Air Test Pass Rate	28%	20%	53%
Percent of total joints sealed	71%	79%	45%

* Pipes included in data analysis

The data shown in Table 2 summarizes grouted seal performance for all non-rubber gasket pipes that were grouted twice. A plot of the time rate of failure with respect to years in service is shown in Figure 17. The data points in Figure 17 are given different symbols depending on how many seals were originally made to emphasize that some points received more statistical weight than others. The rate of seal failure remains relatively constant with time (Figure 17). Two outlier points were observed. One at 0.011 years with 16.8% seal failure, translates to a time rate of seal failure of 1531% per year. Obviously, this is not realistic. Two possible explanations are that the data reported were either for a different line with a duplicate (incorrect) grout report number or that the failure was caused by improper grout application. This point was not considered in the subsequent statistical analysis. The second outlier point was for a mainline that was resealed 1.32 years after its initial grouting and exhibited a 100% seal failure. This translates to a time rate of seal failure of 76% per year. Again, this is an unlikely rate of failure caused perhaps by improper grout application or by abnormal conditions. Since this point was over three times greater than the next highest data point, it was considered inaccurate and disregarded in the final statistical analysis (see Table 3, below).

The data shown in Table 2 were statistically analyzed using Statgraphics software (Statistical Graphics Corp., 1988). First, an analysis was conducted on all data <u>except</u> the extreme outlier at 0.01 years. The results are presented in Table 3(a).

Table 2 - Determination of Rate of Failure from grouting data for non-rubber gasket concrete pipes

Years In Service	Total Original Seals	# Good Seals	% Failed	Rate of Failure (%/yr)
0.01	95	79	17%	1531
0.31	66	65	2%	5
1.32	172	0	100%	76
1.38	94	83	12%	8
1.98	94	83	12%	6
2.14	13	11	15%	7
2.79	92	70	24%	9
5.22	43	0	100%	19
5.27	72	23	68%	13
5.35	60	23	62%	12
5.37	36	0	100%	19
5.41	112	67	40%	7
5.56	44	0	100%	18
5.78	122	101	17%	3
5.85	92	61	34%	6
5.87	83	66	20%	3
6.11	94	62	34%	6
6.13	113	96	15%	2
6.60	6	6	0%	0
7.02	28	24	14%	2
7.18	91	78	14%	2
8.83	72	0	100%	11
9.27	70	0	100%	11
10.05	119	84	29%	3
10.14	131	44	66%	7
10.18	121	30	75%	7
10.39	39	0	100%	10
10.60	27	0	100%	9
11.00	83	0	100%	9
11.61	74	9	88%	8
12.16	130	71	45%	4
12.19	107	0	100%	8
12.54	102	16	84%	7
13.57	115	6	95%	7
13.62	52	0	100%	7
13.69	188	92	51%	4
13.70	80	47	41%	3
13.97	137	20	85%	6
14.29	156	150	4%	0
15.34	145	0	100%	7

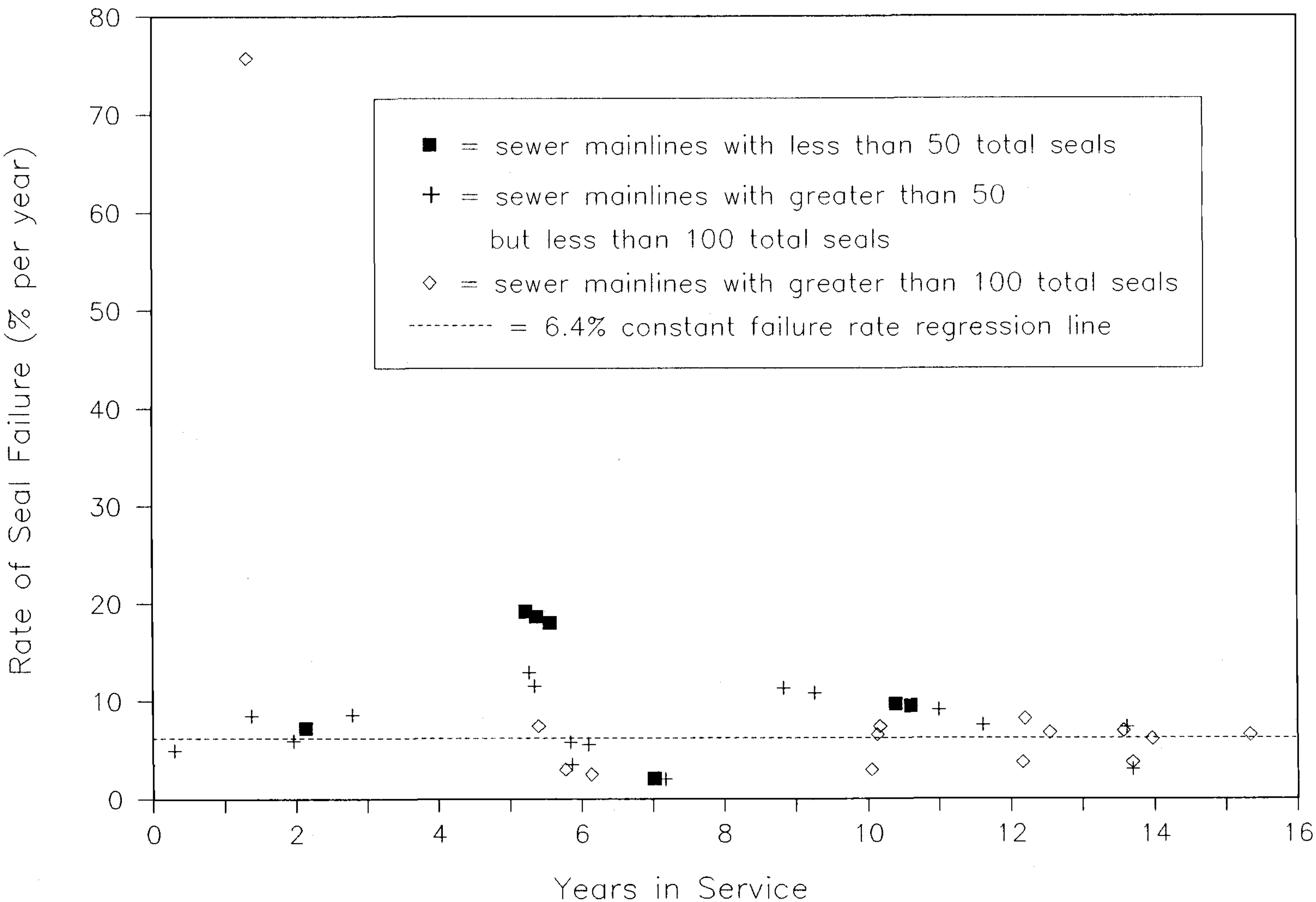


Figure 17 - Relationship between the time rate of sealed joint failure and years in service for non-rubber gasket pipe joints grouted with acrylamide gel, City of Salem, Oregon

A second statistical analysis was conducted by excluding the outliers at 0.01 and 1.32 years. These results are presented in Table 3(b). The outlier at 1.32 years had a significant effect on the slope and intercept values. By eliminating this (most likely erroneous) value, the rate of seal failure for the first year changed from 16.5%/year to 9.3%/year. Table 3(c) uses the same data as Table 3(b) except that a multiple regression analysis is made which gives a statistical weight to each data point that is proportional to the number of total seals made during the first grouting. By weighting the data and excluding the outliers from the analysis, an intercept of 8.48%/year is obtained.

A statistical T-test, to determine whether the slope of the regression line could be zero (Neter, Wasserman, and Cutner, 1983), was conducted on the data in Tables 3(a), 3(b), and 3(c) . In Table 3(a), the hypothesis that the slope was zero was rejected, which means that for this data set (which includes the second outlier at 1.32 years), the slope is a non-zero value. In Tables 3(b) and (c) the hypothesis that the slope was zero was not rejected by the T-test. Therefore, there is no evidence to suggest that the slope is not equal to zero. The basis for rejection by the T-test is the P-level or significance level. For the selected significance level of 95%, if the P level is less than 0.05, then the T-test will reject the hypothesis that the slope is equal to zero.

Table 3. Results of statistical analysis on computed rates of failure

(a) - All non-rubber gasket data except 0.01 y outlier

Parameter	Estimate	Standard Error	T-Value	P-Level
Intercept	16.556	4.046	4.092	0.00022
Slope	-0.9216	0.4402	-2.093	0.04321

(b) - All non-rubber gasket data except 0.01 and 1.32 y outliers

Parameter	Estimate	Standard Error	T-Value	P-Level
Intercept	9.280	1.703	5.405	0.00000
Slope	-0.2353	0.1830	-1.285	0.20671

(c) - Multiple regression of all non-rubber gasket data except 0.01 y and 1.32 y outliers, weighted by number of seals made per line during the first grouting

Parameter	Estimate	Standard Error	T-Value	P-Level
Intercept	8.480	1.484	5.714	0.00000
Slope	-0.2249	0.1467	-1.516	0.1382

Since the time rate of failure was observed to be constant, the average rate of failure was evaluated by taking a weighted average of the data. By knowing the average time rate of failure, the lifetime (years) of the grout can be calculated by taking the inverse of the time rate of failure and multiplying by 100. This failure rate was determined using the data from Table 3(c), with total seals made in the first grouting as a weighting parameter. The constant (weighted average) failure rate was 6.4% per year with a standard error of 0.065%/year. This results in a weighted average lifetime of 15.6 years. The standard error for this lifetime was calculated to be 0.16 years.

Many possible failure mechanisms for chemically grouted joints can be hypothesized. Chemical or biological mechanisms relate to the direct deterioration of the chemical grout. Physical mechanisms relate to the failure of the sealed joint by physical forces acting on the grout mass and/or the pipe.

Since the time rate of failure (percent/year) is constant, then the assumption that acrylamide grout is not subject to chemical or biological degradation is supported since degradation by these means would most likely proceed at a non-constant rate with time. Rates of deterioration of materials such as highway surfaces by combined mechanisms are generally non-linear with time as well (Bell, 1990). Therefore, a linear plot of grouted seal deterioration over time would indicate that the observed time rate of failure of chemically grouted pipe joints may not be a result of any deterioration of the chemical grout itself, rather, it may indicate that other factors are influencing the performance of the sealed joint, such as continued pipe deterioration.

Findings

For a 95% confidence interval, the average effective lifetime of non-rubber gasket concrete pipe joints grouted with acrylamide gel was determined to be 15.6 years ± 0.3 years. This lifetime is for the described pipe and joint type in the city of Salem, Oregon, only. Other pipe types, or pipes in other cities, may not exhibit the same longevity depending on the many factors that affect grout performance.

4.4 - Past Collection System Rehabilitation Effectiveness Studies in Salem

In 1981, two extensive studies were initiated by the City of Salem, conducted by Westech Engineering and others to evaluate collection system rehabilitation effectiveness (Steketee, 1985). The studies focused on two areas of south Salem known to have significant I/I flows. Sewers in the Skyline Rehabilitation Basin study were constructed of rubber gasket concrete pipe in the 1960's. This basin was typical of much of the rubber gasket pipe systems found in south Salem. One objective of the Skyline Rehabilitation Basin study was to compare the percentage of I/I removed by mainline grouting only with that by mainline grouting in conjunction with service lateral rehabilitation.

Most mainline joint repairs were made before the Skyline Rehabilitation study began, yet I/I flows remained high. It was concluded that 8% of the peak I/I flows were contributed by mainlines that had been repaired with chemical grout, 91% by leaking service laterals, and 1% by manhole leaks. Complete rehabilitation of mainlines, manholes, and service laterals was nearly 100% effective in controlling peak I/I flows. Over the entire Skyline Rehabilitation Basin, 92% reduction in peak I/I flow was observed. This degree of I/I control required several phases of rehabilitative work with extensive flow monitoring before, during, and after rehabilitation to determine its overall effectiveness. The various phases are summarized below.

Step A - Measuring Initial Conditions

- Flow Monitoring
- Groundwater Level Measurements
- TV Inspections and Joint Tests
- Smoke Tests
- Service Lateral Testing

Step B - Phase I Rehabilitation Work

- Mainline Repairs
- Manhole Repairs
- Service Lateral Repairs

Step C - Measure Post-Rehabilitation Conditions

- Flow Monitoring
- TV Inspections

Step D - Phase II Rehabilitation Work

- Mainline Repairs
- Manhole Repairs
- Service Lateral Repairs

Step E - Measure Post Rehabilitation Conditions

- Flow Monitoring
- TV Inspections

Step F - Phase III Rehabilitation Work

- Mainline Repairs
- Service Lateral Repairs

A similar study was conducted in the Missouri Basin, which is constructed from non-rubber gasket pipe that was typical of sewers installed in Salem between 1930 and 1958. The same approach was taken on this study as on the Skyline Rehabilitation study, except that only two phases of rehabilitation work were conducted. Sewer flows were measured before, during, and after rehabilitation. The post-rehabilitation analysis concluded that 76% of the peak basin I/I flows had been removed.

The effectiveness analysis for complete vs. partial rehabilitation on the Missouri Basin study was not as conclusive as the same analysis conducted on the Skyline Basin study, due to the extremely poor pipe conditions in the Missouri Basin. After grouting the mainlines, groundwater was observed to be seeping through the porous walls of pipe sections.

The studies conducted on these two basins revealed the importance of groundwater migration control and service lateral rehabilitation in the management of future rehabilitation efforts. Furthermore, it was shown that chemical grouting can be an effective method of rehabilitating leaking sewers when the various methods of rehabilitation are integrated into a comprehensive effort.

Rehabilitation effectiveness is increased when rehabilitation is completed in several phases of repair, with extensive flow monitoring continuing throughout all phases of the project. A comprehensive monitoring strategy is as important to evaluating program effectiveness as is a comprehensive rehabilitation strategy to achieving I/I control.

CHAPTER FIVE

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 - Summary

Since the evolution of the National Pollution Discharge Elimination System (NPDES) in 1972, the overflow and subsequent discharge of raw sewage to streams and rivers has been the object of federal government attention. One major contributing factor to sewage overflows is the infiltration/inflow (I/I) of groundwater and stormwater into the sewage collection system.

Several methods exist for the prevention groundwater infiltration into the sewage collection system including:

- Replacing pipe sections
- Slip-Lining pipe sections
- Inversion Tube Lining of pipe sections
- Chemically grouting leaking pipe joints

Chemical grouting is the most commonly used method of sealing leaky joints in sewer lines that are structurally sound. Two basic types of chemical grout exist for sealing sewer line joints: gels and foams. Gels are more commonly used than foams and the majority of the gel-type grouts are acrylamide monomer based. Prevention of groundwater infiltration is accomplished with chemical grout by injecting the grout into the soil surrounding defective pipe joints, thereby creating an impermeable barrier to water. Correct application of chemical grout requires specialized equipment and experienced technicians. The performance of sealed (grouted) joints is dependent upon a variety of environmental factors including:

- temperature,
- pH,
- sodium and calcium chlorides,
- trench material,
- soil moisture.

Effective control of groundwater infiltration requires a comprehensive rehabilitation program that addresses mainlines, manholes, and service laterals (which have been shown to contribute significant I/I). Knowledge of the effects of groundwater migration is important in planning a strategy for rehabilitation work. Groundwater migration occurs when water prevented by rehabilitation from entering a defect at one point travels along the trenchline, entering at another location where rehabilitation of the sewer main did not occur.

A comprehensive rehabilitation program includes separation of the collection system into drainage basins and utilizes extensive sewer flow monitoring data collected from these basins. Monitoring sewage flows before, during, and after rehabilitation of the collection system has been shown to be essential in evaluating rehabilitation effectiveness.

Adequate data collection and management practices can lead to the establishment of reliable self-evaluation of various methods of rehabilitation. To accomplish this evaluation, key parameters must be selected before data collection begins.

Effective elimination of peak I/I flows has been achieved in past rehabilitation studies in Salem, Oregon by conducting rehabilitation work in phases. During each phase of rehabilitation, repair of mainlines, manholes, and service laterals was conducted where it was identified during previous flow monitoring and t.v. inspections that I/I or the potential for I/I existed. Between rehabilitation phases, the effectiveness of the work was evaluated by comparison of flow measurements taken before and after rehabilitation, and t.v. inspections were made to identify areas requiring additional work.

The collection system rehabilitation program in use by the City of Salem is reported to be among the most progressive in the nation (Sullivan and Ewing, 1985). Rehabilitation efforts include replacement, slip lining, inversion tube lining, and chemical grouting. The sewer collection system has been divided into basins that, when necessary, are divided into smaller sub-basins. Automated flow monitoring is conducted by basin to identify areas with significant I/I problems. However, flow monitoring data is not used for evaluation of rehabilitation effectiveness.

Routine closed circuit t.v. inspections of sewer mainlines is utilized by the City of Salem for problem assessment. Recommendations for rehabilitation work are based on t.v. inspection reports.

Chemical grouting is a technology utilized extensively by the City of Salem to reduce groundwater infiltration through defective joints in sewer mainlines and manholes. A statistical analysis was performed to determine the effective lifetime of chemically grouted concrete pipe joints based on data from the City of Salem, Oregon. Only data from non-rubber gasket concrete pipes that had been grouted twice was used. An effective lifetime of chemically grouted rubber gasket concrete pipe joints was not determined because of insufficient data (an insufficient number of pipes that had a large percentage of joints sealed during their first grouting). The statistical analysis was based on the total number of joints in the line, the total number of air pressure tests conducted, and the total number of joints grouted.

5.2 - Conclusions

Through a statistical analysis of nearly all grouting activity between 1971 and September, 1989, it was determined that the effective average lifetime of a chemically grouted, non-rubber gasket pipe joint, was 15.6 years ± 0.3 years with a 95% confidence level. These joints exhibit a straight line time rate of failure of 6.4% per year.

From this statistical analysis it was concluded that chemical grout can be an effective method of controlling further groundwater infiltration at the point where it is applied. However, this does not establish the effectiveness of Salem's grouting program in eliminating infiltration. The effectiveness of rehabilitation work is evaluated by examination of flow monitoring data prior to and following rehabilitation. This extensive data was not available due to deficiencies in the flow monitoring program at the City of Salem.

Chemical grout program effectiveness in I/I flow reduction is dependent upon the following conditions being satisfied:

1) Proper grouting procedures during application,
2) Structurally sound pipe,
3) Impervious pipe walls,
4) Comprehensive rehabilitation of all system defects where groundwater migration is likely to occur,
5) Subsurface environment that is conducive to the application of chemical grout.

Groundwater levels are a more direct indication of the potential for infiltration to occur than are rainfall records. In areas such as Salem where soils exhibit low permeabilities, measured infiltration flows will be largely dependent upon previous soil moisture conditions. However, when groundwater level records do not exist (as with City of Salem), rainfall records provide adequate information in correlating infiltration quantities to soil moisture conditions.

Based on an examination of the total system flows recorded at Willow Lake Wastewater Treatment Plant and rainfall data recorded at the Public Works shops, it was concluded that significant I/I flows still exist. It is believed that a significant portion of the I/I flows are entering through defective service laterals and non-rehabilitated areas as a result of groundwater migration.

The methods and procedures for chemical grouting in the City of Salem specifications and practiced in the field appear to be consistent with nationally accepted standards for chemical grouting methods for sealing leaking sewer joints.

5.3 - Recommendations

The following list of recommendations resulted from examination of the policies and practices in use by the City of Salem in controlling I/I flows. These recommendations are intended to enhance the management programs currently in use, increase the effectiveness of all rehabilitative efforts in controlling I/I, create the ability to evaluate rehabilitation effectiveness in-house, and promote public awareness and support of the importance of I/I control.

1.) Establish periodic meetings between Facilities Engineering and Wastewater Collections personnel to maintain a broad perspective on, and keep consistent with, the goals and objectives for the elimination of I/I. Concerns, ideas, and suggestions from those involved in collection system management and maintenance should be made open for discussion at these meetings.

2.) Establish a separate I/I abatement group within the Facilities Engineering Division consisting of engineers and technicians who are well informed about goals, objectives, and most effective uses of various rehabilitation methods. This group should be knowledgeable about groundwater migration and the relative contributions of various I/I sources.

3.) Develop a comprehensive approach to collection system rehabilitation. Create more sub-basins, where necessary, so that phases of rehabilitation for entire areas can be completed with available funds and labor resources in the course of a year. During that year, use a comprehensive rehabilitation approach that includes mainlines, manholes, and service laterals. Eliminate combined sewers where it is possible.

4.) Conduct continuous flow monitoring in each area under rehabilitation for one year prior to, during, and following each phase of rehabilitation. Increase the number of flow monitors available to accomplish this extensive approach.

5.) Establish an annual reporting schedule of measured I/I reductions. Convert I/I reductions to cost savings and compare with the costs of rehabilitation. This information is important to maintaining the progressive ideals of the personnel, acquiring funds from budget committees, and improving public support of the public works agency.

6.) Initiate a program to repair and replace leaking service laterals. Evaluate the cost savings of repairing the service laterals and compare with the cost of transporting and treating of the extraneous groundwater which has been shown to be entering through these sources.

7.) Keep grouting data joint-by-joint so that lines with few defects can be included in the statistical analysis of performance. These data can be used to determine grout longevity as well as to estimate quantities, costs, and time requirements of future work.

8.) Expand the capabilities of the principal data base (WCMS) to include the capabilities of the secondary data base (R-BASE) so that only one system needs to be maintained. The system should be capable of recording detailed information in a joint-wise manner for use in effectiveness analyses.

9.) Establish a public awareness program to promote public support through meetings and/or letters with property owners in a given rehabilitation area. Identify the importance of I/I control and present the associated costs of the various options. Identify the contribution of faulty service laterals and the need to repair them. When rehabilitation is in progress, inform the property owners of the progress and future plans.

10.) Encourage personnel to keep current with new publications pertaining to advances in the management of other I/I programs as well as with the research and development of new products, ideas, and techniques.

11.) Keep all employees/contractors involved with the collection system well informed of the goals and objectives of the I/I abatement program.

12.) The inspection of leaking service laterals could be improved by the use of specialized color camera equipment designed for visual inspection of the first 3 to 4 feet (0.9 to 1.2 m) of service lateral connections. For more detailed inspections of entire service laterals, specialized service lateral T.V. equipment is available.

13.) When grouting lines for the first time, every joint in the line should be tested and/or sealed.

14.) When re-grouting previously grouted lines, apply the air pressure test to each joint first, before grouting. This allows for determination of the lifetime of chemically grouted joints.

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Appendices

Appendix A - City of Salem Grouting Specifications

Reference: City of Salem specifications on chemical grouting, Collections Division, Public Works Department, City of Salem, Oregon.

406 INTERNAL GROUTING OF EXISTING SANITARY SEWER LINES

406.1.00 DESCRIPTION

This section covers all work necessary to clean and inspect (via T.V.) the sanitary sewer lines, test the joints, repair and seal all defective joints or cracks and to retest and approve the work including television inspections complete in place.

406.1.01 DEFINITIONS

A. The elimination of groundwater infiltration as used in these specifications shall mean the elimination of infiltration of soil and water through any sewer joint as determined from earlier surveys, the television monitor, and the specified testing procedures.

B. The term "Manhole Section" as used in these specifications shall mean the length of sewer between a manhole and a manhole, cleanout or lamphole. This term is synonymous with the term "Reach," which is also used in these specifications. When one term is used the other is implied.

C. The term joint as used in these specifications, shall mean the junction point of two adjacent lengths of sewer pipe or a crack or other pipe defect which can be made leak-free by grouting.

D. The term "Clean" as used in these

specifications, shall be defined as the removal of sufficient materials to render the sewer line to 95 percent of its original capacity or to allow passage of the necessary inspection, testing and sealing equipment, whichever is greater.

406.1.02 WORKMANSHIP

The contractor shall perform all work necessary to the completion of the grouting work as defined by this contract. This work shall include, but not be limited to, the following:

A. Do all cleaning preparatory to the grouting operation.

B. Do manhole taps to determine average groundwater pressure.

C. Do the low pressure air testing of all joints.

D. Do the sealing, by the injection of chemical grout, of all joints failing the air test.

E. Do the removal of all grout residue left at sealed joints and the periphery of the pipe.

F. Do the retesting (post-sealing pressure test) of each joint sealed.

G. Submit required documents to the owner.

406.2.03 SEALING EQUIPMENT

Chemical grouting of sewer joints shall be accomplished by forcing sealing materials into and through the joints of the sewer pipe from within the sewer pipe in order to completely eliminate infiltration. The chemical grouting equipment and material will have the ability to successfully seal pipe line joints which are offset up to 1-1/2 inches or gaped up to 1-1/2 inches as viewed from the interior of the pipe. An offset joint is a joint where there is transverse displacement of adjacent pipe sections. Offset and/or separated joints beyond the limits specified shall be sealed only with the approval of the engineer and the concurrence of the contractor's supervising technician.

The sealing equipment shall contain two separate pumping systems capable of supplying an uninterrupted continuous glow of the sealing material at rates of between one-quarter and ten gallons per minute at a minimum pressure of 60 psig, for a continuous period of up to ten minutes. Each pumping system shall include a tank for mixing polymerizing materials and additive solids and liquids which will form the final grout mixture. Each of these tanks shall be equipped with mixing and or recirculation systems to allow continuous or frequent agitation of suspended solid additives such as Celite 209, an additive used for added viscosity and strength. Suspended solids shall be agitated continuously throughout the grouting operations. No system of pumps or pressure devices which does not continuously maintain the exact proportioning of the fluids contained in the mixing tanks will be allowed.

The sealing device is referred to hereafter as a packer and shall be a cylindrical case of a size less than pipe size with cables at either end used to pull it through the sewer line.

The packer device shall be constructed in such a manner as to allow a restricted amount of sewerage to flow at all times.

Air-impervious sleeves constructed so that they can be pneumatically expanded, shall be mounted over the cylinder. When the packer is inflated, two widely spaced annular bladders shall be formed, producing an annular void between the cylinder on which they are mounted and the inside wall of the pipe to be sealed. No sealing device which is expanded hydraulically or mechanically will be allowed in order to prevent damage to the pipe.

To insure the complete mixing of the grouting materials from the dual pumping systems, the catalyzed liquid shall be injected from a single orifice on the void area formed by the packer and pipe wall.

The Contractors equipment shall be constructed so that he can furnish representative samples of the grouting material at the request to the Owner. These samples shall be used to test the composition of the material in order to ascertain that it is in conformance with the specifications governing these materials.

406.2.04 SEALING MATERIALS

Sealing Material. Sealing materials shall be a chemical sealant solution containing the principal chemical sealant constituent and a catalyst system recommended by the manufacturer. The principal chemical sealant constituent and the catalyst system shall be of the same manufacturer, specifically recommended for the purpose of sealing leaks in sanitary sewer lines and/or stabilization of earth masses. The chemical sealant used shall have documented service of satisfactory performance in similar usage.

The base solution shall be varied by the addition of from 3% to 5% by weight of total mix, of suspended solids for increased strength. This material may be of a diatomaceous earth like Celite 209 or an approved equal, and which also must be agitated to remain in suspension.

Because of the possible toxicity of mixing and handling the sealant materials by passing through the unbroken skin, by inhalation of dust or droplets of the material, or by swallowing, the contractor will be required to provide whatever protection necessary to prevent anyone from coming in contact with the chemicals.

Handling and mixing shall by performed with proper equipment and personnel thoroughly familiar with the chemical involved and in accordance with the provisions of the Occupational Safety and Health Act of 1970 of the U.S. Department of Labor.

All grouting materials shall be delivered to the project in the unopened, clearly labelled, manufacturer's containers. Labels shall include no less information than the name of the manufacturer, name and chemical formula of the contents, weight, and date produced. Materials not listing this minimum of information may be rejected.

406.2.04A TYPES OF GROUT

ACRYLAMIDE GEL. This chemical grout shall consist of an intimate mixture of dry Acrylamide and dry N,-methylene-bis-acrylamide, in proportions of no less than ten percent (10%) or approved equal.

The chemical sealant in its gel form. after final reaction, shall be a stiff gel (shall not be rigid or brittle) that is impermeable.

The catalyst may be triethanolamine.

Where roots were encountered during cleaning operations, a root inhibitor such as diclobenil shall be added according to manufacturers recommendations.

URETHANE FOAM. This chemical grout is a liquid prepolymer (such as 3M Brand Grouting compound or approved equal) that cures when mixed with water to form a flexible cellular-rubber foam gasket.

The Urethane Foam sealing materials shall have the following basic properties:

a) A controllable cure time from 15 minutes at 40 degrees F. to 4.8 minutes at 100 degrees F. when reacted by water only.

b) When an accelerator is used, cure time shall range from 5.5 minutes at 40 degrees F. to 2.6 minutes at 100 degrees F.

c) Viscosity of the sealing material shall be controlled to between 300 and 350 centipoise.

d) The liquid prepolymer shall contain solid or active material constituting 82-88% of its weight.

e) During injection, foaming and expansion should take place causing steadily increasing viscosity.

f) Physical properties of the cured foam should be approximately 14 lbs/ft^3 density, and 80-90 psi tensile strength and 700-800% elongation.

406.2.05 WATER

The Contractor is referred to SCS 105.12, as amended by these specifications.

406.3.02 SEALING PROCEDURES

Sealant materials shall be pumped at pressures in excess of ground water pressure into the void area between the pipe and the packer, and through the leak into the soil surrounding the pipe. The pressure used shall be less than that necessary to cause grout leakage at the end elements of the packer.

The method and procedure of sealing shall be similar to that used by Gelco Grouting Service or the Penetryn System, Inc. or equivalent as approved by the Engineer.

The sealing repair shall be performed by skilled operators thoroughly familiar with the handling of the chemicals involved. Chemicals for the sealing shall by approved by the Engineer prior to use.

The method of sealing shall be such that the original cross sectional area and shape of the interior of the sewer pipe shall not be permanently reduced or changed. Sealing materials that set to a hard rigid product that might intrude into the sewer line will not be acceptable. In the event that damaged of root-filled service connections and structural failures are discovered during the inspection of the line, the Contractor shall accurately locate such and report them to the Owner. It will be the Owner's option to repair the damaged or root-filled service connections and structural failures with his own forces. If, in the course of the Contractor's work, the sewer pipe is damaged by the application of air pressure to the packer or by any other cause directly attributable to the Contractor's work under the contract, he shall immediately cease work and report the problems encountered to the Owner. It will then be the Owner's responsibility to determine the course of action to be taken. Failure of the Contractor to report pipeline damage shall shift responsibility for repair thereof to the Contractor.

Prior to performing the post-sealing pressure tests, the contractor shall scrape or otherwise dislodge any of the gelled grouting material adhering to the inside of the pipe.

The packer sleeve used to isolate the area to be sealed shall be so constructed so as to be able to regulate and monitor the pressures exerted on the inside of the pipe. These pressures shall not exceed 30 psig without prior consent of the Engineer.

406.4.02 JOINT TESTING

After cleaning and T.V. inspection is completed, joint testing may be performed on sewer line joints in order to determine if leakage exists. Small holes, cracks and other defects which can be successfully tested and/or sealed shall be considered in like manner to a sewer line joint.

Joint testing shall be performed by inducing a specified air pressure into the void area which has been created for the purpose of isolating the joint being tested. Continuous monitoring of the void area pressure shall be maintained at all times and recorded on a pressure metering device which accurately displays the pressure to within plus or minus 1/10th of one psi and responds to and records all changes of the pressure in the void area. Systems which have questionable accuracy will not be approved.

Testing procedures shall consist of applying a precise pressure of no less than 6 psig in excess of ground water pressure into the void area which has been recorded on the ground level meter for a sufficient time to stabilize the system, then the application shall cease. The pressure recording meter shall be observed for a period of 15 seconds. Should the pressure in the void area drop 2 psig in the 15 second period, the joint or joints in the void area will have been deemed to fail the test. Any joint failing the test will be re-sealed as detailed in these specifications.

Appendix B - Recommended Specifications for Testing and Grouting

Reference : National Association of Sewer Service Companies, "Recommended Specifications for Sewer Collection System Rehabilitation", National Association of Sewer Service Companies, Altamonte, FL, 1989

SECTION 6 - SEWER PIPE JOINT TESTING

6.1 Intent: The intent of pipe joint testing is to identify those sewer pipe joints that are defective (allowing groundwater to enter the sewer system) and that can be successfully sealed by the internal pipe joint sealing process. Testing of joints which are visibly leaking (infiltrating) is unnecessary because the intent of testing is obviously attained.

6.2 Application: Sewer pipe joint testing is used to test the integrity (tightness or leakage) of individual pipe joints. Testing cannot be performed and will not be required on cracked or broken pipe, building sewers, or sections of pipe between joints.
Note: Testing of structurally sound sections of pipe between joints is, however, used as a control test to simulate a good joint. If such a test is not positive, leakage from the testing device may be indicated, and may make joint testing invalid. Leakage is often caused by debris on the pipe invert which prevents the testing device from making a pressure-tight seal on the pipe ... Better cleaning is required. In concrete pipe, leakage may also be caused by corrosion (roughness) at the crown or porosity of the pipe itself ... In some cases, joint testing (and sealing) cannot be performed.

6.3 Equipment: The basic equipment used shall consist of a television camera, joint testing device (such as a packer), and test monitoring equipment. The equipment shall be constructed in such a way as to provide a means for introducing a test medium, under pressure, into the

VOID area created by the expanded ends of the joint-testing device and a means for continuously measuring the actual static pressure of the test medium within the VOID area only.
VOID pressure data shall be transmitted electrically from the VOID to the monitoring equipment. Example: via a TV picture of a pressure gage located at the VOID, or via an electrical pressure transducer located at the VOID.
All test monitoring shall be above ground and in a location to allow for simultaneous and continuous observation of the television monitor and test monitoring equipment by the Owner's Representative.

6.4 Test Medium: A fluid (liquid or gas) shall be used as the test medium. Both liquid (usually water) and air are acceptable, but the test procedure is different for each.

6.5 Test Pressure: Joint test pressure shall be 3 psi higher than the groundwater pressure, if any, outside the pipe. Groundwater pressure may be determined by positioning the testing device on a visibly infiltrating joint and measuring the resulting VOID pressure with the VOID pressure monitoring equipment.
In the absence of groundwater pressure data, the test pressure shall be equal to 1/2 psi per vertical foot of pipe depth or 3 psi, whichever is greater.
Note: There is generally a practical limit of 10 psi for the test pressure. Most testing devices and sealing packers cannot retain much more than 10 psi between the expanded end elements (sleeves) without leakage (blow-by). This is a function of pipe cleanliness, pipe surface roughness, and the inflation pressure used.

6.6 Test Procedure: Each sewer pipe joint which is not visibly leaking shall be individually tested at the above-specified test pressure (not exceeding a test pressure of 10 psi) in accordance with one of the following procedures.

(a) Liquid Test Procedure

1. The testing device shall be positioned within the line in such a manner as to straddle the pipe joint to be tested.

2. The testing device end elements (sleeves) shall be

expanded so as to isolate the joint from the remainder of the line and create a VOID area between the testing device and the pipe joint. The ends of the testing device shall be expanded against the pipe with sufficient inflation pressure to contain the test liquid within the VOID without leakage past the expanded ends.

3. Water or an equivalent liquid shall then be introduced into the VOID area until a pressure equal to or greater than the required test pressure is observed with the VOID pressure monitoring equipment. If the required test pressure cannot be developed (due to joint leakage), the joint will have failed the test and shall be sealed as specified (see SEWER PIPE JOINT SEALING).

(b) Air Test Procedure

1. The testing device shall be positioned within the line in such a manner as to straddle the pipe joint to be tested.

2. The testing device end elements (sleeves) shall be expanded so as to isolate the joint from the remainder of the line and create a VOID area between the testing device and the pipe joint. The ends of the testing device shall be expanded against the pipe with sufficient inflation pressure to contain the air within the VOID without leakage past the expanded ends.

3. Air shall then be introduced into the VOID area until a pressure equal to or greater than the required test pressure is observed with the VOID pressure monitoring equipment. If the required test pressure cannot be developed (due to joint leakage), the joint will have failed the test and shall be sealed as specified (see SEWER PIPE JOINT SEALING).

4. After the VOID pressure is observed to be equal to or greater than the required test pressure, the air flow shall be stopped. If the VOID pressure decays by more than 2 psi within 15 seconds (due to joint leakage), the joint will have failed the test

and shall be sealed as specified (see SEWER PIPE JOINT SEALING).

6.7 Control Test: Prior to starting the pipe joint testing phase of the work, a two-part control test shall be performed as follows:

(a) To insure the accuracy, integrity, and performance capabilities of the testing equipment, a demonstration test will be performed in a test cylinder constructed in such a manner that a minimum of two known leak sizes can be simulated. This technique will establish the test equipment performance capability in relationship to the test criteria and insure that there is no leakage of the test medium from the system or other equipment defects that could affect the joint testing results. If this test cannot be performed successfully, the Contractor shall be instructed to repair or otherwise modify his equipment and reperform the test until the results are satisfactory to the Owner's Representative. This test may be required at any other time during the joint testing work if the Owner's Representative suspects the testing equipment is not functioning properly.

(b) After entering each manhole section with the test equipment, but prior to the commencement of joint testing, the test equipment shall be positioned on a section of sound sewer pipe between pipe joints, and a test performed as specified. This procedure will demonstrate the reality of the test requirement, as no joint will test in excess of the pipe capability. Should it be found that the barrel of the sewer pipe will not meet the joint test requirements, the requirements will be modified as necessary.

6.8 Test Records: During the joint testing work, records shall be kept which include...

Identification of the manhole section tested;
The test pressure used;
Location (footage) of each joint tested;
A statement indicating the test results for each joint tested.

The NASSCO Inspector Handbook contains a detailed explanation of the recommended joint test method. An understanding of the variables (test device design, water in the pipe, leak location, groundwater pressure, test medium ... water/air) provides a rationale for the recommended procedure.

SECTION 7 - SEWER PIPE JOINT SEALING

7.1 Intent: It is the intent of the sewer pipe joint sealing work to seal sewer pipe joints which have leakage rates of 1/4 gallon per minute or more utilizing the internal joint sealing method. It is realized that this method may only be used on sewer pipe sections in sound physical condition. Longitudinally cracked or broken pipe will not be sealed. When bell cracks or ships are evident from pipe section offset, sealing may be undertaken where the offset is small enough to allow proper seating of the sealing packer on both sides of the joint to be sealed.

7.2 Equipment: The basic equipment shall consist of a closed-circuit television system (see TELEVISION INSPECTION), necessary chemical sealant containers, pumps, regulators, valves, hoses, etc., and joint sealing packers for the various sizes of sewer pipes. The packer shall be cylindrical and have a diameter less than the pipe size and have cables attached at each end to pull it through the line. The packer device shall be constructed in a manner to allow a restricted amount of sewage to flow. Generally, the equipment shall be capable of performing the specified operations in lines where flows do not exceed the maximum line flows for joint testing/sealing (see SEWER FLOW CONTROL).

7.3 Joint Sealing Procedure: Joints showing visible leakage or joints that have failed the joint test specified (see SEWER PIPE JOINT TESTING), shall be sealed as specified. Joint sealing shall be accomplished by forcing chemical sealing materials into or through faulty joints by a system of pumps. hoses, and sealing packers. Jetting or driving pipes from the surface that could damage or cause undermining of the pipe lines shall not be allowed. Uncovering the pipe by excavation of pavement and soil (which would disrupt traffic, undermine adjacent utilities and structures, and cause further damage to the pipe lines being repaired) shall not be allowed. The packer shall be positioned over the faulty joint by means of a measuring device and the closed-circuit television camera in the line. It is important that the procedure used by the Contractor for positioning the packer be accurate to avoid overpulling the packer and thus not effectively sealing (grouting) the intended joint. The packer ends (end elements, sleeves) shall be expanded using controlled pressure. The expanded ends shall seal against the inside periphery of the pipe to form a VOID area at the faulty joint, mow completely isolated from the remainder of the pipe line. Into this isolated area, sealant materials shall be pumped through the hose system at controlled pressures which are in excess of groundwater pressures. The pumping unit, metering equipment, and the packer device shall be designed so that proportions and quantities of materials can be regulated in accordance with the type and size of the leak being sealed.

7.4 Joint Sealing Verification: Upon completing the sealing of each individual joint, the packer shall be deflated until the VOID pressure meter reads zero pressure, then reinflated and the joint retested as specified (see SEWER PIPE JOINT TESTING). Should the VOID pressure meter not read zero, the Contractor shall clean his equipment of residual grout material of make the necessary equipment repairs/adjustments to produce accurate VOID pressure readings. Joints that fail to meet the specified test criteria shall be resealed and retested until the test criteria can be met in order to receive payment.

7.5 Residual Sealing Material: Residual sealing materials that extend into the pipe, reduce the pipe diameter, or restrict the flow shall be removed from the joint. The sealed joints shall be left reasonably "flush" with the existing pipe surface. If excessive residual sealing materials accumulate in the line (and/or if directed by the Owner's Representative) the manhole section shall by cleaned to remove the residual materials.

7.6 Records: Complete records shall be kept of joint sealing performed in each manhole section. The records shall identify the manhole section in which the sealing was done, the location of each joint sealed, and the joint sealing verification results (see SEWER PIPE JOINT TESTING, Test Records).

7.7 Guaranty: All sewer pipe joint sealing work performed shall be guaranteed against faulty workmanship and/or materials for a period of one year after the completion of the work.
Prior to the expiration of the guaranty period, an initial retest area consisting of specific manhole sections shall be selected by the Engineer/Owner. Manhole sections to be retested shall be randomly selected throughout the project area and shall be representative of the majority of the sealing work originally performed. The initial test area shall consist of at least 5%, but not exceed 10%, of the linear feet contained in the original project.
Within the initial retest area, the Contractor shall retest all previously sealed joints as specified (see SEWER PIPE JOINT TESTING). Any joints failing the retest shall be resealed. If the failure rate of the retested joints is less than 5% of the joints tested, the work shall be considered satisfactory and no further retesting will be required. Payment for retesting the initial area shall be at the unit price bid for each item of work required (e.g.: cleaning, TV inspection. testing, etc.). No compensation shall be provided for resealing (grouting) joints that fail.
If, in the initial retest area, the failure rate of the retested joints exceeds 5% of the joints retested, an additional retest area of equivalent size shall be selected and all previously sealed joints shall be retested. This additional testing and sealing, if necessary, will continue until a failure rate of less than 5% is met. Any additional testing/sealing required beyond the initial retest area shall be accomplished at no cost to the Owner.
Should as much as 25% of the original project be retested and fail to meet the 5% requirement, the Contractor will be required to provide the same number of crews as utilized in the original project so that the retesting will proceed at a more rapid rate.

The NASSCO Inspector Handbook contains a detailed explanation of sewer pipe joint sealing including history, proper application, conditions required, fluid mechanics of the procedure, grout dilution, and monitoring VOID pressure.
Note: The mixing of chemical root treatment materials with chemical sealing materials can have a disastrous effect on

chemical grout performance and is strongly discouraged. Pipes needing sealing are usually below groundwater and usually do not have roots. Pipes having roots are usually above groundwater.

Appendix C - Summary of Contacts Made During Research

The following represents a summary of the municipalities, contractors, manufacturers, and recognized authorities contacted during this research project and key information obtained from those who provided it.

Contact/Municipality	Key Information
Scotty McMillan Supervisor Maintenance/Inspection Little Rock Wastewater Utility Little Rock, AR	Grout Program Description
Bert McCollam Flood Control and Sewers Manager City of Sacramento Sacramento, CA	Management of Sewer Maintenance
Lawrence Rugaard District Manager/Engineer Stege Sanitary District El Cerrito, CA	<u>Sewer System Evaluation Survey Report For Stege Sanitary District</u>
Chuck Striffler/Thomas King Director of Utilities/ Utility Superintendent Brevard County Water/Wastewater Division Merrit Island, FL	Past experience with chemical grout. Grout Program Description
Jim Wilson Trades Foreman, T.V. Section Orange County Public Works Division Orlando, FL	Grout Program Description

Contact/Municipality	Key Information
Tom Feger Sewer Engineer City of Springfield Springfield, IL	Collection System Description
Casey Smith Collection Systems Manager Department of Public Works Baton Rouge, LA	Management of Sewer Maintenance
Philip Hannan, P.E. Division Head, Maintenance Reconstruction Division Washington Suburban Sanitary Commission Hyattsville, MD	National Alternative Methodology for Sewer System Evaluation
Paul Saey, Jr. Watershed Supervisor Metropolitan St. Louis District St. Louis, MO	Grout Program Description
Henry Gregory Manager, Wasteload Control Dept. of Public Works City of Houston Houston, TX	Pipe corrosion effects on the ability to grout sewer lines
Paul Huston Chief, Infiltration Abatement Branch - Line Maintenance Division County of Fairfax Burke, VA	Grout Program Description

Contractor/Manufacturer	Key Information
Bob Summers Hanson Software, Inc Sacramento, Ca	"Wastewater Collection Management System" (WCMS) Capabilities

Contractor/Manufacturer	Key Information
William Clark President Geochemical Corporation Ridgewood, NJ	AC-400 chemical grout literature
Vi McCoy Technical Representative Gelco Supply Co. Salem, OR	Insituform literature
CUES, Inc Orlando, FL	Chemical grouting equipment literature
F. David Magill, Jr., P.E. President Avanti International Webster, TX	Chemical grouting products literature
Lori Walton Sales Service Coordinator 3-M Products St. Paul, MN	Chemical grouting products literature

Other Contacts	Key Information
Richard Field U.S. Environmental Protection Agency - Municipal Environmental Research Laboratory Edison, NJ	Importance of service laterals in comprehensive I/I control programs
Lam Lim U.S. Environmental Protection Agency - Municipal Construction Division Washington, D.C.	<u>Evaluation of Infiltration/Inflow Program - Final Report</u>
National Association of Sewer Service Companies (NASSCO) Altamonte, FL	<u>Recommended Specifications for Collection System Rehabilitation</u>