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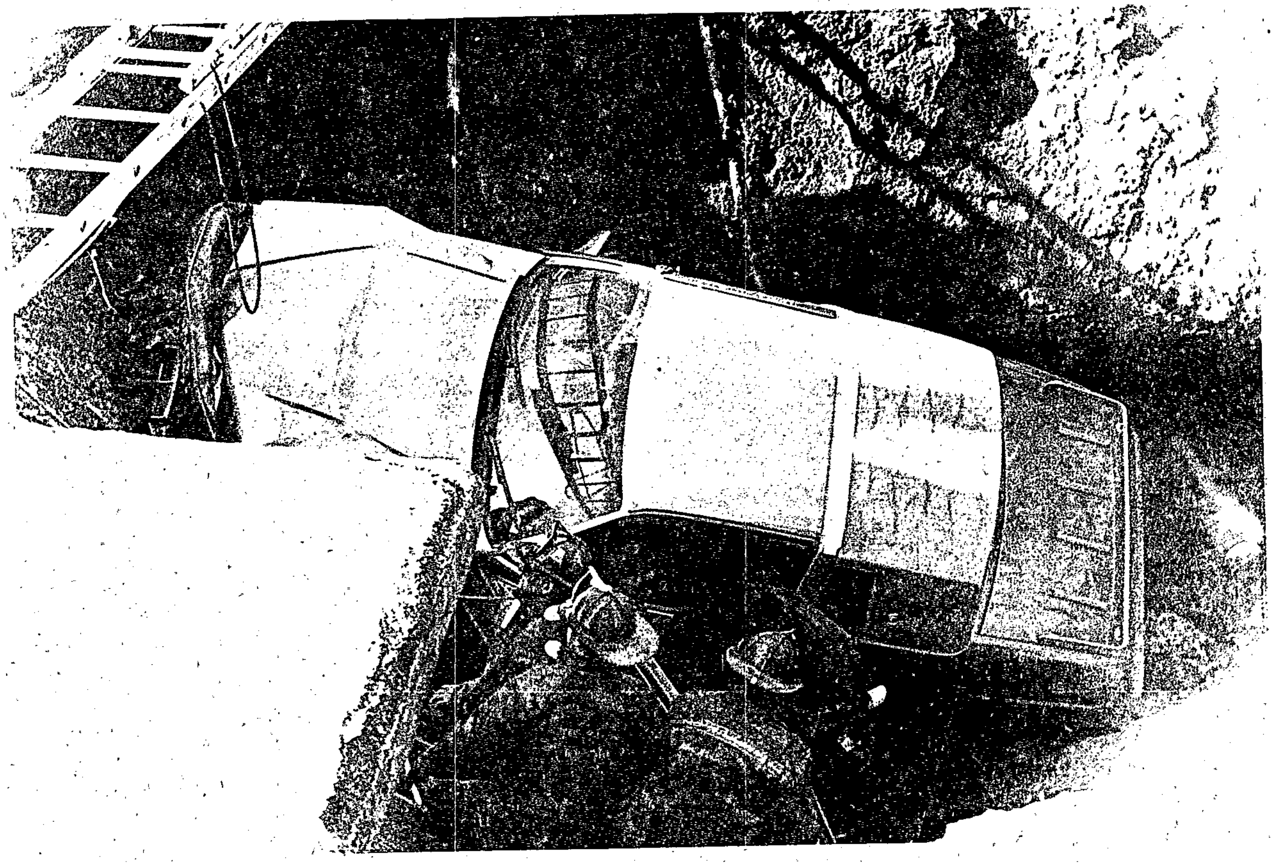
Hydrogen Sulfide Corrosion: Its Consequences, Detection and Control



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The information in this document is a summary of the larger, detailed report entitled, *"Detection, Control, and Correction of Hydrogen Sulfide Corrosion in Existing Wastewater Systems."* Mention of trade names or commercial products does not constitute endorsement by EPA. Omission of certain products from this document does not reflect a position of EPA regarding product effectiveness or applicability.

Cover: Unexpected Street Collapse Due to Sewer Corrosion
(photo courtesy of Insituform, Inc.)

Introduction

Is undetected hydrogen sulfide corrosion causing steady deterioration of your sewerage system? Will you be faced with costly sewer replacement or rehabilitation projects in ten or twenty years even though the design life of the system may be fifty years or more? Unfortunately, many municipalities do not recognize corrosion problems until extensive damage has occurred, such as a sewer collapse or equipment failure. The cost to repair or replace pipes, equipment and structures deteriorated by hydrogen sulfide corrosion may exceed by many times the cost to control the corrosion and avoid infrastructure damage. Nationally, the cost to repair corrosion damage by hydrogen sulfide is in the billions of dollars, and many communities will spend millions of dollars in the next few years to correct corrosion problems. Severe corrosion experienced in Los Angeles County and municipalities throughout the United States prompted Congress to direct the U.S. Environmental Protection Agency to conduct a national assessment of the problem, resulting in the *Report to Congress: Hydrogen Sulfide Corrosion in Wastewater Collection and Treatment Systems* in 1990. As a follow-up to that work, a technical handbook was prepared entitled *Detection, Control, and Correction of Hydrogen Sulfide Corrosion in Existing Wastewater Systems.* This brochure provides an overview of that document.

Sewer replacement can be a very costly proposition, especially in urban areas.

What Are The Implications Of Hydrogen Sulfide Corrosion?

Consequences of H_2S Corrosion

The presence of hydrogen sulfide can lead to rapid and extensive damage to concrete and metals used in the construction of wastewater collection and treatment systems. Sewers, pump stations, and treatment facilities, including electrical controls, instrumentation, process equipment, tankage and ventilation systems can be affected. In the U.S. the problem is not limited to warm climates, and it is rarely brought to the attention of the public until a catastrophic event occurs, such as a sewer collapse resulting in street cave-in. Hydrogen sulfide corrosion in wastewater systems often results in costly, premature replacement or rehabilitation of systems used in the transport and treatment of wastewater. Sewers designed to last 50 to 100 years have failed due to hydrogen sulfide corrosion in as little as 10 to 20 years. Electrical and mechanical equipment with an expected source life of 20 years has required replacement in as little as five years.

Social and Economic Costs

The economic implications of hydrogen sulfide corrosion are staggering. A 1989 study conducted by the Sanitation Districts of Los Angeles County estimated that over $150 million is currently needed to repair or replace 25 miles of extensively damaged sewers. An additional $35 million may also be required to repair or replace 16 miles with moderate corrosion unless it can be controlled. The report further states that if the additional 500 miles of sewers were to be severely damaged by corrosion, their replacement cost would be $1 billion. Similarly, the City of Houston currently estimates the cost of its sewer rehabilitation program at $477 million. Seventy percent of the problem is attributed to hydrogen sulfide corrosion. On a national scale, sewer rehabilitation alone is estimated to cost $6 billion. In addition to direct costs associated with planned sewer repairs and replacement, unplanned replacement costs resulting from sewer collapse and the increase in preventative maintenance costs are similarly very high. It is clearly evident that a means to detect, control and correct hydrogen sulfide corrosion in existing wastewater systems is the preferred alternative to premature replacement of system components.

Hydrogen sulfide is an odorous, toxic gas. Each year, deaths result from exposure of workers to hydrogen sulfide gas in confined spaces. Odor complaints result from neighbors living near wastewater handling systems who are exposed to low levels of the gas. Although difficult to quantify, these costs are substantial.

What Causes Hydrogen Sulfide Corrosion?

■ Mechanism of Sulfide Corrosion

Hydrogen sulfide corrosion can occur by two mechanisms: 1) acid attack resulting from the biological conversion of hydrogen sulfide gas to sulfuric acid in the presence of moisture, and 2) direct chemical reaction with metals such as copper, iron and silver with hydrogen sulfide gas. The first mechanism is the one which is the principal cause of internal sewer corrosion, while the second can cause premature failure of electrical and instrumentation systems, and mechanical equipment used in the transport and treatment of wastewater.

The principal mechanism by which sulfide generation and corrosion occurs in sewers is illustrated in Figure 1, while Figure 2 depicts the process by which hydrogen sulfide corrosion causes sewer failure.

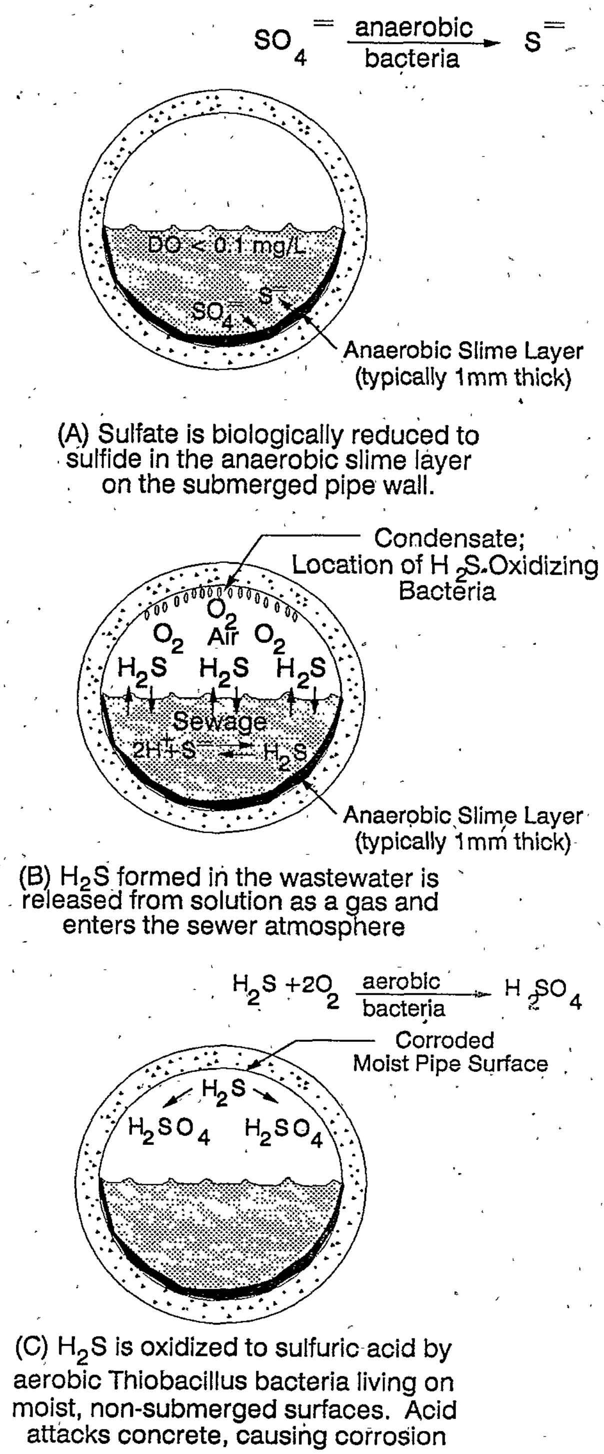


Figure 1. Mechanism of Sulfide Generation and Corrosion in Sewers

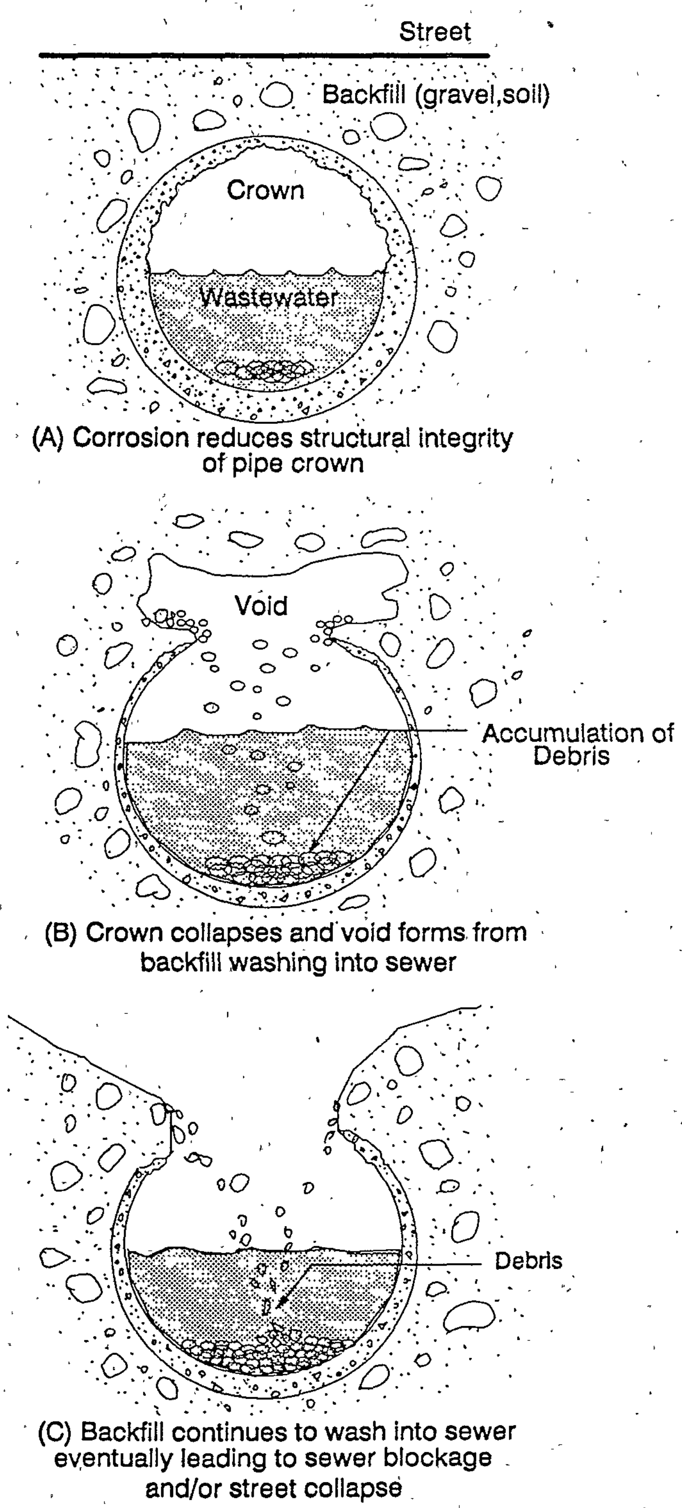


Figure 2. Process of Sewer Failure Due To Hydrogen Sulfide Corrosion

Factors Affecting Corrosion of Sewers

Four conditions must be satisfied in order for hydrogen sulfide corrosion to take place in sewers:

1. Absence or very low levels of dissolved oxygen in the wastewater
2. Generation of sulfide in the wastewater and release of hydrogen sulfide gas from solution
3. Presence of moisture on the material to be corroded
4. Material which is subject to corrosion by sulfuric acid attack.

Dissolved oxygen depletion is affected by sewage velocity, wastewater characteristics, detention time and temperature. When the dissolved oxygen is depleted, the rate of sulfide generation is controlled by the concentration of organic materials, nutrients and temperature. The subsequent release of hydrogen sulfide gas to the atmosphere of a sewer, wet well or other confined space is dependent upon the sewage pH, extent of turbulence and wastewater temperature. Finally, the rate of corrosion is governed by the temperature, the quantity of hydrogen sulfide available to be biologically converted to sulfuric acid, and the material's inherent resistance to acid attack.

In wastewater treatment plants, damage can be caused by two mechanisms: 1) acid attack as described above, and 2) direct attack of metals such as iron and copper by hydrogen sulfide.

How Do I Know If A Corrosion Problem Exists?

It is essential that corrosion problems be identified early while the corrosion can still be controlled. Otherwise you may be faced with the high cost of sewer replacement or rehabilitation, and/or premature replacement or reconstruction of mechanical equipment, structures and electrical controls used in wastewater pumping stations and treatment plants. Corrosion detection and monitoring can be conducted economically, and the cost of such programs is only a small fraction of the cost to repair damage caused by hydrogen sulfide corrosion. Figure 3 shows a flow diagram of the basic steps involved in identifying existing or potential corrosion problems.

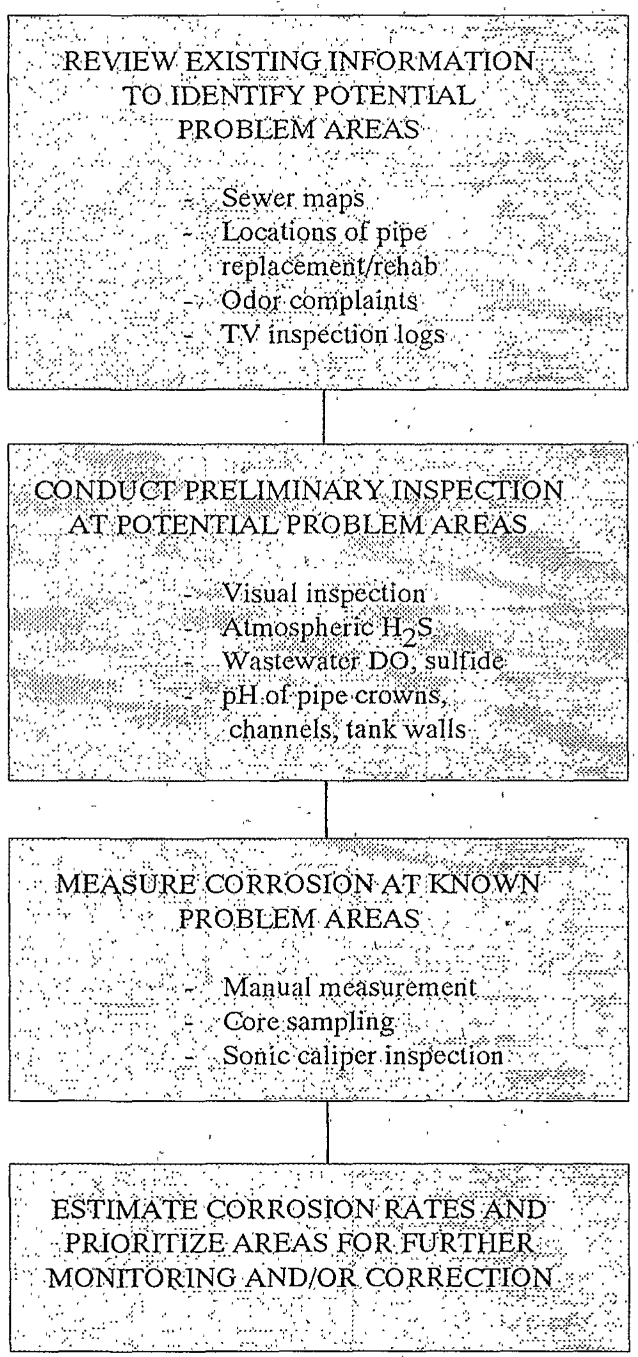
Identifying Potential Problem Areas

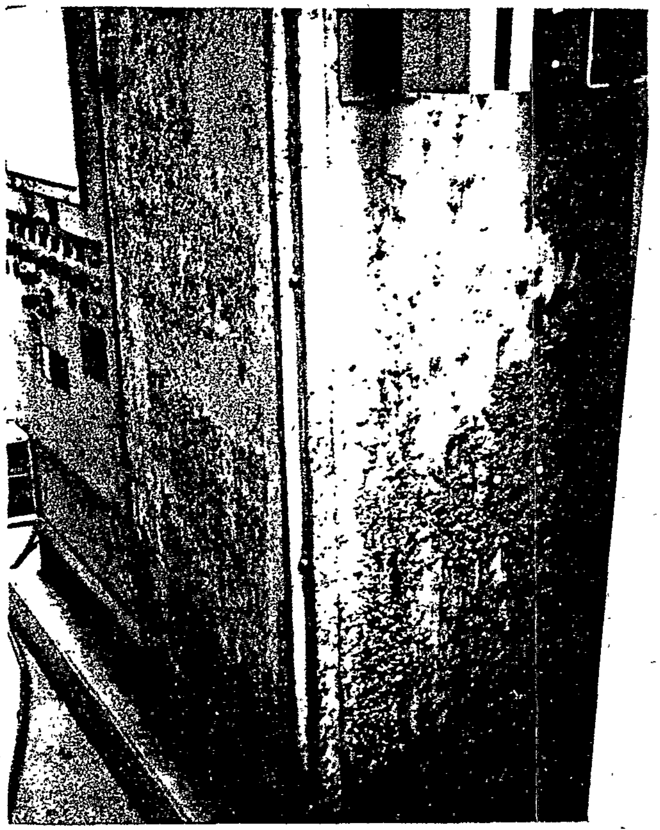
Hydrogen sulfide corrosion can be detected at many locations in wastewater collection and treatment systems. Areas where corrosion is likely to be found include the following:

- Sewers with flat slopes, low wastewater velocities, and long detention times
- Manholes and junction chambers
- Force main discharges
- Areas of high turbulence
- Pump station wet wells
- Treatment facility headworks
- Primary clarifier effluent channels
- Sludge handling structures and equipment
- Heating, ventilating, electrical and instrumentation systems

Hydrogen Sulfide Corrosion Can Significantly Reduce the Useful Life of Sewers.

Figure 3. Approach to Identifying Existing and Potential Corrosion Problems





Hydrogen Sulfide Corrosion Can Cause Premature Failure of Electrical Systems Used in Pump Stations and Treatment Plants.

Sewer maps should be gathered, updated and reviewed along with any odor complaint logs, videotapes of sewers, maintenance records and any other information sources that are available. Locations of potential corrosion problems, such as discharges of force mains, areas of odor complaints, pump stations, and plant headworks should be highlighted on a sewer map for further investigation. Figure 4 shows a typical sewer map with potential trouble spots targeted for inspection.

■ Conducting Inspections

A visual inspection should be conducted wherever possible. If entry into a manhole or confined space is required, precautionary measures as directed by OSHA and NIOSH should be carefully followed. A low-power scope used in conjunction with a mirror and a light source mounted at the end of a long rod can be used to inspect sewers without entry.

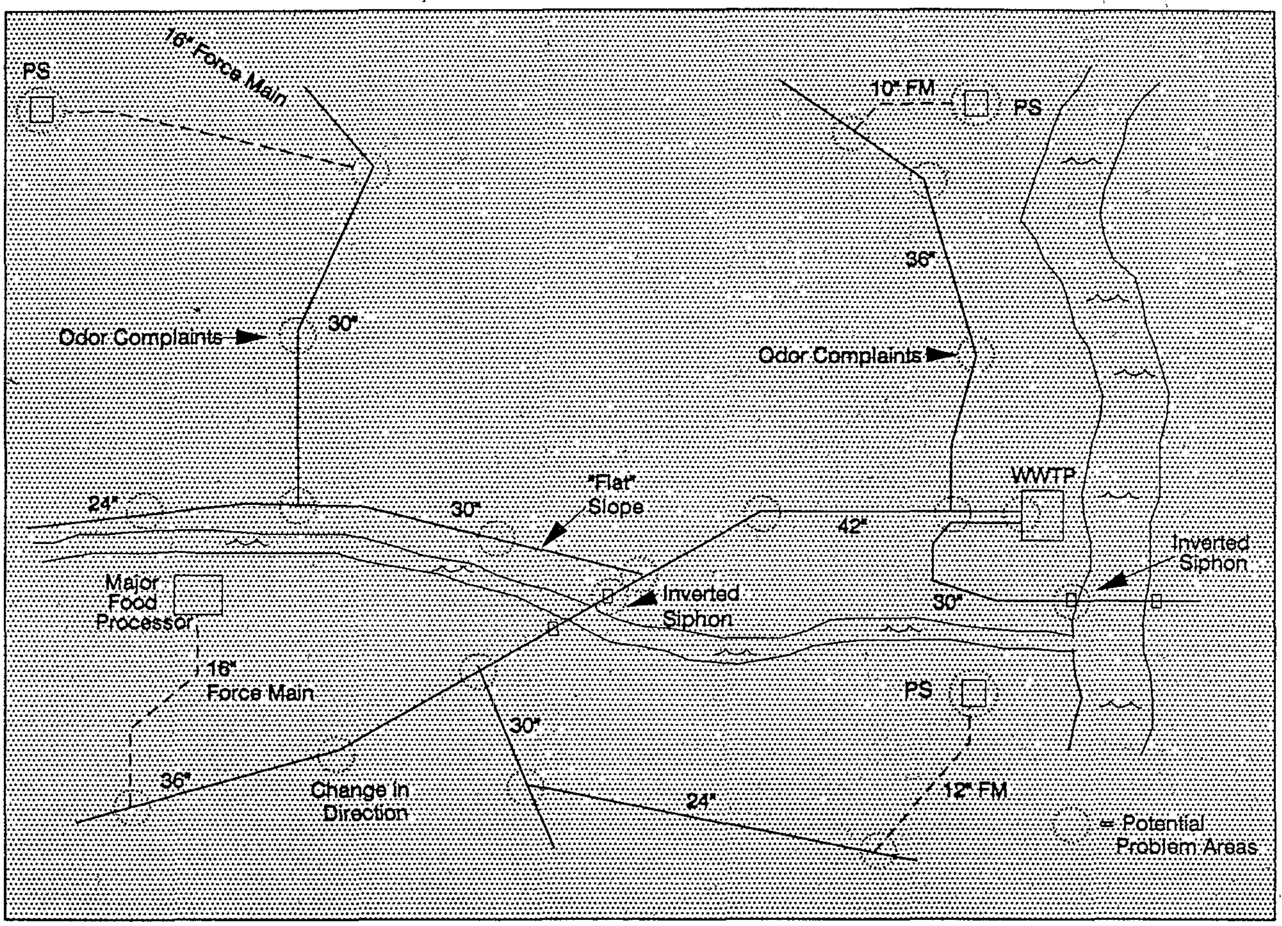
Measuring pH of pipe crowns, and walls of manholes, junction chambers and other confined spaces is probably the best early warning that a potential or existing corrosion problem exists. Color-sensitive pH paper can be used to determine the concrete surface pH. New pipe has a pH of about 10 but under corrosive conditions, pH may be 2 or lower. Generally, pH values below 4 are indicative of corrosion problems.

Atmospheric H_2S is also a useful indicator of potential corrosion problems. Dissolved sulfide concentrations in the wastewater should also be measured. The conditions of the sewer or structure, as well as other data collected, should be entered on an inspection checklist.

■ Measuring and Predicting Corrosion

Several techniques are available to measure the extent of corrosion. A simple but often inaccurate method is to remove the corrosion product down to sound concrete and measure the depth of penetration. Extendable rods are also used to measure the inside diameter of the sewer. Coring of pipe crowns at corroded and uncorroded reaches provides good documentation of corrosion severity, and can be used to estimate depth of corrosion penetration and the thickness of remaining concrete over reinforcing steel.

Figure 4. Sewer Map Showing Locations of Potential Corrosion Problems



A remote method of measuring corrosion is the sonic caliper. Sonic caliper technology is a relatively new development whereby sonic signals determine the distance from the transmitter to the target (e.g. crown, waterline, invert). Television inspection cannot be used to measure corrosion, but it can provide a relative indicator of the severity of corrosion to the trained observer.

Predictive models exist to allow estimates of the rate of hydrogen sulfide generation and corrosion, and the anticipated service life of a sewer or structure. These empirical equations are presented in publications by the U.S. Environmental Protection Agency, the American Society of Civil Engineers and the American Concrete Pipe Association. As with all predictive models, actual data should be collected to confirm and calibrate the predictive equations.

■ Prioritizing Problem Areas

Rates of corrosion can be estimated based on physical measurements or predictive models. Where data are available on depth of corrosion penetration, average corrosion rate can be calculated by dividing corrosion depth by the age of the pipe or structure. The remaining useful lifetime of the pipe can then be estimated based on, for example, corrosion reaching reinforcing steel. This information serves as a basis for prioritizing areas for corrective action. For example, if severe damage has already occurred, replacement or rehabilitation may be necessary. If damage is not extensive but the service life has been significantly reduced, implementation of a corrosion control program may be warranted.

How Do I Control Corrosion?

There are several methods available to control the rate of hydrogen sulfide corrosion. These include 1) reducing the dissolved sulfide content of the wastewater, 2) using corrosion-resistant materials and coatings, 3) providing ventilation of the enclosed area or sewer, and 4) conducting routine preventative maintenance. These techniques are discussed below and presented in Table 1.

■ Dissolved Sulfide Reduction

Atmospheric hydrogen sulfide levels can be reduced by controlling the amount of dissolved sulfide available in the wastewater. Three basic techniques are used to achieve this goal.

1. Oxidation by addition of chemical oxidants such as hydrogen peroxide, chlorine or potassium permanganate, or by the introduction of air or oxygen.
2. Precipitation of dissolved sulfide by the addition of metallic salts such as ferrous chloride and ferrous sulfate.
3. pH elevation through the addition of sodium hydroxide (caustic soda).

Table 1. Summary of Corrosion Control Methods

CLASSIFICATION	METHOD	PROCESS
1. Dissolved sulfide reduction		
Oxidation	Oxygen, air, hydrogen peroxide, chlorine or potassium permanganate addition	Chemical or biochemical oxidation of sulfide
Precipitation	Iron salt addition	Chemically binds sulfide to form insoluble precipitate
pH Elevation	Slug doses of sodium hydroxide	Inactivates sulfate-reducing bacteria
2. Corrosion-resistant materials and coatings	Use of corrosion resistant metals, plastics, concrete; application of corrosion resistant paints or coatings	Material is resistant to acid attack; and/or provides effective barrier against H_2S or acid migration
3. Ventilation	Mechanical ventilation of enclosed spaces; purging with clean air or nitrogen	Reduces atmospheric H_2S levels and surface moisture
4. Maintenance	Sewer cleaning by flushing or pigging	Minimizes accumulation of debris that can reduce velocities, increase organic matter deposition and increase sulfide generation

The basic goals and treatment levels for the three basic techniques must be developed individually for each system, but generally the goals strive to meet the following guidelines:

1. Maintain dissolved oxygen greater than 0.5 mg/l.
2. Keep dissolved sulfide levels below 0.3 mg/l.
3. Maintain atmospheric hydrogen sulfide levels below 5 ppm.
4. Increase concrete pH to 4 or greater.

■ Corrosion-Resistant Materials and Coatings

Another method used to prevent corrosion or control the rate of corrosion is to utilize corrosion-resistant materials, both in the collection system and at the wastewater treatment plant. Corrosion-resistant materials fall under the following categories: 1) metallic coatings, 2) metal alloys, 3) corrosion-resistant concrete, and 4) plastics.

Metallic coatings include galvanizing and electroplating systems. Metal alloys include copper, aluminum, nickel, and stainless steel.

The corrosion resistance of concrete can be improved by two ways: 1) use of high alumina or high-silica cement, or 2) use of calcareous (e.g. limestone) aggregate. The use of such concrete in low-pH environments may still lead to concrete degradation but at a somewhat lower rate. In cases where corrosive conditions are anticipated, concrete pipe can be manufactured with a cast-in-place PVC liner.

The use of polyvinyl chloride, polyethylene, fiberglass reinforced polyesters and other plastics are becoming more commonplace in the wastewater field. Many of these materials offer excellent corrosion resistance.

Certain paints and protective coatings can provide some degree of corrosion resistance. Paints and protective coatings include vinyl, epoxy and silicone resin primers and paints. Paints can be classified as either thermoplastic, which is applied hot and cured by cooling, or thermosetting, which cures by chemical reaction with a setting agent. Thermoplastic paints include asphaltic/coal tar and polyethylene; thermosetting paints include polyurethane and epoxy. The proper preparation, application and curing procedures must be closely followed for any coating system to be successful. Even adherence to proper procedures may not result in adequate coating performance in corrosive environments, as the success of such coatings has been highly variable.

■ Ventilation

Ventilation of sewers and enclosed spaces can potentially reduce hydrogen sulfide corrosion by reducing the concentration of hydrogen sulfide in the atmosphere, and by drying the walls of the pipe or structure. Ventilation of sewers apparently had some success for corrosion control in Austin, Texas, Los Angeles, California and Sydney, Australia. Air discharged from a sewer would normally require treatment to control odors. There is some question regarding the effectiveness and practicality of controlling corrosion by this technique.

Ventilation with clean air can be used to control corrosion in electrical cabinets or rooms housing sensitive electronic equipment. Electrical cabinets can be purged with nitrogen to provide excellent corrosion protection.

■ Maintenance

Routine sewer cleaning can be an effective deterrent to the hydrogen sulfide corrosion process. This is because accumulations of debris tend to reduce the wastewater velocity and thus increase its detention time within the sewer, allowing it to become anaerobic. As the wastewater velocity decreases, further deposition of organic matter occurs, which results in increased biological activity, depletion of oxygen, and generation of sulfide. Deposition of solids is likely due to excessively flat sewer grades combined with low flows - these areas should be monitored for solids accumulation. Gravity sewers should be routinely flushed or pressure-washed; force mains may require pigging.

What Options Do I Have To Rehabilitate Corroded Sewers?

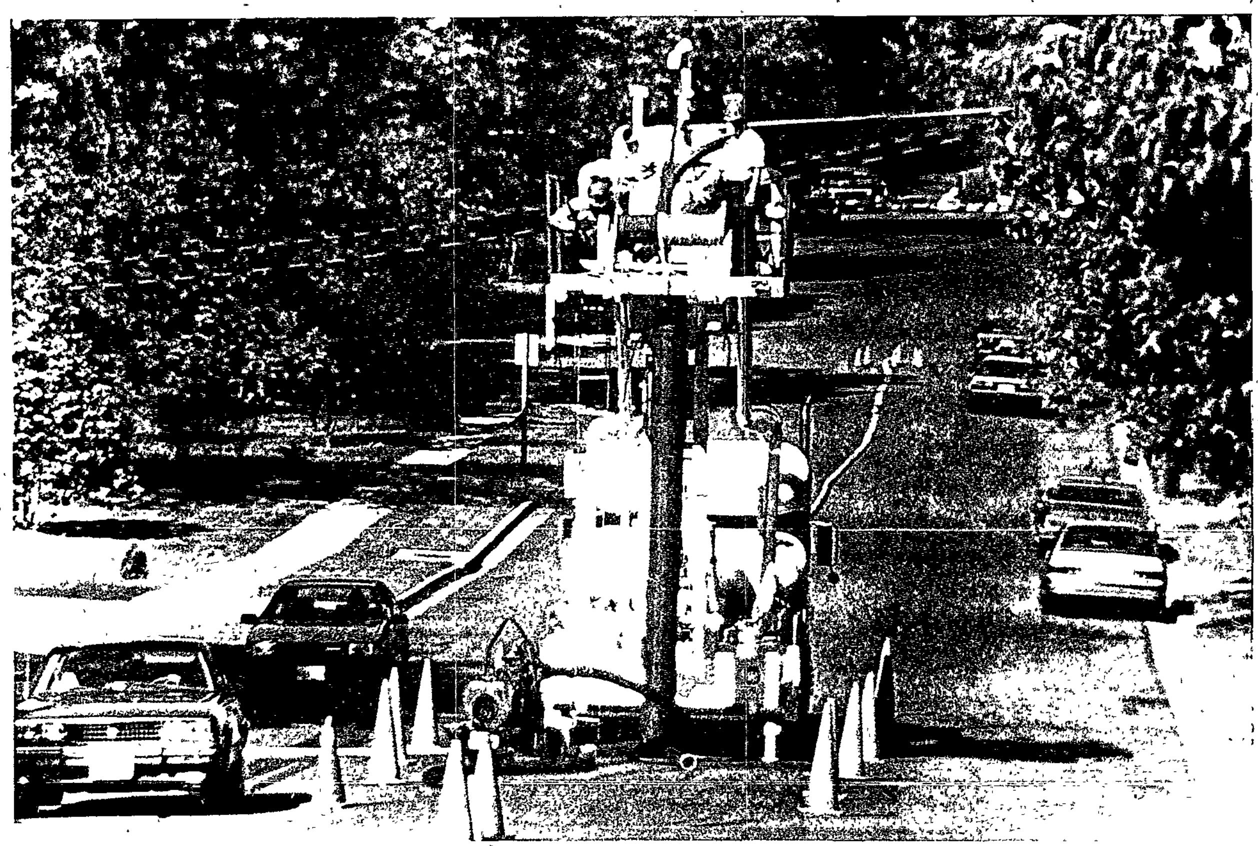
Methods Available

Various methods are available for rehabilitating corroded sewers, and these methods continue to be improved. The basic categories are as follows:

- Excavation and replacement
- Cured-in-place inversion lining
- Insertion renewal
- Liners
- Specialty concrete

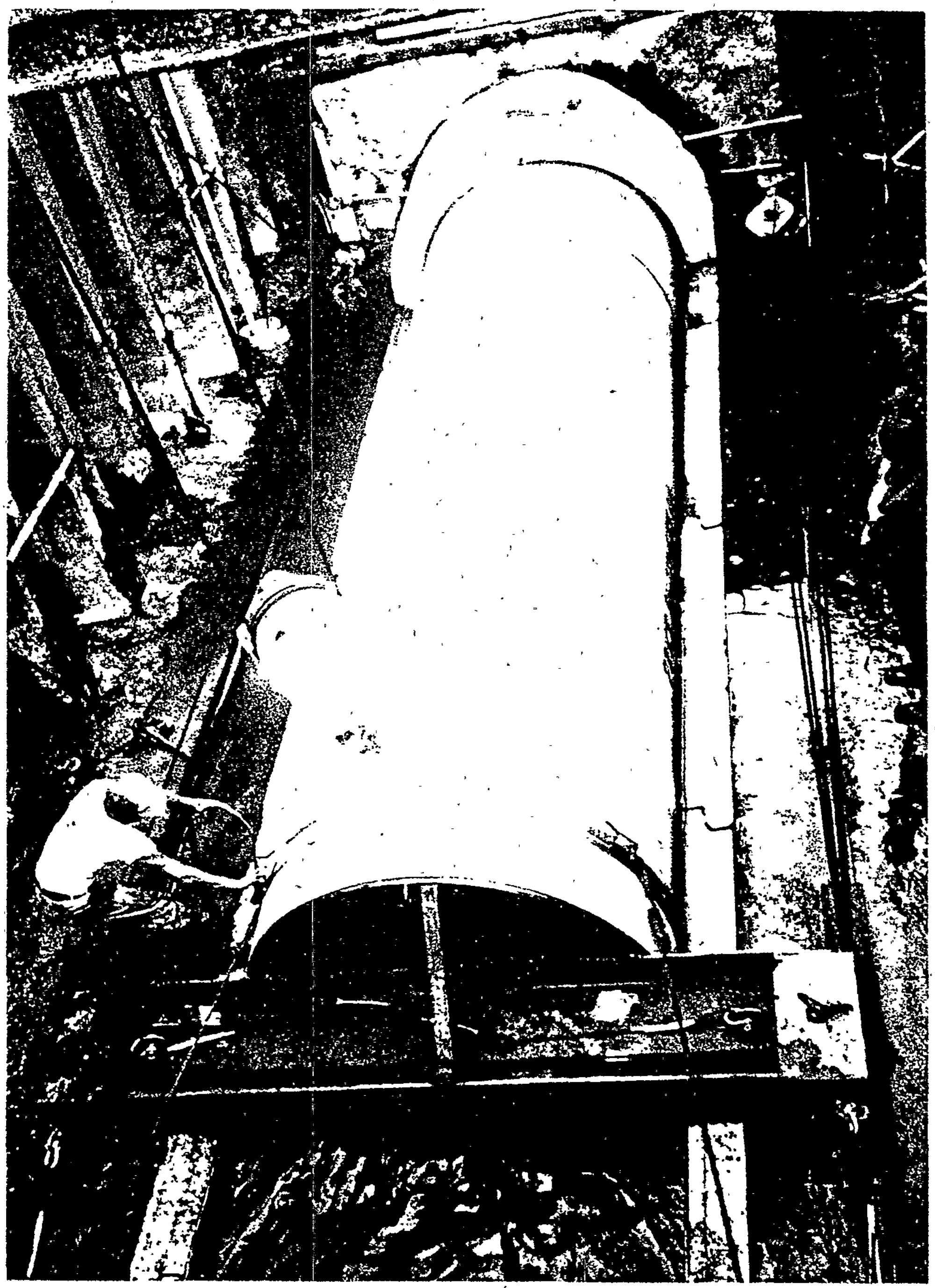
Excavation and replacement is usually the most costly and most disruptive means by which to correct sewer deficiencies. The same problem will likely redevelop however, if a similar noncorrosion-resistant material is used in the replacement without other corrective measures taken to decrease the severity of the corrosion problem.

Trenchless technology is presenting new methods to protect against corrosion. One such method is the use of cured-in-place inversion linings, whereby a flexible "sock" is inserted into the pipeline, set in place by the addition of water, and cured in place.



Rehabilitation Using Cured-in-Place Inversion Lining Can Be An Economical Alternative To Replacement of Severely Corroded Sewers (photo courtesy of Insituform, Inc.)

Insertion renewal consists of jacking a pre-formed pipe through the existing sewer. Some methods involve the use of an insertion pipe of slightly smaller diameter than the existing sewer, while others involve the use of a tool which first breaks away the existing sewer and is followed immediately by the new pipe. An alternate method of insertion renewal involves the use of a deformed pipe which is inserted and then expanded to its final shape.



Insertion of a corrosion-resistant liner made of fiberglass, PVC, or polyethylene is an effective means of sewer rehabilitation (photo courtesy of Price Bros., Inc.).

Liners can be used on larger-diameter sewers. Prefabricated PE or PVC panels are installed onto the existing pipe substrate, forming a continuous interlocking strip.

Specialty concrete consists of different cements and/or aggregates which are more resistant to hydrogen sulfide corrosion than Portland cement concrete. These concretes may still be susceptible to corrosion, though at a reduced rate.

Table 2 summarizes the principal methods of pipeline rehabilitation.

Table 2. Principal Methods for Pipeline Rehabilitation

METHOD	APPLICATION
Insertion Renewal (Sliplining)	Used for cracked or deteriorated sewer pipes.
Deformed Pipe Insertion	Similar applications as for sliplining but for relatively small (<24) circular pipe.
Cured-in-Place Inversion Lining	Sewer pipe of any geometry; largest current application is for 96 inch diameter pipe.
Specialty Concrete (Spot repair)	Large sewers or manholes needing structural repairs.
Coatings	Rapidly growing method for pipes and manholes with new application methods being marketed continually; variable effectivness.
Liners	Should be used only in structurally sound sewers. Can easily fit variations in grades, slopes, cross-section for manually applied strip applications.
Pipe Replacement	Any pipe with major structural defects.
Exterior Wrap and Cap	Provides back-up corrosion protection and structurally reinforces existing pipeline. Similar method applicable to monolithic structures.

■ Selecting a Rehabilitation Technique

The rehabilitation method to be used in pipeline repair is dependent upon the actual condition of the existing sewer, its location, number of service connections, surface cover and intended service life. These factors also directly impact the cost to perform the work.

In cases where the wastewater flow within the existing pipe cannot be diverted, sliplining may be the only practical approach short of constructing a new sewer. In most situations however, both tangible and intangible factors will enter into the decision-making process.

Conclusions

- Hydrogen sulfide corrosion is suspected to occur in over 50% of all wastewater collection and treatment facilities, regardless of geographic location, age or size. In some cases, the first sign of hydrogen sulfide corrosion problems is a sewer collapse or other catastrophic failure.

- On a national scale, the cost to correct existing corrosion problems is estimated to be in the billions of dollars. Many communities will need to spend millions of dollars in the near future to address the consequences of hydrogen sulfide corrosion.

- Establishing a corrosion monitoring plan and conducting corrosion inspections as part of routine operation and maintenance will provide valuable information on the conditions of existing systems, shed insight into the causes of hydrogen sulfide corrosion problems, and allow selection of cost-effective approaches to control corrosion.

- The end result will be collection systems and treatment facilities that last longer and operate more efficiently.

- The cost of monitoring and control of corrosion will be easily offset by the savings accrued by avoiding premature replacement or rehabilitation.

Sources of Additional Information

Several recent publications are available from EPA that address the problems of hydrogen sulfide corrosion, procedures for detecting and controlling corrosion, and methods for rehabilitating corroded sewers and structures. These include

1) *Hydrogen Sulfide Corrosion in Wastewater Collection and Treatment Systems, Report to Congress;*

2) *Detection, Control, and Correction of Hydrogen Sulfide Corrosion in Existing Wastewater Systems*; and

3) ***Handbook - Sewer System Infrastructure Analysis and Rehabilitation.***

These and other relevant publications are listed in Appendix A. Questions regarding the EPA publications listed above may be directred to the EPA Office of Wastewater Enforcement and Compliance, Municipal Technology Branch at (202) 260-7356, or to one of the EPA Regional Offices shown in Appendix B.

References

1. Morton, R., R. Caballero, Ching-Lin Chen and J. Redner, *Study of Sulfide Generation and Concrete Corrosion of Sanitary Sewers.* In-house report; Sanitation Districts of Los Angeles County, Whittier, CA, 1989.

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3. *A Guide to Safety in Confined Spaces,* National Institute for Occupational Safety and Health (NIOSH), No. 87-113, Morgantown, WV.

4. Bowker, R.P.G., J.M. Smith, and N.A. Webster, *Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants, Design Manual,* U.S. Environmental Agency, Center for Environmental Research, Cincinnati, OH, 1985.

5. *Sulfide in Wastewater Collection and Treatment Systems,* ASCE Manual No. 69, American Society of Civil Engineers, New York, NY, 1989.

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

7. Redner, J.A., R.P. Hsi, and E.J. Esfandi, *Progress Report - Evaluation of Protective Coatings for Concrete,* paper presented at EPA Technology Transfer Seminar on Sewer System Infrastructure Analysis and Rehabilitation, 1991.

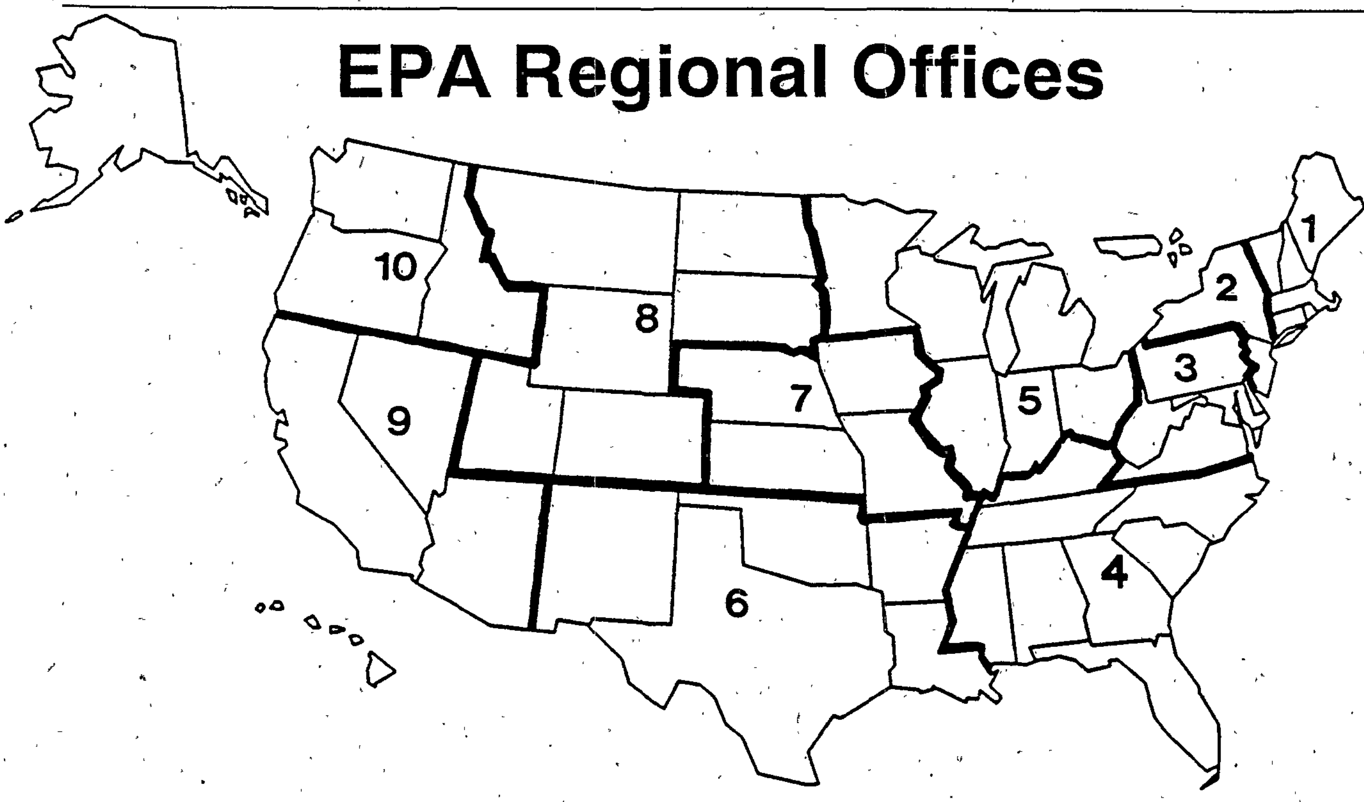
8. *Sulfide Corrosion in Wastewater Collection and Treatment Systems,* Report to Congress, U.S. Environmental Protection Agency, Office of Water, Washington, DC, 1991.

9. *Hydrogen Sulfide Corrosion in Wastewater Collection and Treatment Systems, Report to Congress - Technical Report,* U.S. Environmental Protection Agency, Office of Water, Washington, DC, 1991.

10. *Detection, Control and Correction of Hydrogen Sulfide Corrosion in Existing Wastewater Systems,* U.S. Environmental Protection Agency, Office of Water, Washington, DC, 1991.

11. *Handbook - Sewer System Infrastructure Analysis and Rehabilitation,* EPA-625/6-91/030, U.S. Environmental Protection Agency, Center for Environmental Research Information, Cincinnati, OH, 1991.

EPA Regional Offices



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