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Exfiltration in Sewer Systems

by

Robert S. Amick, P.E.
Environmental Quality Management, Inc.
Cincinnati, Ohio 45240
and
Edward H. Burgess, P.E.
Camp, Dresser & McKee
Cincinnati, Ohio 45249

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Project Officer

Ariamalar Selvakumar, Ph.D., P.E.
National Risk Management Research Laboratory
Edison, New Jersey 08837

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Notice

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E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Abstract

This report was submitted in fulfillment of Order No. 8C-R551-NASX by Environmental Quality Management, Inc. and Camp, Dresser & McKee of Cincinnati, Ohio under the sponsorship of the United States Environmental Protection Agency. This report covers the period from September 1998 to February 2000 and work was completed in April 2000.

The study focused on the quantification of leakage of sanitary and industrial sewage from sanitary sewer pipes on a national basis. The method for estimating exfiltration amounts utilized groundwater table information to identify areas of the country where the hydraulic gradients of the sewage are typically positive, i.e., the sewage flow surface (within pipelines) is above the groundwater table. An examination of groundwater table elevations on a national basis reveals that the contiguous United States is comprised of groundwater regions (established by the U.S. Geological Survey) which are markedly different. Much of the northeastern, southeastern, and midwestern United States has relatively high groundwater tables that are higher than the sewage flow surface, resulting in inflow or infiltration. Conversely, a combination of relatively low groundwater tables and shallow sewers creates the potential for widespread exfiltration in communities located in the western United States.

This report presents information on typical sewer systems, identifies and assesses the factors that cause or probably cause exfiltration, presents commonly used and advanced corrective measures and their costs for dealing with exfiltration, identifies technology gaps, and recommends associated research needs and priorities. This report also examines urban exfiltration, including a case study of Albuquerque, New Mexico.

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Acknowledgement

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Chapter 1
Introduction

1.1 Background

Many municipalities throughout the United States have sewerage systems (separate and combined) that may experience exfiltration of untreated wastewater from both sanitary and combined sewers. Sanitary sewer systems are designed to collect and transport to wastewater treatment facilities the municipal and industrial wastewaters from residences, commercial buildings, industrial plants, and institutions, together with minor or insignificant quantities of ground water, storm water, and surface waters that inadvertently enter the system. Over the years, many of these systems have experienced major infrastructure deterioration due to inadequate preventive maintenance programs and insufficient planned system rehabilitation and replacement programs. These conditions have resulted in deteriorated pipes, manholes, and pump stations that allow sewage to exit the systems (exfiltration) and contaminate adjacent ground and surface waters, and/or enter storm sewers. Exfiltration is different from sanitary sewer overflows (SSOs). SSOs are overflows from sanitary sewer systems usually caused by infiltration and inflow (I/I) leading to surcharged pipe conditions. SSOs can be in the form of direct overflows to receiving water, street flooding, and basement flooding; whereas exfiltration is not necessarily caused by excess I/I and is merely caused by a leaking sewer from its inside to its surrounding outside.

Untreated sewage from exfiltration often contains high levels of suspended solids, pathogenic microorganisms, toxic pollutants, floatables, nutrients, oxygen-demanding organic compounds, oil and grease, and other pollutants. Exfiltration can result in discharges of pathogens into residential areas; cause exceedances of water quality standards (WQS) and/or pose risks to the health of the people living adjacent to the impacted streams, lakes, ground water, sanitary sewers, and storm sewers; threaten aquatic life and its habitat; and impair the use and enjoyment of the Nation’s waterways.

1.2 Objectives

Although it is suspected that significant exfiltration of sewage from wastewater collection systems occurs nationally, there is little published evidence of the problem and no known attempts to quantify or evaluate it on a national basis. Accordingly, the objectives of this study were to quantify through desk-top estimates the magnitude of the exfiltration problem in wastewater collection systems on a national basis; identify the factors that cause and contribute to the problem; and document the current approaches for correcting the problem, including costs. The resulting information was used to identify information and technology gaps and research priorities.

Chapter 2 identifies and qualitatively assesses the causative factors and health impacts of exfiltration; the methodology employed for quantification of exfiltration on a national scale is presented in Chapter 3; Chapter 4 presents corrective measures applicable to exfiltration; national magnitude of exfiltration and corrective measure costs results are presented in Chapter 5; and Chapter 6 identifies existing information/data gaps and makes recommendations for further research.

Chapter 2
Identification and Assessment of Causative Factors and Health/Environmental Impacts

2.1 Causative Factors

A search for publications regarding exfiltration of sewage from wastewater collection systems did not locate any exfiltration-specific discussion of unique/causative factors because most factors which cause inflow/infiltration are identical to those associated with exfiltration (i.e., they both occur through leaks in pipes, depending on the relative depth of the ground water).

Factors that contribute to exfiltration include:

- size of sewer lines
- age of sewer lines
- materials of construction (sewer pipe, point/fitting material, etc.)
- type and quality of construction (joints, fittings, bedding, backfill)
- depth of flow in the sewer

Geological conditions that contribute to exfiltration include:

- groundwater depth (in relation to sewer line/depth of flow of sewage)
- type of soil
- faults

Climate conditions that influence exfiltration include:

- average frost line in relation to sewer depth
- average rainfall, which helps determine groundwater depth

In a typical exfiltrating sanitary sewer system, with the groundwater level below the sewage flow surface, exfiltration can occur in several areas. Figure 2-1 schematically represents these exfiltration sources, including defective joints and cracks in the service laterals, local mains, and trunk/interceptor sewers. The level of ground water and the depth of flow in the sewer will influence the extent of exfiltration rates, since the pressure differential

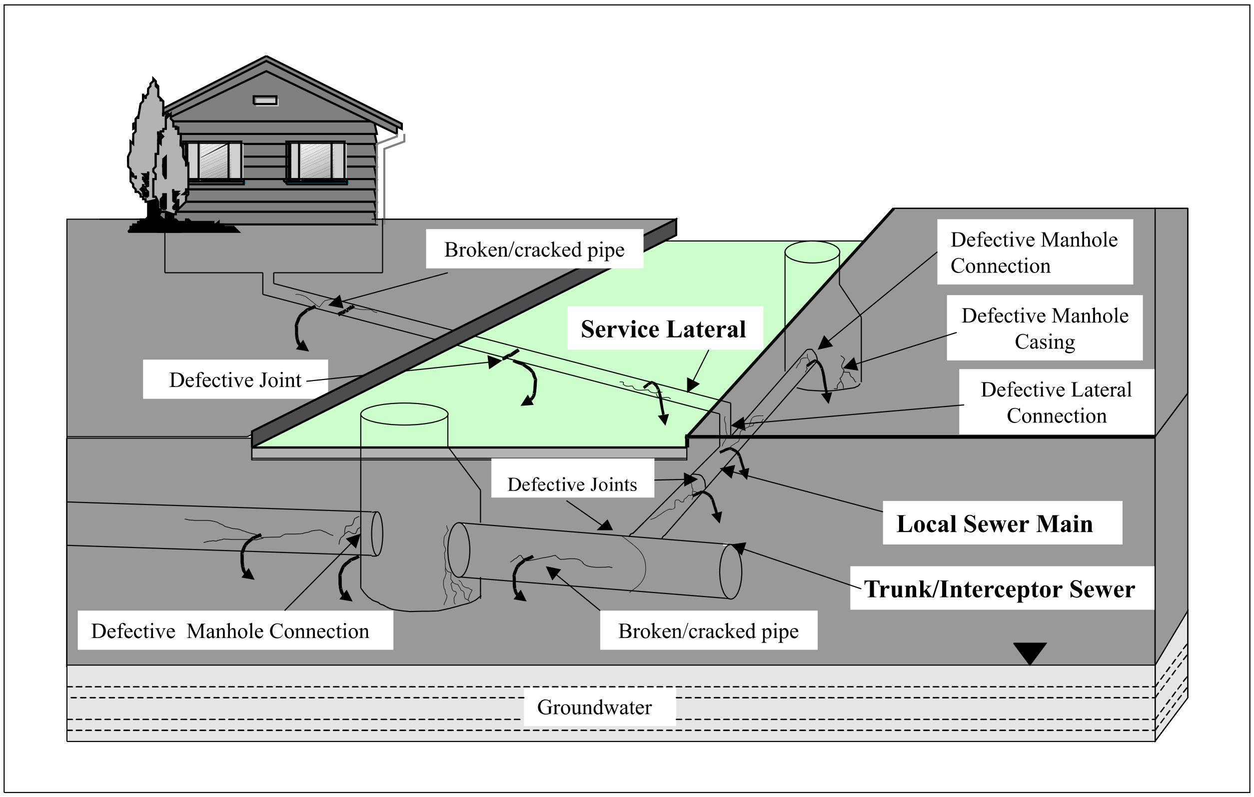

Figure 2-1. Sanitary sewer system components and exfiltration sources.

between the hydraulic head in the sewer and the groundwater hydraulic head will force water out of the sewer apertures into the surrounding soil material.

2.2 Health and Environmental Impacts

This section addresses the potential health impacts of exfiltration on ground water, drinking water distribution systems, and surface water.

2.2.1 Ground Water

Little published data is available on specific incidents of groundwater pollution and associated health/environmental impacts arising from leaking sewers, despite the widespread acknowledgment that these incidents occur. Several studies have indicated widespread pollution of ground water in urban areas arising from the general leakiness of sewers, including bacteria and ammonium reported from Wisconsin and general pollution in the San Joaquin Valley in California.[1]

Transport of the sewage and pollutants leaking into the subsurface/ground water depends on a variety of factors, including but not limited to: the difference in hydraulic head between the sewage surface and the groundwater table level, the substrate physical/chemical/ biological characteristics (which determines attenuation potential), and the sewage pollutants and their concentrations. Fecal bacteria contamination is the most serious health risk associated with domestic sewage exfiltration. Contamination by viruses, protozoa, and other microorganisms is also a concern. Increased concentrations of total organic carbon, nitrate, chloride, and sulfate, however, can also make the water unfit for consumption. Phosphate and boron are good indicators of sewage pollution since they are not naturally occurring in ground water.[2]

The solids present in sewage can plug the porous media beneath the pipe and rapidly decrease the exfiltration rate. In an experiment completed to examine this effect, the leakage was reduced to a steady state within an hour.[3]

As evidence of pollution from sewage, chloride and nitrate have been found to travel together. A California study indicated that ammonium disappeared within 4 feet, probably by adsorption and bacteriological activity. Bicarbonate and nitrate increased several hundred percent and nitrite disappeared.[4]

2.2.2 Water Supply Distribution Systems

Because of minimum separation requirements for potable water supply distribution systems and sanitary sewers and vigilant application of cross-connection control programs, the opportunity for sewer exfiltration to contaminate drinking water supplies is theoretically rather limited. Only one such potential documented case was found in a comprehensive data/information search.[5] Sewage from exfiltration can enter a distribution system through a broken water main or, under reduced pressure conditions, through a hole which leaks drinking water out under normal positive pressure conditions. Situations which could allow infiltration of the sewage through a lowering of water main pressure primarily involve backflow and surges.

Main Breaks

Despite the best efforts of utilities to repair water main breaks using good sanitary procedures, these breaks represent an opportunity for contamination from exfiltration to enter the distribution system. When a main breaks, utilities typically isolate the affected section, superchlorinate, and flush the repaired pipe. Flushing velocities may not always remove all contaminated debris, however, and microbiological testing of the final water quality may not detect contaminating microorganisms. In 1989, Cabool, Missouri[5] experienced a suspected cross-connection between sewage overflow and two major distribution system line breaks (backflow may have occurred during simultaneous repair of numerous water meters) caused by freezing temperatures, resulting in 243 cases of diarrhea, 32 hospitalizations, and four deaths due to *E. coli* O157:H7 strain. This town of

2000 was on an untreated groundwater system and did not superchlorinate during repairs of the water main breaks.

Backflow

Backflow devices to prevent the entry of contaminated water constitute an important distribution system barrier. Because of cost considerations, backflow-prevention devices are primarily installed on commercial service lines at facilities that use potentially hazardous substances. Such facilities include hospitals, mortuaries, dry cleaners, and industrial users. It is uncommon for all service connections to have backflow prevention devices; thus, back siphonage can occur at these unprotected points. Furthermore, installation of backflow devices at all service connections would make routine checking of the devices nearly impossible. Without routine inspection, proper functioning of the units cannot be determined.

Surges

Recent research is focusing on transient pressure waves that can result in hydraulic surges in the distribution system. These waves, having both a positive and negative amplitude, can draw transient negative pressures that last for only seconds and may not be observed by conventional pressure monitoring. Because these waves travel through the distribution system, at any point where water is leaking out of the system, the transient negative pressure wave can momentarily draw water and sewage (if present) back into the pipe.[6]

2.2.3 Surface Water Pollution

No data or narrative information in the literature demonstrate, or even suggest, that sewer exfiltration has directly contaminated surface waters. Several factors that control the occurrence of sewer exfiltration may explain the absence of a linkage between exfiltration and surface water pollution.

The occurrence of exfiltration is limited to those areas where sewer elevations lie above the groundwater table. Since groundwater elevations near surface water bodies are typically near the ground surface, sewers near surface water bodies generally are below the groundwater table, and infiltration (rather than exfiltration) will dominate the mode of sewer leakage in these areas. In areas of steep topographic conditions, where sewers are located near surface waters and at elevations that lie above the surface water, exfiltration impacts may be possible. However, these situations are assumed to be sufficiently rare that exfiltration impacts on surface waters are not observed.

Chapter 3
Methodology for Determining the Magnitude of Exfiltration on a National Scale

The process of estimating the magnitude of the exfiltration problem on a national scale has been performed as a series of two independent steps:

- Qualitatively assessing the portion of the nation's sewer systems that are susceptible to exfiltration;
- Applying assumptions about exfiltration rates (percent of base sewer flow) to the exfiltration susceptible sewer systems to provide an assessment of the extent of sewer exfiltration on a national scale.

3.1 Identification of Exfiltration Susceptible Sewer Systems

The key factor influencing the occurrence of exfiltration is the direction of the hydraulic gradient between the sewer flow surface and the groundwater table (GWT) external to the sewer. Where (and/or when) the direction is toward the sewer, exfiltration will be <0 (i.e., the hydraulic gradient will cause infiltration, rather than exfiltration). This situation is probably best analyzed by evaluating the depth of the sewers (and service laterals) relative to the groundwater table. In much of the northeastern, southeastern, and midwestern United States, relatively high groundwater tables typically result in infiltration conditions. Exceptions include shallow sewers, service laterals, and seasonal variation in GWTs that can significantly change the spatial extent of the sewer system that lies above the GWT (i.e., that can be considered to be "exfiltration susceptible"). To a lesser degree, short-term reversals in the gradient that may occur during wet weather (e.g., surcharged sewers which temporarily experience high sewage flow surface above the GWT, and may therefore briefly exfiltrate) may also need to be considered.

Given the importance of first screening out those areas that are not "exfiltration susceptible," the initial desktop analysis task was to perform spatial analysis of sewer depth relative to regional GWT elevations. Existing national-scale groundwater information was examined, such as that provided by the U.S. Geological Survey (e.g., USGS Groundwater Regions of the United States). As the various national groundwater data sources were reviewed, however, it was determined that mapping in support of the purposes of this study was not readily available. For this reason, a national depth-to-groundwater map was prepared under this project from groundwater level data available in the national databases (U.S. EPA STORET and USGS WATSTORE) and presented in Section 5 of this report.

It is recognized that there may be seasonal variability in the portion of sewer systems susceptible to exfiltration in some areas, as GWTs can vary seasonally. The extent to which seasonal differences must be accounted for was assessed in reviewing the correlations to sewer depth.

National-scale sewer depth data does not exist, but for purposes of the desktop analysis some assumptions about this parameter can be made. For example, typical service lateral depth can be assumed to be 8 feet for buildings with basements, and 2 to 4 feet for houses built on slabs. Typical sewer main depth can be assumed to be 6 to 10 feet; it may be possible for more detailed assessments to develop a typical depth distribution (i.e., x % 4-10 ft deep, y% 11-15 ft deep, z% > 15 ft deep). Regional differences should be considered; for example, sewer depths typically are shallower in the western United States than in other areas of the country. Sewer system density (miles/acre) can be correlated with readily available national population density data to create a GIS coverage of sewer system density.

GIS processing incorporating the general spatial (mapped) relationships between sewer depth and groundwater elevations allowed the development of a characterization of the "exfiltration susceptibility" of various areas. This was attempted at the national level, but the data required to support this analysis are unavailable; thus, a representative area (Albuquerque, New Mexico) for which a recent exfiltration study had been completed, was selected on which to perform the analysis. National exfiltration rate assessments can be extrapolated from this analysis. However, more detailed identification and inventory of exfiltration susceptible areas is required to support a meaningful quantification of national exfiltration rates.

3.2 Estimating National Exfiltration Rates

Estimation of the extent of exfiltration that actually occurs was addressed with the same set of parameters that are applied to characterize and quantify the infiltration problem: sewer condition, joint type, pipe material, age, etc. Similarly, correcting the problem can be assumed to involve the same technologies as are applied to infiltration (various lining approaches, etc.). For purposes of this project, however, it was necessary to make simplifying assumptions about exfiltration rates and corrective actions. More detailed investigations in the future can examine the spatial variability in exfiltration rates that can be correlated to the sewer condition, joint type, pipe material, and sewer age parameters. Corrective action costs can also be refined later with more detailed assessments of required actions.

For purposes of this study, unit rates for exfiltration (gallons/day/inch/mile) available from the 1989 EPA study[7] were used to generate the assessment of the magnitude of the national exfiltration problem. These unit rates were applied to the “exfiltration susceptible” areas (together with assumptions about the inch-miles of sewers/service laterals in those areas) to generate exfiltration rates in the Albuquerque case study. The unit rates based on gallons/day/inch/mile were compared with estimates based on percent of base sewer flow. Comparisons of the two methods proved useful in developing the final estimates.

Chapter 4
Corrective Measures

The proper selection of corrective or rehabilitation methods and materials depends on a complete understanding of the problems to be corrected, as well as the potential impacts associated with the selection of each rehabilitation method. Pipe rehabilitation methods to reduce exfiltration (and simultaneously infiltration) fall into one of the two following categories:

- External Rehabilitation Methods
- Internal Rehabilitation Methods

Certain conditions of the host pipeline influence the selection of the rehabilitation method. It is therefore necessary to assess these factors to prepare the pipe for rehabilitation. Rehabilitation is proceeded by surface preparation by cleaning the pipe to remove scale, tuberculation, corrosion, and other foreign matters.

4.1 External Sewer Rehabilitation Methods

External rehabilitation methods are performed from the aboveground surface by excavating adjacent to the pipe, or the external region of the pipe is treated from inside the pipe through the wall. Some of the methods used include:

- External Point Repairs

- Chemical Grouting
  - Acrylamide Base Gel
  - Acrylic Base Gel

- Cement Grouting
  - Cement
  - Microfine Cement
  - Compaction

4.2 Internal Sewer Rehabilitation Methods[8, 9, 10]

The basic internal sewer rehabilitation methods include:

- Chemical Grouting - Internal grouting is the most commonly used method for sealing leaking joints in structurally sound sewer pipes. Chemical grouts do not stop leaks by filling cracks; they are forced through cracks and joints, and gel with surrounding soil, forming a waterproof collar around leaking pipes. This method is accomplished by sealing off an area with a "packer," air testing the segment, and pressure injecting a chemical grout for all segments which fail the air test. The three major types of chemical grout are:

  – Acrylic
  – Acrylate
  – Urethane

- Sliplining - In this method, pipes are inserted into an existing line by pulling or pushing pipes into a sewer. The space between the existing pipe and liner pipe is grouted. Sliplining can be segmental or continuous. Small pipes including service laterals are usually continuous, with the larger sizes being segmental. Major types of sliplining are:

  Continuous Pipe - insertion of a continuous pipe through the existing pipe

  – Polyethylene
  – Polypropylene

  Segmental - Short segments of new pipe are assembled to form a continuous line, and forced into the host pipe. Generally, this method is used on larger sized pipe and forced into the host pipe.

  – Polyethylene
  – Polyvinyl Chloride
  – Reinforced Plastic Mortar
  – Fiberglass Reinforced Plastic
  – Ductile Iron
  – Steel

- Cured-in-Place Pipe (CIPP) - The CIPP process involves the insertion of a flexible lining impregnated with a thermosetting resin into a cleaned host pipe using an inversion process (hot water or steam). The lining is inserted using existing manholes.

  Because the liner initially is flexible, the pressurized steam or water also serves to form it in the shape of the existing pipe. The resin hardens with the application of heat and with the passage of time (generally a few hours) to form a pipe within the existing pipe.

- Closed-fit Pipe - This involves pulling a continuous lining pipe that has been deformed temporarily so that its profile is smaller than the inner diameter of the host pipe. After installation, the new pipe expands to its original size and shape to provide a close fit with the existing pipe. Most lining pipe is deformed in the manufacturing plant.

- Fold and Form Pipe - This is similar to sliplining, except that the liner pipe is deformed in some manner to aid insertion into the existing pipe. Depending on the specific manufacturer, the liner pipe may be made of PVC or HDPE. One method of deforming the liner is to fold it into a "U" shape before insertion into the existing pipe. The pipe is then returned to its original circular shape using heated air or water, or using a rounded shaping device or mandrel. Ideally, there will be no void between the existing pipe and the liner pipe after expansion of the liner pipe with the shaping device. For the "U" shape liner, the resulting pipe liner is seamless and jointless.

- Spiral Wound Pipe - This involves winding strips of PVC in a helical pattern to form a continuous liner on the inside of the existing pipe. The liner is then strengthened and supported with grout that is injected into the annular void between the existing pipe and the liner. A modified spiral method is also available that winds the liner pipe into a smaller diameter than the existing pipe, and then by slippage of the seams, the liner expands outward.

- Pipe Bursting - Pipe Bursting is a method of replacing existing sewers by fragmenting the existing pipe and replacing the pipe in the void.

    1. Hydraulic Method - In this method a solid rod is inserted into the existing pipe and a bursting head is attached to the rod, which is then attached to a new replacement pipe. Hydraulic power is used to retract the rod and bursting head, and draw in new pipes. Existing sewer pipe is broken into fragments, which are driven into the surrounding soil.

    2. Pneumatic Method - This system consists of a pneumatic burster unit that splits the existing pipe while simultaneously installing a new polyethylene pipe of the same size or larger. Over 90 percent of the bursting is done by this method.

    3. Static Head - Static heads have no moving parts. The head is simply pulled through the old pipe by a heavy-duty pulling device.

- Spot (Point) Repair - Point repairs are used to correct isolated problems in a pipe. Sometimes they are used as the initial step in the use of other rehabilitation methods. Point repairs include:

1. Robotic Repair
2. Grouting/Sealing
3. Special Sleeves
4. Point CIPP

4.3 Issues Related to the Limitations of Existing Technologies

The City of Houston, Texas recently completed model simulations and determined that comprehensive rehabilitation was not cost-effective.[11] It was found cheaper to relieve Houston's collection system bottlenecks for the short duration. This study noted that many types of rehabilitation and varying levels of rehabilitation, however, were not tested and could prove to be cost-effective. Soil characteristics and climatology vary from region to region, as do sewer system conditions and available system capacity, and the conclusions found in Houston may not be applicable to other parts of the country.

Thousands of communities have rehabilitated portions of their collection systems; yet very few know whether or not they have been successful. The problem is that no one can forecast how effective the rehabilitation will be. A recent literature search found that only 91 sewer sheds worldwide have post rehabilitation infiltration/inflow (I/I) reduction information available.[12] Average reported reduction is 49 percent of peak I/I rate. No data was found on the amount of exfiltration reduction from rehabilitation.

Pipe bursting may be limited in use where the pipe has sags. This technology's use is limited to cast or ductile iron pipe or concrete encasement. Pipe bursting may not be applicable where other existing utilities are close to the pipe.

Some sliplining applications require a round host pipe. Clearance should be checked before this method is employed.

Chapter 5
Results

This section describes the results of using various methods to estimate exfiltration from sewers. These methods have been developed and used in several locations in the United States and Europe. Some of these methods have been applied to calculate potential exfiltration in Albuquerque's sewer system, for which one of the most extensive exfiltration studies in the United States to-date has been completed.[12] For this reason, Albuquerque has been selected as a case study, from which the national extent of sewer exfiltration can be assessed.

The results of the 1998 exfiltration study from Albuquerque are extrapolated qualitatively by evaluating the exfiltration susceptibility of sewer systems throughout the United States. Susceptibility is defined by the relative depths of the sewers and groundwater table. In cases where sewer depths are generally shallower than the surrounding ground water, the potential to exfiltrate exists (because the direction of the hydraulic gradient is toward the exterior of the sewer) and these sewers can therefore be considered exfiltration susceptible. A national depth-to-groundwater map has been prepared for use in this assessment of the national extent of exfiltration susceptible sewer systems.

The findings of the Albuquerque case study were combined with the national depth-to-groundwater mapping to present a qualitative assessment of the extent to which sewer exfiltration represents a risk to water quality and human health on a national scale. Much of the information presented in Section 5.1 is taken from the 1998 Albuquerque study.[12]

5.1 National Scale Quantification

Although exfiltration is not a widely studied phenomenon, several exfiltration studies and investigations have been completed throughout the world. These include work completed in the United States for the U.S. EPA and several studies in Europe, the majority of which are focused on Germany. Some of the more applicable previous studies are discussed below.

Three basic approaches have been used to quantify sewer exfiltration rates: 1) direct measurement of flow in isolated sewer segments, 2) theoretical estimates using Darcy's Law and related hydraulic theory, and 3) water balance between drinking water produced/delivered and wastewater collected/treated. Each of these approaches has been applied to the Albuquerque case study and is described below.

5.1.1 Estimates Based on Direct Measurements (U.S. EPA Study)

An EPA study entitled "Evaluation of Groundwater Impacts of Sewer Exfiltration" was completed in the late 1980's.[7] The work estimated exfiltration in two California city sewer systems to develop a correlation between exfiltration and infiltration. The tests were conducted in areas of vitrified clay pipe (VCP) predominance, where older pipe of known or suspected poor condition existed. Only those pipe segments located above groundwater levels were tested. Water consumption was metered for all sewer service connections corresponding with each measured sewer line to determine the actual quantity of wastewater flow entering the system. It was assumed that all internal household water entered the sewer system. Measurements of sewage flow in the sewer lines were made by continuous flow monitoring and hydrostatic testing. Calculated sewer exfiltration was reported in units of gallons per inch diameter per mile length per day (gpimd). Table 5-1 presents a summary of the exfiltration rates.

Table 5-1. Summary of Exfiltration Rates from Continuous Flow Monitoring and Hydrostatic Testing (Engineering Science, Inc., 1989)

Location	Pipe Information	Exfiltration Rate Cont. Flow Monitoring (gpimd)[a]	Exfiltration Rate Hydrostatic Testing (gpimd)
Berkeley, CA Pardee Street	320 linear feet (lf) of 8-in. - diameter VCP	5,649 (34% of flow)	6,327
Berkeley, CA 7th Street	298 lf of 6-in. - diameter VCP	5,283 (56% of flow)	5,649
Santa Cruz, CA Beach Street	260 lf of 8-in. - diameter VCP	6,557	2,417
Santa Cruz, CA Riverside Parking Lot	124 lf of 6-in. - diameter VCP	77,745	8,324

[a] gallons per inch diameter per mile length per day

This table shows that a large discrepancy exists between the results from the continuous flow monitoring and the hydrostatic testing at one Santa Cruz location. The study concludes that the continuous flow monitoring achieved reliable data and that the hydrostatic test data was influenced by the tidal cycle. A correlation model between exfiltration and infiltration was developed, but not field tested.

A second evaluation was performed using field measurements at another location to verify the correlation model. This evaluation used similar methodologies as the first task.

Exfiltration measurements were made in the Washington Suburban Sanitary Commission (WSSC) sewer system near Washington, D.C., and in Lexington, Kentucky. Table 5-2 presents a summary of the measurement results from the evaluation.

Table 5-2. Summary of Exfiltration Measurements (Engineering Science, Inc., 1989)

Location	Pipe Information	Average Exfiltration Rate (gpimd)[a]	Exfiltration as Percentage flow (%)
WSSC John Hanson Highway	1,400 lf of 8-in. -diameter VCP	16,248	16.6
WSSC University of MD	832 lf of 10-in. -diameter VCP	63,312	49.1
Lexington, KY Lumber Yard	455 lf of 8-in. -diameter VCP	17,103	22.6
Lexington, KY Car Lot	1,029 lf of 8-in. -diameter VCP	9,061	31.3
Lexington, KY Various Shops	586 lf of 10-in. -diameter VCP	5,664	11.9
Lexington, KY Various Shops	586 lf of 10-in. -diameter VCP	15,689	34.5

[a] gallons per inch diameter per mile length per day; lf = linear feet

Several problems with the measurement methodologies were noted, and overall the hydrostatic test method was judged to be not successful. It was resolved that the flow monitoring procedure worked well and should be applied to areas with a minimum of 400-500 linear feet of pipe with little or no service connections.

5.1.2 Estimates Based on Darcy's Law and Related Theory (European Studies)

The study of exfiltration has been of great interest in Germany. This country has a very old, deteriorated infrastructure. The cost to complete the necessary repairs to Germany's sewer systems is estimated to be nearly $100 billion (U.S.). Therefore, several exfiltration studies have been conducted to prioritize repair work. These studies have both applied theoretical (Darcy's Law) approaches and direct measurements to estimate sewer exfiltration. Excerpts from some of the studies are summarized below.

- A report from England[13] provided an estimate of 300 x 10^6 m^3/yr (793 x 10^8 gal/yr) or approximately 1 liter/day/m (397 gal/day/mile) for the exfiltration of the 880,000 km (547,000 miles) of sewer lines in Germany, although the basis of the estimate is not clear. This very low sewer leakage rate is actually net exfiltration, which is the difference between exfiltration and infiltration. The study indicates that total exfiltration and infiltration in Germany are nearly equal, but the amounts are not provided.

- To better understand the mechanics of exfiltration, sewage migration from leaking pipes to ground water was correlated in a study using Darcy's Law (see Equation 1).[3] The rate of exfiltration is linearly dependent on the area of the pipe exfiltrating and the pressure head:

  (1) $Q = L\ A\ dh$

  where Q is the exfiltration rate (ft^3/s) through a pipe leak area A (ft^2) at a pressure head of dh (ft), and L is leakage factor (s^{-1}).

  The leakage factor is defined in Equation 2:

  (2) $L = K/dL$

  where K is the permeability of the surrounding soil (ft/s) and dL is the thickness of the settleable soil layer (ft).

  This study found that the settleable solids in the wastewater act to reduce the permeability of the bedding material and lower the exfiltration rate rapidly at low flows and velocities. This clogging reduces the rate of exfiltration immediately. In fact, a steady-state rate of exfiltration was reached after one hour, even with large area of joint damage.

- A research project undertaken by the Institute of Environmental Engineering (ISA) at the University of Technology of Aachen, Germany, studied the water pollution hazard of leaking sewers.[14, 15, 16] The ISA developed and used a special exfiltration measuring device at every joint in several sections of sewer pipe on several tests conducted throughout Germany. This study determined that the most significant VCP sewer damages which permit exfiltration are leaking service junctions, leaking sewer joints, pipe cracks, and pipe fractures. At a pressure head below the sewer crown, which is typically the case in gravity flow sewer lines, exfiltration rates were minimal. At a pressure head of one pipe diameter, the exfiltration rate increased dramatically, to more than 26 gal/hour (gph) per joint in some segments. This high leakage rate can, in part, be attributed to the generally poor condition of the old sewer systems. A linear correlation between pressure head and exfiltration rate for several types of sewer defects was noted for pressure heads greater than 500 mm (20 inches). It was also noted that at lower flows and pressure heads, the exfiltration rate decreases exponentially, most likely from self-sealing from sewer film and settleable solids in the sewage. If the flow and pressure head increases, however, this self-sealing property is broken and the exfiltration rate increases rapidly.

5.1.3 Estimates Based on Drinking Water - Wastewater Balance

In this section, exfiltration from Albuquerque's sewer system is estimated using a water/sewage balance calculation, backed up by some previous local studies on infiltration. The results are then compared with leakage rates calculated from the other methodologies and unit rates derived from the EPA and European studies presented above.

A direct method for estimating exfiltration is to compare water pumpage and usage with wastewater received at Albuquerque's Southside Water Reclamation Plant (SWRP). To make this comparison, it is necessary to identify the base water demand, which is the indoor component of the total household use. Demands during mid-winter (January and February) are assumed to be near base flow because no or very minimal outdoor water usage occurs. Water and wastewater data obtained from the City for January 1998 revealed the following:

- Average daily influent flow at the SWRP: 51.4 mgd

- Average daily water pumpage into transmission/distribution system: 61.2 mgd (this is then considered to be the daily base flow for that month)

Subtracting wastewater flow from the pumpage rate yields a difference of 9.8 mgd, which is the first approximation of sewage leakage. However, several other factors also impact the water balance in the water and wastewater systems. These are:

- Sewer infiltration
- In-house water consumption
- Water distribution system leakage
- Sewer exfiltration

City of Albuquerque staff, using a range of available information (including meter and billing records, pumpage records, and other data), have estimated losses in the water system at about 11 percent of the total amount pumped. A 1997 study[17] found water system losses ranging from 8 percent in Hong Kong, which is considered to have a relatively "tight" and high-quality system, to the 20-25 percent range in England, which has many very old distribution systems. An 11 percent loss in the system would account for a daily average loss of about 6.73 mgd.

In-house consumption is the portion of the water entering the house that does not leave as sewage, but is consumed in cooking, drinking, watering plants, cleaning, etc. National experience indicates that about 3 percent of water entering the home is consumed on an average day in January 1998. With negligible non-domestic consumption, the remaining amount of water, about 1.4 mgd, represents the net difference between the two other factors in the water balance: sewer infiltration and exfiltration. The net amount is positive, indicating that exfiltration exceeds infiltration by 1.4 mgd, which is plausible given that the great majority of Albuquerque's sewers, and particularly those most susceptible to exfiltration (older VCP), are in exfiltration areas (well above groundwater levels).

In order to estimate the exfiltration volume, previous studies addressing infiltration in the Albuquerque sewer system were reviewed. One of the studies[18] utilized several approaches to gain an approximation of inflow and infiltration in the Albuquerque system, most of which was attributed to infiltration in the valley of the Rio Grande. Some of these methodologies are described below:

- A flow comparison between winter water use and sewage flow. This methodology resulted in an infiltration flow of 3.7 mgd. However, the report stated that "this estimation is probably within $\pm$ 50 (percent) of the actual value…"

- Early morning sewage flow versus water use. This methodology resulted in an infiltration flow of nearly zero.

- Sewage flow versus population. Using a 100-gallons-per-capita-per-day wastewater flow and a population of 300,000, infiltration was estimated at 5 mgd. It was also noted that the average sewage flow for Albuquerque at this time was actually 117 gpcd.

- Influent BOD versus domestic wastewater BOD. The expected BOD concentration in the wastewater was calculated based upon a generally accepted BOD loading of 0.17 lb/cap/day. This BOD concentration was compared with the average influent concentration to calculate an infiltration flow of 5.9 mgd. However, this was thought to be a high estimate based upon the relatively small industrial component and the high institutional contribution.

In addition, the study field-verified the areas subject to infiltration. Based upon the above calculations and results of the field tests, infiltration was thought to be somewhat less than 3 mgd, or 9 percent of the wastewater flow in 1975. Nine percent of today's wastewater flow would be in the 5 mgd range.

Another infiltration analysis was completed as part of the Albuquerque ASAM Model Loading and Verification Task.[19] Interceptor manholes that were within 2 feet of ground water were identified. Flow monitoring was completed in a sewer subbasin, and the resulting flows were compared with the predicted flows to determine infiltration. The infiltration rate for Albuquerque was calculated at 0.925 mgd, but, again, the impact of exfiltration was not included. Therefore, the work revealed a net infiltration rate, indicating that actual infiltration is about 1 mgd greater than total exfiltration.

From the foregoing investigations, it is estimated that the total average infiltration rate for the Albuquerque system is in the vicinity of 3.5 mgd. The 9 percent field-verified rate reported in the Molzen-Corbin report is probably high, given the repair and replacement of major interceptors in the valley that have occurred since 1975, as well as the use of better quality materials and construction techniques for new pipelines since then. On the other hand, repairs have generally not been made to the sewers most susceptible to exfiltration -- old vitrified clay pipes (VCP).

The total exfiltration rate is obtained by adding the 1.4 mgd remaining in the water balance to the infiltration rate, for a total of 4.9 mgd, or approximately 5 mgd.

5.1.4 Comparison of the Various Methodologies – Albuquerque Case Study

Unit Rates from U.S. EPA Study

The 1989 U.S. EPA exfiltration study is discussed in Section 5.1.1 above, and some of the results are summarized in Tables 5-1 and 5-2. Application of measured exfiltration rates from this study (in gpimd) to the 66.5 miles of Albuquerque VCP sewers (average diameter of 8.57 inches) that are potentially in condition C (major cracks) or D (severe cracks) results in total exfiltration rates ranging from 1.38 mgd to 44.1 mgd (504 Mg/yr to 16,907 Mg/yr). These calculated quantities are listed in Table 5-3. Although there is a very wide range in calculated rates, many of them are in the 3 to 4 mgd range calculated above using a water balance.

Table 5-3. Calculated Exfiltration Rates Using United States EPA Study Results

Location	Measured Unit Rates (gpimd)	Equivalent Albuquerque Quantities[a] (mgd)
Berkeley, CA, Pardee Street	5,649; 6,327	3.2; 3.6
Berkeley, CA, 7th Street	5,283; 5,649	3.0; 3.2
Santa Cruz, CA, Beach Street	6,557; 2,417	3.7; 1.4
Santa Cruz, CA, Riverside Parking Lot	77,745; 8,324	44.3; 4.7
WSSC, John Hanson Highway	16,248	9.3
WSSC, University of MD	63,312	36.1
Lexington, KY, Lumber Yard	17,103	9.8
Lexington, KY, Car Lot	9,061	5.2
Lexington, KY, Various Shops	5,664; 15,689	3.2; 8.9

[a] For 66.5 miles of suspected Class C and D pipe, average diameter 8.57 inches.

European Methods

Section 5.1 discusses the results of several exfiltration studies carried out in Germany. Applying these methods and unit rates to the Albuquerque sewer system yields several estimates as follows:

- The study by Lerner and Halliday[13] presented an estimated net exfiltration rate of 397 gal/day/mile for the whole of Germany. Applying this figure to the entire length of clay and concrete sewers in Albuquerque's system yields a total net exfiltration rate (net leakage) of about 0.46 mgd. This is reasonably close to the net exfiltration rate of 1.4 mgd calculated by the water balance in Section 5.1.3. It is expected that, on average, a greater percentage of Germany's sewers are in infiltration areas than is the case in Albuquerque. On the other hand, Germany's sewers are also older and undoubtedly in overall worse condition, therefore more susceptible to exfiltration. Thus, a near balance in exfiltration and infiltration is possible. Albuquerque has a greater percentage of sewers above groundwater level, but a smaller portion that is likely to heavily exfiltrate.

- The study completed by Rauch and Stegner[3] determined that exfiltration could be correlated by Darcy's Law. A leakage factor dependent upon the bedding grain size and permeability affects the exfiltration rate (refer to Equations 1 and 2 in Section 5.1.2). For this study, the leakage factor was back-calculated using Darcy's Equation with the data presented in Rauch's report. This calculated leakage factor was then used in Darcy's Equation to calculate the exfiltration rate for 8-inch-diameter pipes flowing half full, with every joint separated one-quarter inch to approximate conditions for Albuquerque. The exfiltration rate was calculated as 7.9 mgd (2,900 Mg/yr). However, not every joint will have a quarter-inch separation. The ISA German studies discussed above[14, 15, 16] summarized the sewer damage noted in the project. About 30 percent of the VCP sewers have leaking sewer joints. The infrastructure in Albuquerque is not as old as that of Germany and therefore is in better condition. If we assume every fourth joint (25 percent) will be separated one-quarter inch, the exfiltration quantity is 2 mgd or 725 Mg/yr.

- The German ISA project determined that at a 4-inch head (equivalent to an 8-inch pipe flowing half full), the exfiltration rate was nearly zero. However, a storm sewer was found to have an exfiltration rate, dependent upon the type of damage, ranging from 4 to 10.5 gallons per hour per joint. This rate yields an exfiltration quantity of 8.2 to 21.9 mgd (3,000 to 8000 Mg/yr) for the Albuquerque sewer system. It is probable, however, that not every joint is leaking even in pipe of condition C or D. Assuming every fourth joint is leaking (25 percent as discussed above) presents an estimate of 2 to 5.5 mgd (769 to 2,000 Mg/yr).

Table 5-4 presents a summary of the estimates of sewer exfiltration for the Albuquerque area based on data from the European studies.

Table 5-4. Estimates of Sewer Exfiltration Quantities for the Albuquerque Sewer System Based on Published European Exfiltration Rates

Source/Study Location	Daily Quantity	Annual Quantity
Munich, Germany measurement of 24,600 gpmd	1.65 mgd	600 Mg/yr
Darcy's Equation, every joint offset 0.25 inch	7.9 mgd	2,900 Mg/yr
Darcy's Equation, every 4th joint offset 0.25 inch	2 mgd	730 Mg/yr
ISA Study – every joint leaking 4 g/hr	8.2 mgd	3,000 Mg/yr
ISA Study – every joint leaking 10.5 g/hr	22 mgd	8,000 Mg/yr
ISA Study – every 4th joint leaking 4 g/hr	2 mgd	730 Mg/yr
ISA Study – every 4th joint leaking 10.5 g/hr	5.5 mgd	2,000 Mg/yr

Based on a review of the above exfiltration rates for Albuquerque as calculated with the various EPA and European unit figures and methodologies, it can be seen that the rate of 5 mgd determined in Section 5.1.3 is very much within the range that would be expected. Although the calculated rates vary widely, the majority are within the 2 to 10 mgd range. Therefore, the rate of 5 mgd, as determined by the water balance described in Section 5.1.3, is presented as the best estimate of the average daily wastewater exfiltration rate from Albuquerque's sewer system.

It is further concluded that the majority of this leakage will occur in those areas most susceptible to exfiltration, as approximately 15 percent of the sewer system in Albuquerque is estimated to be below the groundwater table and therefore not exfiltration susceptible.

5.2 National Depth to Groundwater Mapping

In order to extrapolate the Albuquerque findings to a national scale, a qualitative assessment of exfiltration susceptibility has been made using depth-to-groundwater information. Since no such mapping at a national scale suitable for this purpose was readily available, an initial mapping effort was undertaken as part of this study.

The development of a nationwide depth-to-groundwater atlas is difficult at best due to the lack of easily obtainable data for most of the country. Data to determine the depth to the shallowest water table may be gathered from local, state, federal, and private sources through well logs, water level measurements, location of wetlands and seeps, characterization of streams and rivers, and locations of lakes and other water bodies. A thorough characterization of the U.S. water table is a long and exacting process.

Within the context of this study, the depth-to-groundwater map presented in Figure 5-1 is a generalized view created using readily available data from the EPA STORET and USGS WATSTORE databases of depth-to-groundwater parameters. The data were downloaded from CDROM databases resident at the CDM Hydrodata Center in Denver, Colorado. The data were screened to eliminate missing depth-to-water values, missing latitude and longitude, duplicate data, and easily recognized anomalous data. The resultant set contained approximately 93,000 data points in the coterminous United States, Alaska, and Hawaii (only the coterminous U.S. is shown below). Since the data retrieved from STORET and WATSTORE is dependent upon the data owner for accuracy, there is no comprehensive method of quality control. USGS data are continually reviewed, however, and these data may be deemed reasonably accurate. The STORET and WATSTORE databases, while certainly robust, do not contain all data available; therefore, data gaps exist which are labeled (in the data tables) as insufficient data.

Despite the large dataset applied to build the map, many regions of the United States have relatively limited data; these areas are unshaded on the map. Areas with the greatest concentration of valid data points within the deep groudwater range are generally west of the Mississippi River and along the Appalachian Mountains.

The data set was plotted upon a map of the United States using ESRI Arcview 3.1 GIS application with a Spatial Analyst extension. A grid was produced with a cell size of 10000 for the coterminous U.S. and Alaska and 1000 for Hawaii. An inverse distance weighted interpolation method (IDW) was used based on the 12 closest points. The IDW interpolator assumes that each point has a local influence that diminishes with distance.

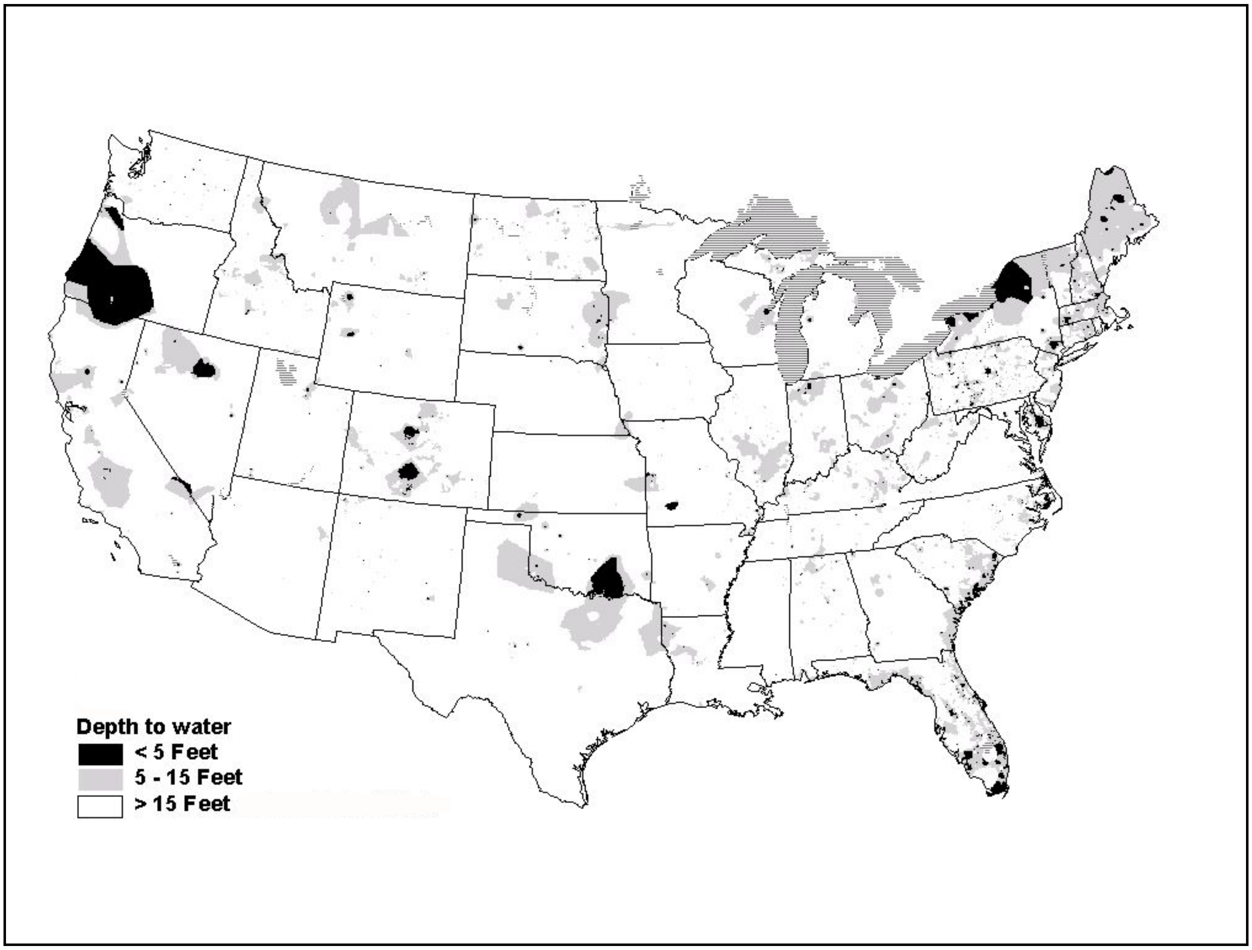

Figure 5-1. National depth-to-groundwater map.

Note: It is important to read Section 5.2 for a detailed explanation of background data basis.

5.3 Conclusions

Most of the urban areas in the northeastern, southeastern, and coastal areas of the U.S. have relatively shallow groundwater tables (<15 feet). In these areas, where a significant portion of the population (and therefore sewer systems) exists, relatively few exfiltration-susceptible sewer systems are expected. One caveat is exfiltration from service laterals. Even in the areas mentioned, many shallow service laterals may exist above groundwater tables. However, the hydraulic head available to drive exfiltration in these service lines is generally very low (typically only one or two inches, and intermittent). Further study in this area may be warranted to assess the extent of service lateral exfiltration.

Based on a review of the depth-to-groundwater map, it is expected that widespread exfiltration is probably limited to a relatively small portion of the total U.S. population, as relatively few large urban areas in the U.S. are located in these deeper groundwater areas. Cities such as Albuquerque, Phoenix, Tucson, and others, are among the larger urban areas where significant exfiltration potential exists. Further study of exfiltration conditions in cities such as these, with relatively large areas with sewers above the groundwater table, may be warranted on a case-by-case basis where evidence of exfiltration (e.g., groundwater contamination) has been observed, or is revealed by more detailed evaluations. Areas with extremely deep groundwater tables probably experience relatively less risk associated with exfiltration due to the long subsurface travel times and distances of the exfiltrated sewage from the sewer to the groundwater table. Areas with significant portions of the system above, but in close proximity to, the groundwater table are probably at greatest risk. There is an increased risk in the relatively few areas with significant exfiltration potential when there is, for example, a thin soil and fractured rock hydrogeologic setting which allows pathogens and other contaminants from the sewage to reach the ground water quickly and with minimal attenuation. However, since public water supplies are treated with chlorination, ozonation, or other systems to kill fecal bacterial contamination, an added measure of protection is provided.

A greater potential problem, albeit isolated, may be exfiltration from sewers carrying industrial wastewater. Organic and inorganic constituents of industrial sewage can be much more persistent than those of domestic sewage, and therefore much more likely to reach the ground water in areas of significant exfiltration potential. The disposition of industrial sewage contaminants which reach ground water used for drinking water supplies may not be the same as that of fecal bacteria from domestic sewage [i.e., the treatment processes (flocculation, filtration, chlorination, activated carbon filtration, etc.) may not eliminate or reduce these contaminants to render them harmless]. Untreated well water in some rural, small community, commercial, and private-owner drinking water systems does not enjoy this added protection. However, these systems are not typically in close proximity to large municipalities and associated sewer systems/exfiltration potential.

The Albuquerque Case Study concluded that the rate of exfiltration from that sewer system, expressed as a percentage of base flow, is on the order of 10% of average daily base wastewater flow - in absolute terms, roughly 5 mgd. This rate, expressed as an average annual rate, is 1,825 Mg/yr. Another relevant conclusion of the Albuquerque study was that there is a greater impact on ground water from septic tank usage than from sewer exfiltration. As the foregoing depth-to-groundwater analysis indicates, however, exfiltration is expected to vary significantly on a regional basis. Further study should expand the initial depth-to-groundwater analysis performed here and identify more precisely the “exfiltration susceptible” sewer systems throughout the U.S. and the extent to which exfiltration impacts ground water in these systems.

In summary, exfiltration appears to be a problem in certain cities in the United States (mainly located west of the Mississippi River and along the Appalachian Mountains) based on an evaluation of: 1) available groundwater table data to nationally assess the extent to which sewer systems are susceptible to exfiltration, 2) past studies of measured and estimated exfiltration rates, and 3) protective mechanisms, particularly natural soil/hydrogeological setting attenuation and drinking water treatment plants. Exfiltration may be a regional, or more likely, local problem where the GWT lies closely under the sewage flow surface. Situations where the exfiltrate can reach even deep ground water through a thin soil/fractured rock hydrogeologic setting, especially where persistent, potentially toxic contaminants are present (such as those often associated with industrial sewage) also pose a problem.

5.4 Corrective Measure Costs

Given the relatively high rates of exfiltration that potentially discharge from exfiltration-susceptible sewer systems in the U.S., corrective measures may be required to adequately protect groundwater resources, and in some limited instances surface waters, in these areas. The site-specific nature of exfiltration problems, however, requires a more detailed assessment of the larger urban areas in the exfiltration-susceptible western U.S. be completed before a meaningful estimate of corrective costs can be developed.

Corrective actions to address exfiltration in those situations where local-level evaluation calls for such action will generally be accomplished with similar technologies as those used to address infiltration. These technologies are described in Section 4. Although an estimate of national-scale costs to address exfiltration must follow more detailed evaluation of exfiltration-susceptible sewer systems, it is possible to identify corrective action costs on a unit basis (i.e., cost ($) per linear foot of sewer) in this study. The following table provides an example of those costs assuming the use of cured-in-place lining as the method of sewer rehabilitation.[20]

Table 5-5. Example Sewer Rehabilitation Costs for Exfiltration Corrective Action

Sewer Diameter (inches)	Cost ($) per linear foot
8	60
10	71
12	77
15	130
18	160
21	225
24	295
27	310
30	535
36	590

Chapter 6
Recommendations

This study identified the following data/technology gaps associated with exfiltration. Recommendations for research and development to fill these gaps were developed for each data/technology gap identified.

1. <u>Data Gap - comprehensive national depth-to-groundwater maps</u>: Although a large portion of the U.S. has readily available, accurate depth-to-groundwater data, many regions of the United States have relatively limited data.

   <u>Recommendation</u>:

   An effort to refine the initial depth-to-groundwater mapping produced in this study with an expanded and updated database would support a more detailed national estimate of exfiltration and the cost of associated corrective measures.

2. <u>Data Gap - extent of exfiltration in municipalities</u>: There are relatively few large urban areas in the U.S. which have the potential for widespread exfiltration. Western arid U.S. cities such as Albuquerque, Phoenix, and Tucson are among the larger metropolitan areas where significant exfiltration potential exists and little is known about it. Albuquerque's exfiltration has recently been studied extensively.

   <u>Recommendation</u>

   Further study of localized exfiltration conditions in cities with high exfiltration potential may be warranted on a case-by-case basis where evidence of exfiltration has been observed, or is revealed by more detailed groundwater study. This study should be preceded by assessment using the refined depth-to-groundwater mapping recommended above to produce a national inventory of exfiltration susceptible areas. This localized study will be of greater value than an attempt to quantify the problem nationally, due to the localized nature of the problem.

3. <u>Data Gap - exfiltrate fate and transport</u>: No information is available regarding the biological disposition of sewage exfiltrate. Also, it would be useful to determine if a biological crust forms in the bedding below an exfiltrating sewer that would serve to insulate/protect groundwater and/or water supply distribution systems.

Recommendation:

Research to fill the exfiltration disposition data gap could involve the use of existing sewage systems known or determined to be leaking in significant amounts (using carefully excavated examination of the bedding beneath and adjacent to the leaking sewer joints), or by construction of an experimental leaking sewer system (artificially introducing sewage into the sewer systems bedding). An analysis of bedding samples from points at increasing depths and horizontal distances from the leak would help to reveal the extent of exfiltrate transport.

4. Combined/Separate Sewer Considerations for Detailed Urban Study

Recommendation

The sewer systems to be considered in future exfiltration assessments should include both combined and separate sewer areas, since combined sewers are often located in highly urbanized areas where imperviousness is high. The result is a decreased rainfall infiltration into the soil and lowering of the GWTs, making these sewers potentially more susceptible to exfiltration. Additionally, combined sewers are often shallower than separate sewers, older than separate sewers, and constructed with less-watertight pipe joints - all factors that can contribute to higher exfiltration rates. Another special case that must be considered in more detailed studies is force mains. Although they are often constructed with tighter pipe joints and more durable pipe material, they nonetheless operate under pressure and may therefore be more exfiltration susceptible.

5. Inclusion of Service Laterals

Recommendation

It will be important to more detailed exfiltration assessments of urban areas to consider service laterals together with public sewers in identifying and evaluating the exfiltration susceptible sewers. Service laterals are the shallowest portion of the sewer system (largest hydraulic gradient difference with GWT) and typically of the poorest construction.

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Glossary Of Terms[1]

1. Combined Sewer

   A sewer intended to serve as a sanitary sewer and a storm sewer, or as an industrial sewer and a storm sewer.

2. Excessive Infiltration/Inflow

   The quantities of infiltration/inflow which can be economically eliminated from a sewer system by rehabilitation, as determined by cost-effectiveness analysis that compares the costs for correcting the infiltration/inflow conditions with the total costs for transportation and treatment for the infiltration/inflow.

3. Exfiltration

   Exfiltration is the leaking of wastewater from a sanitary or combined sewer into the surrounding soil, and potentially, into the groundwater. Exfiltration occurs when the sewer condition degrades to an extent where pipe defects (cracks, joint separation, etc.) allow wastewater to leak out of the sewer. Exfiltration can cause groundwater pollution if the rate and/or volume of wastewater leakage exceeds the ability of the subsurface soil to filter, absorb or immobilize certain pollutant constituents that may be present in the wastewater. Exfiltration is distinguished from infiltration (see below) by the direction of the hydraulic gradient across the sewer wall boundary. For exfiltration to occur, the hydraulic gradient must drive flow external to the sewer; with infiltration, groundwater depths above the flow line in the sewer drive flow into the sewer.

4. Infiltration

   The water entering a sewer system and service connections from the ground, through such means as, but not limited to, defective pipes, pipe joints, connections or manhole walls. Infiltration does not include, and is distinguished from, inflow.

5. Infiltration/Inflow

   The total quantity of water from both infiltration and inflow without distinguishing the source.

6. Infiltration/Inflow Analysis

[1] U.S. Environmental Protection Agency, Office of Water Program Operations, Handbook for Sewer System Evaluation and Rehabilitation, December 1975.

An engineering and, if appropriate, an economic analysis demonstrating possibly excessive or nonexcessive infiltration/inflow.

7. <u>Inflow</u>

The water discharged into a sewer system, including service connections, from such sources as, but not limited to, roof leaders, cellar, yard and area drains, foundation drains, cooling water discharges, drains from springs and swampy areas, manhole covers, cross connections from storm sewers and combined sewers, catch basins, storm waters, surface run-off, street wash waters, or drainage. Inflow does not include, and is distinguished from, infiltration.

8. <u>Internal Inspection</u>

An activity of the Sewer System Evaluation Survey. This activity involves inspecting sewer lines that have previously been cleaned. Inspection may be accomplished by physical, photographic and/or television methods.

9. <u>Physical Survey</u>

An activity of the Sewer System Evaluation Survey. This activity involves determining specific flow characteristics, groundwater levels and physical conditions of the sewer system that had previously been determined to contain possibly excessive infiltration/inflow.

10. <u>Preparatory Cleaning</u>

An activity of the Sewer System Evaluation Survey. This activity involves adequate cleaning of sewer lines prior to inspection. These sewers were previously identified as potential sections of excessive infiltration/inflow.

11. <u>Rainfall Simulation</u>

An activity of the Sewer System Evaluation Survey. This activity involves determining the impact of rainfall and/or runoff on the sewer system. Rainfall simulation may include dyed water or water flooding the storm sewer sections, ponding areas, stream sections and ditches. In addition, other techniques such as smoke testing and water sprinkling may be utilized.

12. Rehabilitation

Repair work on sewer lines, manholes and other sewer system appurtenances that have been determined to contain excessive infiltration/inflow. The repair work may involve grouting of sewer pipe joints or defects, sewer pipe relining, sewer pipe replacement and various repairs or replacement of other sewer system appurtenances.

13. Sanitary Sewer

A sewer intended to carry only sanitary and industrial wastewaters from residences, commercial buildings, industrial plants and institutions.

14. Sewer System Evaluation Survey

A systematic examination of the tributary sewer systems or subsections of the tributary sewer systems that have demonstrated possibly excessive infiltration/inflow. The examination will determine the location, flow rate and cost of correction for each definable element of the total infiltration/inflow problem.

15. Storm Sewer

A sewer intended to carry only storm waters, surface run-off, street wash waters, and drainage.