MANAGEMENT, OPERATION, AND MAINTENANCE OF WASTEWATER SYSTEMS

A Field Study

Presented to

The Faculty of the College of Graduate Studies

Lamar University

In Partial Fulfillment

of the Requirement for the Degree

Doctor of Engineering in Civil Engineering

by

Joseph G. Majdalani, P.E.

December 2010

MANAGEMENT, OPERATION, AND MAINTENANCE OF WASTEWATER SYSTEMS

JOSEPH G. MAJDALANI, P.E.

Approved:

Enno Koehn
Supervising Professor

Hsing- Wei Chu
Committee Member

Hani J. Tohme
Committee Member

Qin Qian
Committee Member

Robert Yuan
Chair, Department of Civil Engineering

Jack Hopper
Dean, College of Engineering

Victor A. Zaloom
Interim Dean, College of Graduate Studies

ABSTRACT

MANAGEMENT, OPERATION AND MAINTENANCE OF

WASTEWATER SYSTEMS

by

Joseph Gebran Majdalani

The goal of this study is to provide a guide for the management, operation, and maintenance of a typical domestic, commercial, and industrial wastewater system serving a population of 100,000 or larger. The study will take into account that wastewater industries are regulated by state and federal agencies.

The large number of wastewater treatment plants and sanitary sewer lift stations, miles of gravity systems and pressure mains varying in material type, size, depth, and age make it very difficult and expensive to operate and maintain a wastewater system.

Wastewater infrastructure is greatly influenced by the aggressive environment that is present around the system at all times. Unstable soil conditions, high temperatures, flat terrain, and high annual rainfall accelerate system corrosion.

The maintenance of every component in the wastewater system is essential for prolonging its life and maximizing its capacity. Changing regulatory requirements, growing population and economy, aging infrastructure, and advancing technologies must be considered as part of the daily operation of a wastewater system.

Inflow/infiltration (I/I) of storm water entering the collection system limit its capacity, increase cost of treatment, negatively impact customer relations, and cause wet weather discharges. The reduction of I/I is an important element in a successful

wastewater system's operation.

The Sanitary Sewer Overflow Initiative (SSOI) is a tool made available by the Texas Commission on Environmental Quality (TCEQ) that can be used by municipalities to reduce Sanitary Sewer Overflows (SSOs) in a timely manner while avoiding fines.

Several rehabilitation techniques are available to replace sanitary sewer pipes and related appurtenances. However, optimizing the wastewater system's operations requires rehabilitation as well as management of existing operational infrastructure.

Capital improvement projects must be constructed utilizing a strong construction management program that insures a high quality final product, built to specifications, and exceed its life expectancy.

Security must be integrated in every component of a wastewater system to deter potential attackers. It is the responsibility of the utility system managers to provide protection to the critical sites and the public.

Finally, funding is required for an efficient management, operation, maintenance, rehabilitation, and capital improvements program (CIP). All funding sources must be evaluated to minimize the impact on the customers and maximize the effect of the final product.

The objective of this field study will be satisfied using the methodology of merging the actual field experiences with theoretical principles to provide a practical approach to efficiently manage, operate, and maintain large wastewater systems. The merging methodology is made possible because of the author's twenty five years of wastewater experience.

ACKNOWLEDGEMENTS

The author would like to recognize the contribution, dedication, and support of the following people who helped complete this dissertation:

Dr. Enno Koehn – Thank you for your encouragement, guidance, and support all these years. You have been both a mentor and a family member who helped me every time I needed help without asking. Your patience and wisdom made this educational trip fun.

Family – It all began with a dream. My parents, Gebran and Olga Majdalani, sent me to the United States to receive an education and better myself. I regret that they didn't live long enough to fulfill this chapter in my life. I know they are looking down at me and are very proud of my accomplishments.

To my three girls, Christina, Crystal, and Carolyn, I thank them for their love and support.

My daily encouragement came by the telephone from my mother-in-law, Marie Bando. She asked me for daily updates and kept me on time. She has given me the best thing in my life....my wife, Cathy, of 25 years. We met in college and here we are 25 years later at the end of my education dream. She has been my sounding board and gave me strength to complete this book. It is because of her and her faith that I have the vision and encouragement needed.

Friends – Many thanks to all my friends and anyone who has come along my path during this journey to accomplish my dream.

TABLE OF CONTENTS

Contents **Page**

LIST OF FIGURES

NOMENCLATURE

AMSA .... Association of Metropolitan Sewerage Agencies

AMWA .... Association of Metropolitan Water Agencies

ANSI .... American National Standards Institute

ARRA .... American Recovery and Reinvestment Act

ASTM .... American Society for Testing and Materials

BOD .... Biological Oxygen Demand

CBI .... Compliance Biomonitoring Inspection

CCTV .... Closed Circuit Television

CEI .... Compliance Evaluation Inspection

CIPP .... Cured-in-Place Pipe

CWA .... Clean Water Act

CM .... Construction Manager

CMOM .... Capacity Management, Operation and Maintenance

CPM .... Critical Path Method

CSI .... Compliance Sampling Inspection

CWA .... Clean Water Act

CWSRF .... Clean Water State Revolving Fund

DWF .... Dry Weather Flow

EDAP .... Economically Distressed Areas Program

EPA .... Environmental Protection Agency

ERP .... Emergency Response Plan

FOG.................................. Fat, Oil, and Grease

Ft .... Feet

FWPA .... Federal Water Pollution Act

GAO................................. U.S. Government Accountability Office

GASB .... Governmental Accounting Standards Board

GIS .... Geographic Information System

GPM................................. Gallons Per Minute

gpm/in/mile .... Gallons Per minute Per Inch Diameter Per Mile Length

HDPE .... High Density Polyethylene

I/I...................................... Inflow/Infiltration

In .... Inches

IST.................................... Inherently Safer Technologies

MCC................................. Motor Control Center

MGD .... Million Gallons Per Day

NAPD............................... Notice of Application and Preliminary Decision

NFPA .... Nation Fire Protection Association

NORI................................ Notice of Receipt of Application and Intent

NOV .... Notices of Violation

NPDES............................. National Pollutant Discharge Elimination System

PAD.................................. Planning, Acquisition, Design

PAI .... Performance Audit Inspection

POWTS .... Publicly-Owned Wastewater Treatment Systems

PVC .... Polyvinyl Chloride

PWWF............................. Peak Wet Weather Flow

RCP .... Reinforced Concrete Pipe

RDII .... Rainfall-Derived Inflow and Infiltration

RWAF............................. Rural Water Assistance Fund

SBEA .... Small Business and Environmental Assistance Division

SCADA........................... Supervisory Control and Data Acquisition

SRF .... State Revolving Fund

SSES .... Sanitary Sewer Evaluation System

SSO .... Sanitary Sewer Overflow

SSOI................................ Sanitary Sewer Overflow Initiative

SSOs................................ Sanitary Sewer Overflows

TAC................................. Texas Administrative Code

TCEQ .... Texas Commission on Environmental Quality

TDS .... Total Dissolved Solids

TMDL .... Total Maximum Daily Load

TPDES .... Texas Pollutant Discharge Elimination System

TSS.................................. Total Suspended Solids

TWDB............................. Texas Water Development Board

USEPA............................ United States Environmental Protection Agency

Water ISAC..................... Water Information Sharing and Analysis Center

WQA .... Water Quality Act

WERF .... Water Environment Research Federation

WWF................................ Wet Weather Flow

XSI .... Toxics Sampling Inspection

1. Introduction

Raw wastewater is the number one cause of disease on planet earth. Containing it in a sealed collection system, until it undergoes treatment prior to discharging it into the waterways, is vital to protecting public health and the environment. The main objective of a wastewater system is to store, transport, and treat residential, commercial, and industrial wastewater. Many of the existing wastewater systems have exceeded their life expectancy, a problem that is magnified by the inflow and infiltration (I/I) of ground and storm water into the collection system causing the occurrence of sanitary sewer overflows (SSOs). Therefore, the wastewater system operators have the challenge of developing and implementing a plan to restore the integrity of the collection system by utilizing tools such as design criteria and asset management.

A major component of a wastewater system is the sanitary sewer lift stations. In areas with flat terrain, sanitary sewer lift stations replace the need for deep gravity sewer pipes by lifting the sanitary sewer to a shallow piping network. Regardless of the type of lift station used, dry well or submersible lift station, an intense maintenance program is required to minimize the effect of items such as grease on pump efficiency and daily operations. New technologies, such as Supervisory Control and Data Acquisition (SCADA) or telemetry system, can be used for better monitoring as well as remote control of the operations. To optimize the use of a sanitary sewer lift station and overcome disadvantages such as operational costs, the lift station must be part of the asset management program.

Once the wastewater is collected, it must be transported to wastewater treatment facilities prior to discharge into the waterways. Different types of wastewater treatment facilities, such as tricking filters and activated sludge, can be used depending on the physical and chemical characteristics of the waste that will be treated. The discharged treated wastewater must improve the quality of water in the receiving stream. Designing a wastewater treatment facility must follow established design criteria and be regulated by the Environmental Protection Agency (EPA) and the Texas Commission on Environmental Quality (TCEQ). The daily operations should include a maintenance program that will ensure permit limits are satisfied and the facility is in an inspection ready status at all times.

The EPA and the TCEQ established rules to regulate the discharge of treated wastewater into the waterways to ensure the safety of the public and the environment. The Federal Water Pollution Act (FWPA), Clean Water Act (CWA), and Water Quality Act (WQA) are some of the major enacted legislations to provide the EPA and the TCEQ with the authority to regulate, monitor, inspect, and fine wastewater facilities. The permitting process of a wastewater system authorized by the Clean Water Act is known as the National Pollutant Discharge Elimination System (NPDES). It is usually monitored by the state, and for Texas, it is known as the Texas Pollutant Discharge Elimination System (TPDES). The regulations may result in fines if inspections indicate that the wastewater system has failing components or operations. However, the wastewater system operators utilize the regulations as tools to secure funding from the governmental entities.

Inflow and infiltration of ground and storm water into the collection system through old deteriorated pipes, manholes, and service line connections during a wet weather event presents the operators with operational challenges in the collection system as well as at the treatment facilities. Inflow and infiltration overwhelms the collection system with ground and storm water interrupting services to customers and generating sanitary sewer overflows that jeopardize public health and pollute the environment. Flow conditions in sanitary sewers vary and are unsteady and non uniform. During dry-weather conditions, flow in gravity flow portions of sanitary sewer systems generally are designed with the water surface at less than pipe crown, i.e., free-surface flow. This flow may be either sub-critical or super-critical. During wet-weather, flows typically increase, often significantly (U.S. Environmental Protection Agency October 2007).

Once in the collection system, the ground and storm water will have to go through the same treatment process as raw wastewater prior to discharging it into the waterways. The wastewater system operators and the design engineers are faced by the challenge of finding a balance between the size of pipe and treatment facilities needed, an organized wastewater system management program, and keeping the negative effects of inflow and infiltration on cost, public health, and the environment to a minimum.

The EPA and the TCEQ understand the planning, designing. and funding demands associated with the rehabilitation of wastewater systems and related time constraints. Therefore, in an effort to act as a partner to the wastewater systems in protecting public health and the environment, the EPA and the TCEQ established a Sanitary Sewer Overflow Initiative (SSOI). In brief, the SSOI is a voluntary agreement between the wastewater system and the TCEQ that will protect the system from fines if a certain amount of improvements are completed within a certain amount of time. The system is allowed to develop its own rehabilitation plan and submit it to TCEQ for approval. Once the plan is completed, the system should be able to measure the impact of the changes and show a reduction in inflow and infiltration and the number of overflows.

Rehabilitation and renewal efforts since the late 1970s have proven effective in reducing inflow and infiltration into the collection system. However, the reduction of the number of overflows can also be enhanced through a well planned wastewater system management program. An evaluation of the wastewater system, gathering information about the assets, and studying historical data must be used to determine if management can be through diversion of flow from one basin to another or it is going to require the construction of new infrastructure.

Replacement and rehabilitation of sanitary sewer infrastructure is costly. Therefore, all construction techniques must be evaluated prior to choosing a rehabilitation method so that the available funds can produce the most productivity. In the past, the open cut method was used to install sanitary sewer pipe in the ground. This method causes major surface damage and adversely affects the economy of the area. Trenchless technologies such as directional drilling, pipe bursting and cured in place can be used to replace the open cut method with minimal interruption to the customers. The location of the project, existing pipe materials and condition, and the hydraulic capacity required will determine the rehabilitation method to be used, size, and type of pipe to be installed.

A successful project with a final product that will exceed its life expectancy is highly dependent on high quality engineering design, proper installation, and the use of materials, products, and equipment specified in the contract documents. Construction management should be part of every phase of the process for it to be cost effective. Construction management practices such as value engineering and construction planning have to abide by state and federal regulations while ensuring the completion of the project on schedule.

The vulnerabilities associated with a wastewater system because of an unmanned infrastructure and the number of people that can be affected by a successful attack on a wastewater system forces the issue of security on any topic related to wastewater systems. Although a determined attacker will find a way to destroy or damage his target, a wastewater system should design a security system based on deterrence, detection, delay, and response. Security should become a culture to the wastewater system operators implementing procedures and projects to reduce the interdependency between the system's different components on each other, replacing treatment gases and methods with less vulnerable techniques, and improving local, state, federal, and regional collaboration. The security of a wastewater system is mandated by state and federal regulations to ensure the safety of the public and the environment.

Construction and rehabilitation of wastewater system infrastructure is costly. Therefore, planning a capital improvement program that prioritizes the projects must be paralleled with a funding plan that explores potential sources such as local, state, and federal funding. A funding plan should include a water and sewer rate structure with possible future rate increases.

2 Wastewater Collection System

2.1 Introduction

A wastewater collection system stores and transports domestic, commercial, and industrial wastewater coming from the customers to the wastewater treatment plant for the purpose of providing treatment prior to release to the environment. The collection and treatment of wastewater is vital to the public health and the environment.

Wastewater collection infrastructure is mainly underground and not visible. Therefore, a deteriorated pipe is not immediately detected and in most cases requires a complete failure prior to repair or rehabilitation. Many cities throughout the United States are suffering from problems associated with an aging underground infrastructure. One way of identifying pipes and pump stations that will receive the most immediate inspection or rehabilitation is to rank pipes in term of their criticality (or consequence of failure) and condition (probability of failure) (Caldwell 2007). Deteriorated piping that has exceeded its life expectancy is a major threat to public health and safety. Sewer collection systems can contribute substantial pollutant loading to receiving waters during wet weather events because of Sanitary Sewer Overflows (SSOs) (Sample, Bocarro and Latalladi 2005). Once the piping network is ranked, funding to repair it, replace it, and rehabilitate it, must be secured.

2.2 Components

Based on the topography of the service area, a wastewater collection system consists of one or a combination of gravity piping networks, manholes, and lift stations that pump into force mains which are used for collection and transmission of wastewater from individual service connection laterals to wastewater facilities for treatment and disposal.

"A gravity line is a sewer pipe that is sloped to convey flow via gravitational forces. Typical design standards are based on open channel flow equations under normal flow conditions utilizing Manning's equation. Design criteria for a gravity line generally take into consideration anticipated defects as a pipe remains in service. An allowable rate of inflow and infiltration expressed in terms of gallons per minute per inch diameter per mile length (gpm/in/mile) is included in hydraulic design of gravity lines. It is also typical to select a frictional coefficient that is based upon a sediment accumulation at the invert of the pipe. The minimum diameter of a gravity line (excluding service laterals) is typically 8 inches (in.); however, large interceptors can have diameters in excess of 12 feet (ft). Older systems may contain 6-in. gravity lines" (U.S. Environmental Protection Agency August 2010).

"Service laterals are the gravity lines that convey wastewater from a building's foundation to the sanitary line or main in the street. The ownership of the service lateral varies widely from area to area. It may be defined by property line limits, with the private sewer lateral extending from the house or building foundation to the property line with the municipal or public lateral located within the public right of way. In other cases, the property owner may own the service lateral all the way to the main" (U.S. Environmental Protection Agency August 2010).

"A force main is a pressure line used to convey sewage pumped by a lift station. The Water Environment Research Federation (WERF) 2004 survey indicated that force mains comprise, on average, 7.5% of a wastewater collection system. This percentage varies considerably depending on the region and the topography. Approximately 46% of the force mains have diameters less than 12-in. and 20% are greater than 36-in. The most common pipe materials for force mains are cast iron and ductile iron" (U.S. Environmental Protection Agency May 2009).

2.3 Typical Collection System Problems

2.3.1 System Reliability

A wastewater collection system's reliability decreases with time. Factors such as deteriorated pipes, separated pipe joints, unstable soil conditions, reduced pump stations efficiency, lack of scheduled maintenance, and pipe cleaning occurring simultaneously drastically decrease the wastewater collection system's reliability.

"Municipal sanitary sewer collection systems are an expensive, valuable, and complex part of the nation's infrastructure. The collection system of a single large municipality can include thousands of miles of pipe and represent an investment worth billions of dollars. The underlying challenges affecting the performance of collection systems are influenced by a number of factors including the following" (U.S. Environmental Protection Agency June 2010):

- Much of the nation's sanitary sewer infrastructure is old; some parts of this infrastructure date back over 100 years. Over the time period associated with building these systems, a wide variety of materials, design, and installation practices, and maintenance/repair procedures have been used, many of which are inferior to those available today;
- Infrastructure has deteriorated with time and continues to age;
- Investment in infrastructure maintenance and repair has often been inadequate;
- The location of problems (e.g., roots, debris) and other variables may

continually change throughout a system;

- Wastewater systems may fail to provide capacity to accommodate increased sewage delivery and treatment demand from increasing populations; and
- Institutional arrangements relating to the operation of sewers may present a barrier to effective operation and maintenance of sewer systems. Almost all building laterals in a municipal system are privately owned. In many municipal systems, a high percentage of collector sewers are owned by private entities or municipal entities other than the entity operating the major interceptor sewers. The proper operation and maintenance of collection system assets is critical to minimizing the frequency and volume of SSOs. Municipalities need to manage their assets effectively and ensure adequate and sustainable funding to support appropriate investments (U.S. Environmental Protection Agency June 2010).

The wastewater collection system's reliability is highly dependent on a scheduled maintenance program accompanied by future planning and implementing of a capital improvements program that rehabilitates infrastructure prior to its failure.

2.3.2 Fat, Oil, and Grease (FOG)

"When fat, oil and grease (FOG) is released into the sanitary sewer lines, in any amounts, it poses a serious threat to the sanitary sewer collection system. As fat, oil and grease sticks to the sides of sewer pipes it reduces the pipe's capacity to move wastewater and, over time, it can block the pipe entirely...Clogged sewers can lead to overflows. As sewage overflows onto streets and enters storm drain systems it is carried to local waterways, creating health risks for the public and [introducing pollutant into] the environment" (Echochem 2008).

"The Department of Public Works and Engineering at the City of Houston has developed its 'Corral the Grease' program to help educate resident on the safe disposal of grease that could, otherwise, solidify inside pipes and restrict the flow of sewage. 'This overloads the system, causing sewage to overflow into streets, yards and storm ditches, which eventually will pollute the bayous and Galveston Bay,' the department says. 'The grease that blocks the sewer pipes generally comes from two sources – commercial and residential kitchens.' While commercial establishments are regulated by city ordinance and are required to install and clean grease traps, residents are encouraged to keep grease out of sewer pipes all together by collecting it in containers and disposing of it with their regular trash" (Majdalani, Golloby and Irish 2007).

Municipalities know that a high percentage of their sanitary sewer pipe blockages are from FOG. Every connection to the sanitary sewer collection system has the potential to be a source of FOG and individual monitoring is impossible. Therefore, educating the public on the proper disposal methods of FOG to minimize its impact on the wastewater collection system is the most effective method used to keep it out of the pipes.

2.3.3 Capacity

Texas Commission on Environmental Quality (TCEQ) and U.S. Environmental Protection Agency (EPA) establish guidelines and regulations that provide engineers typical flow data to be used for different types of facilities. In the past, the design engineer sized the pipes and lift stations based on flow data without taking into consideration existing and future inflow and infiltration flows. However, increased population growth also results in increased wastewater flows. A main problem facing existing collection systems throughout the nation is their inability to handle inflow and infiltration of ground and storm water in addition to the average daily flows. Therefore, the collection system does not have the hydraulic capacity to transport flow received at all times.

"The sanitary sewer collection systems of major cities in the United States were constructed during the 1800's or early 1900's. As a result of physical, chemical, and biological impacts, some of the components of sanitary sewer collection systems for major cities have incurred defects such as collapsed pipes, cracked pipes, offset joints, and cracked manholes. During periods of wet weather, defective components of sanitary sewer collection systems allow the entry of surface runoff and/or groundwater due to inflow/infiltration (I/I)" (Kung'u 1999).

"In addition to I/I, rainwater enters the sanitary sewer collection system through illicit connections from buildings. The combination of wastewater, I/I, and rainwater from illicit connections cause the capacities of some segments of the sanitary sewer collection system to be exceeded. This results in surcharges or overflows from manholes located upstream of the pipe segments. The total flow also often exceeds the capacities of wastewater treatment plants resulting in the bypassing of untreated wastewater into receiving waters. This bypass has the potential to impair human health and the environment" (Kung'u 1999).

Designing pipes to transport average daily flows as well as inflow/infiltration is not economically feasible. Therefore, the design engineer should find a balance between a planned rehabilitation program and pipe network that will minimize the number of overflows during wet weather events.

2.3.4 Inflow & Infiltration (I/I)

Inflow and infiltration are terms used to describe how stormwater and groundwater get into the sewer system (3 Rivers Wet Weather 2010).

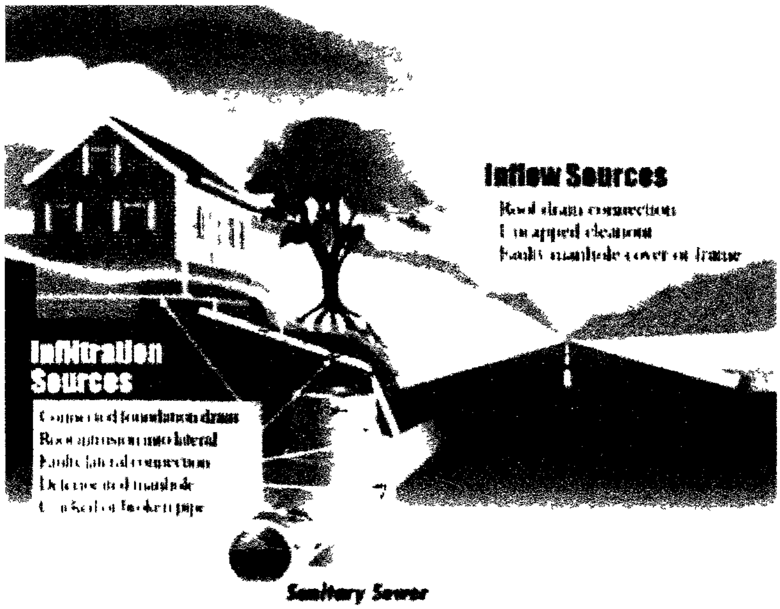

Figure 2.1 Inflow Sources

Source: (3 Rivers Wet Weather 2010)

Inflow is stormwater that is directly piped into the sanitary sewer system. These are illegal connections, which may include storm drains in streets, parking lots, driveways, and roof gutters. Stormwater should never be connected into a sanitary [sewer] system designed to carry wastewater only (3 Rivers Wet Weather 2010).

Figure 2.2 Example of Inflow: A Down Spout Connected

Directly to the Sanitary Sewer System

Source: (3 Rivers Wet Weather 2010)

An ideal wastewater collection system collects and transports waste generated by customers connected to the system. Aging infrastructure results in a deteriorated pipe with separated joints and broken manhole tops and deteriorated walls. In a gravity system, the wastewater is designed to flow at half full pipe. The hydrogen sulfide gases generated from the flowing wastewater in the pipe deteriorate the dry part of the pipe creating a location for ground and storm water to enter the collection system. Service lines connecting wastewater customer's facilities to the collection system are typically four and six inches in diameter. Service lines are usually crossing yards and areas where tree roots invade pipe joints creating another location for ground and storm water to enter the collection system. Finally, a major source of ground and storm water is old, unsealed brick manholes. Inflow and infiltration play a significant role in the sewage overflow problem and wet weather magnifies the problem (3 Rivers Wet Weather 2010).

"Infiltration is excess water that gets into the sewer system through open joints, cracks, and breaks in the pipes. These deficiencies may allow constant infiltration of groundwater. The average sewer pipe is designed to last about 20-50 years, depending on the material. In many cases, collection system pipes and household laterals have gone much longer without inspection or repair and are likely to be cracked or broken" (3 Rivers Wet Weather 2010).

Figure 2.3 Example of Infiltration: A Deteriorated House Lateral that Allowed Water to Seep into the Sewer Collection System

Source: (3 Rivers Wet Weather 2010)

2.3.5 Maintenance

A wastewater collection system requires regular maintenance to maximize its capacity and extend its life expectancy. The maintenance of a wastewater collection system includes pressure cleaning the pipes with specialized equipment and removing built-up grease, deposited solids, and debris accumulated in the pipes and manholes. From the surface, maintenance includes visual inspection of major interceptors to locate cavities and collapses. Surface indentations on top of the pipe are indications of pipe failures. An effective maintenance program should include service lateral pipes as well as major interceptors. After installing new pipes they are televised to assure that they are free from defects and debris.

"Operation and maintenance of a wastewater collection system is the process of making sure that the system is kept in good operating condition. It requires that the facilities be adequately maintained, so that the system can efficiently accomplish its intended function of collecting and conveying wastewater to the treatment plant in a sanitary manner" (Government of Japan 2005).

"Provision of an adequate operation and maintenance of a wastewater collection system extends beyond that of the operation. An efficient system involves joint responsibility of the planners, the designers, the construction managers and the administration, acting homogeneously. The operator can only function on the basis of available resources provided to him. The greater part of the responsibility lies with those who plan, [build, and rehabilitate] the system" (Bureau of Engineering 1992).

"A wastewater collection system is subject to a variety of operational problems. Depending on the wastewater flow characteristics, condition of surrounding soils, and quality of construction, the pipeline can suffer from clogging, scouring, corrosion, collapse, and, ultimately, the system's deterioration. The collection system is designed to serve for a specific useful life. Hence, it is incumbent for the owner to provide adequate operation and maintenance to maximize the benefit throughout its designed useful life" (Bureau of Engineering 1992)

"The objective of a good maintenance program is to keep the system in good operating condition so that it can function efficiently throughout its design life. Lack of good maintenance can result in serious health hazards to the public. It can also cause damage to private property due to sewer backups and overflows. Additionally, it could expose the city to liability suits arising from such hazards and property damage" (Bureau of Engineering 1992).

"Maintenance can be categorized into preventive and corrective maintenance. Preventive maintenance involves inspection of the collection system and analysis of existing data to identify trouble areas. This can provide guidance in developing the type, degree, and frequency of preventive maintenance required" (Bureau of Engineering 1992).

"Corrective maintenance refers more to emergency maintenance. This can be an actual collapse of an existing sewer; stoppage due to roots, grease, or other foreign materials; or excessive inflow or infiltration. These conditions require immediate action to correct the problem. The objectives are to improve service, reduce emergency occurrences, and to minimize the cost of the preventive maintenance program" (Bureau of Engineering 1992).

In general, the greater the amount of preventive maintenance performed, the less the amount of corrective maintenance that will be required. However, there should be a reasonable balance between the cost of preventive maintenance and the corresponding benefit derived. While no precise method is available to determine just exactly how much preventive maintenance should be undertaken, a review of historical maintenance costs on similar facilities can serve as a useful guide to planners and designers.

Maintenance of a wastewater collection system should be integrated into its daily operations. The type and quantity of maintenance required should be directed towards maximizing the efficiency of the system and hence will vary based on the location and age of the system.

2.4 Planning

2.4.1 System Evaluation

Effective planning for the rehabilitation and optimization of a wastewater collection system requires thorough knowledge of the system. The evaluation of every component of a wastewater collection system should include its design criteria and its current condition and capacity. The information will be used by the design engineer to determine if the component can handle the current flows, if it needs to be upsized, or is it in need of rehabilitation or replacement. Once the entire system is evaluated, a base line can be established and the system can be ranked to determine where and when the rehabilitation should start and end.

For example, the City of Houston's wastewater infrastructure network is complex. In order to correctly assess the magnitude, location, and cause of SSO's, a basic understanding of its network is required. An effective evaluation process should include the experience and knowledge of all employees involved in the daily operations, the engineers' education and experience, and the use of available technologies.

2.4.2 Public Awareness & Education

The wastewater collection system is owned by the public. The revenue generated from the sales of water and wastewater services is invested back into the system. Customers need to be aware of their responsibilities towards protecting their investment. The public should be taught that pouring grease in the sink, connecting storm drains to the sanitary sewer collection system, and draining yards into the sanitary sewer manholes can cause blockages, overload the sanitary sewer system, and cause sanitary sewer overflows jeopardizing public health and safety.

In general, the public is not aware of the negative impact of FOG and storm water on the wastewater collection system. Establishing a public awareness and education program that convinces the customers to become part of the solution rather than the problem will minimize the impact on the wastewater collection system and increase its efficiency.

2.4.3 Hydraulic Modeling

"Hydraulic models are an essential tool used by engineers to understand wastewater collection system behavior for system design, operations, assessment of performance, development of rehabilitation programs, support of permit applications, and demonstration of regulatory compliance. Hydraulic models are also used for designing new wastewater collection systems, providing adequate capacity to convey base and peak flows, detecting and correcting inefficiencies in existing systems, and minimizing the costs of pumping" (Bentley 2010).

"A properly developed hydrologic and hydraulic computer model can provide an effective means of evaluating the hydraulic capacity of a sanitary sewer system under dry weather flow (DWF) and wet weather flow (WWF) conditions. Model development includes data collection, Rainfall-derived Inflow and Infiltration (RDII) analysis, model input development, and model calibration and verification" (Vallabhaneni, Chan and Burgess 2007).

2.4.4 Pipe Renewal and Lift Station Rehabilitation

Most wastewater collection systems are over twenty years behind schedule on rehabilitation programs. For many years, patching broken pipe, and deteriorated lift stations instead of replacing problem areas was the preferred method of repair. Part of planning a successful pipe renewal program is identifying the areas with the most inflow and infiltration problems and determining the best renewal method to be used. With the available new technologies, such as pipebursting, directional drilling, and sliplinning, pipes can be replaced with minimal surface disturbance and reasonable cost. Sanitary sewer lift stations must be rehabilitated, replaced, or upgraded to meet current demands.

"Based on its analysis of wastewater collection system conditions and management, the City of Houston proposes a program of structural and nonstructural response to overflows. The structural response recognizes the years of system understanding and acknowledges that reduction of overflows must start with a significant reinvestment of funds over a period of years. To that end, the City will commit to a 10 year program with the following structural and nonstructural components" (City of Houston May 2004):

Structural

Pipe renewal – 9,500,000 linear feet of gravity sewer pipes

7,000,000 linear feet scheduled pipe renewal

2,500,000 linear feet unscheduled pipe renewal

Lift station and force main renewal

Nonstructural

20,000,000 linear feet of targeted pipe cleaning

Lift station and force main preventive maintenance

Enhanced ordinance enforcement related to fats, oils and grease

Improve management information system

The City of Houston's rehabilitation program is one of the most aggressive in the United States. Cities should establish pipe renewal programs at a rate that will continuously reduce the percentage of inflow and infiltration into the system, and hence, sanitary sewer overflows.

2.4.5 Scheduled Maintenance

Routine, preventive, predictive, and even, reactive maintenance can serve to mitigate system deterioration, but at some point, rehabilitation must be performed to extend the asset life of the facilities.

All components of a wastewater collection system must be maintained on a regular basis to prolong its life expectancy and maintain its capacity. On average, sanitary sewer pipes should be cleaned once every seven to ten years. Debris and grease from sanitary sewer lift stations should be vacuumed on a weekly basis or more often as needed and pump efficiency should be checked annually. Sanitary sewer manholes should be inspected for infiltration of storm water and structural integrity annually.

"Under existing regulations at 40 CFR 122.41, all NPDES permits must contain two standard conditions addressing operation and maintenance: proper operation and maintenance requirements at 40 CFR 122.41(e) and duty to mitigate at 40 CFR 122.41(d). These provisions require the permittee to properly operate and maintain its collection system as well as take all reasonable steps to minimize or prevent SSO discharges to waters of the United States that have a reasonable likelihood of adversely affecting human health or the environment" (U.S. Environmental Protection Agency June 2010).

All maintenance performed on the wastewater collection system should be documented and organized so that the information collected can be used for future planning and rehabilitation projects.

2.5 Design Criteria

TCEQ and EPA rules and regulations provide minimum design criteria for wastewater collection systems to be used by the design engineers. However, the design engineers shall size the wastewater collection system based on the given criteria as well as his/her experience and knowledge of the area, population, and industry that will be served.

"Design and sizing of municipal separate wastewater collection systems considers population served, commercial and industrial flows, flow peaking characteristics and wet weather flows. Although separate sewer systems are intended to transport only sewage, all sewer systems have some degree of inflow and infiltration of surface water and groundwater which can lead to sanitary sewer overflows. Inflow and infiltration is highly affected by antecedent moisture conditions, which also represents an important design consideration in these systems" (Texas Secretary of State 2008).

"Wastewater collection lines shall be designed for the projected future population to be served, plus adequate allowance for industrial and commercial flows. The collection system design shall provide a minimum structural life cycle of 50 years, and shall provide for the minimization of anaerobic conditions" (Texas Secretary of State 2008).

"The choice of sewer pipe shall be based on the chemical characteristics of the [waste] water delivered by the water suppliers, the character of industrial wastes, the possibilities of septicity, the exclusion of inflow and infiltration, the external and internal pressures, abrasion, and corrosion resistance. Materials used for sewer joints shall have a satisfactory record of preventing infiltration and root entrance. An infiltration, exfiltration, or low-pressure air test shall be performed on all new installations. The width of the trench shall be minimized, but shall be ample to allow the pipe to be laid and jointed properly and to allow the backfill to be placed and compacted as per manufacturer's specifications" (Texas Secretary of State 2008).

"To prevent any possibility of sewage entering the potable water system, water lines and sanitary sewers shall be installed no closer to each other than nine feet between outside diameters unless pressure pipes are used" (Texas Secretary of State 2008).

"The peak flow of domestic sewage, peak flow of waste from industrial plants, and maximum infiltration rates shall be considered in determining the hydraulic capacity of sanitary sewers. The design of extensions to sanitary sewers should be based on the data from the existing system. If this is not possible, the design shall be based on data from similar systems. New sewers shall be sized using an appropriate engineering analysis of existing and future flow data. Minor sewers shall be designed such that when flowing full they will transport wastewater at a rate approximately four times the system design daily average flow. Main trunk, interceptor, and outfall sewers shall be designed to convey the contributed minor sewer flows" (Texas Secretary of State 2008).

"No sewer other than service laterals and force mains shall be less than six inches in diameter. All sewers shall be designed and constructed with slopes sufficient to give a velocity when flowing full of not less than 2.0 feet per second, based on Manning's formula with an assumed "n factor" of 0.013. Sewers shall be laid in straight alignment with uniform grade between manholes. Manholes shall be placed at all points of change in alignment, grade, or size of sewer, at the intersection of all sewers and the end of all sewer lines that will be extended at a future date. Manholes shall be monolithic, cast-in-place concrete, fiberglass, precast concrete, HDPE, or of equivalent construction. Brick manholes shall not be used, nor shall brick be used to adjust manhole covers to grade. Manholes shall be of sufficient inside diameters to allow personnel to work within them and to allow proper joining of the sewer pipes in the manhole wall. The inside diameter of manholes shall be not less than 48 inches. Manhole covers of nominal 32-inch or larger diameter are to be used for all sewer manholes" (Texas Secretary of State 2008).

"Alternative wastewater collection systems may be considered when justified by unusual terrain or geological formations, low population density, difficult construction, or other circumstances where an alternative wastewater collection system would offer an advantage over a conventional gravity system. Alternative wastewater collection system types include pressure sewers, small diameter gravity sewers, vacuum sewers, and combination of all or some of the available systems" (Texas Secretary of State 2008).

For more information, see the Texas Administrative Code (TAC) - Rule 317.2 Wastewater Collection System.

2.6 Asset Management

Having an accurate location map of the wastewater system that is updated as the system expands and changes is vital to proper management, operation, and maintenance of the wastewater infrastructure. Similarly, having an accurate database of attribute data for all wastewater infrastructure facilities is vital to proper asset management.

"The assets of a wastewater collection system are what make it operate efficiently and effectively. The managers and operators of the wastewater collection system should have a thorough knowledge of the assets condition, performance, age, and capacity. This knowledge will assist the design engineers in planning the rehabilitation program. The manipulation of the assets can optimize the operation of the system. As an example, an area with deteriorated pipe with high volumes of inflow and infiltration can be diverted to an area where capacity is available. Such manipulation will reduce sanitary sewer overflows and provide uninterrupted service to the customers" (Governmental Accounting Standards Board 2010).

Asset management is a continuous process that guides the acquisition, use, and disposal of infrastructure assets to optimize service delivery and minimize costs over the asset's entire life (Pierce County Public Works and Utilities 1996 - 2010). "Sewer system assets that are not regularly maintained usually deteriorate faster than expected and lead to higher replacement and emergency response costs. The key elements of asset management are" (Governmental Accounting Standards Board 2010):

- Level of service definition
- Selection of performance goals
- Information system
- Asset identification and evaluation
- Failure impact evaluation and risk management
- Condition assessment
- Rehabilitation and replacement planning

- Capacity assessment and assurance
- Maintenance analysis and planning
- Financial management
- Continuous improvement

These elements should be implemented by everyone in the organization, involving management, financial, engineering, and administrative and field staff.

2.7 Components of an Asset Management System for a Sewer Collection Network

"A basic level of service definition for most collection systems will be to deliver reliable sewer collection services at a minimum cost consistent with applicable environmental and health regulations. Level of service criteria will be system-specific, but should address Capacity Management, Operation and Maintenance (CMOM) and the Governmental Accounting Standards Board 34 (GASB) requirements (Governmental Accounting Standards Board 2010), particularly in areas where improvements are most needed and will yield the greatest benefits. Examples include" (Governmental Accounting Standards Board 2010):

- Ensuring adequate system capacity for all service areas
- Eliminating system bottlenecks due to pipe blockages
- Reducing peak flow volumes through inflow/infiltration (I/I) controls
- Providing rapid and effective emergency response service
- Minimizing cost and maximizing effectiveness of CMOM programs

Performance measurements are specific metrics designed to assess whether or not the level of service objectives are being met. Some examples of performance measurements (Governmental Accounting Standards Board 2010):

- Annual performance goals for sewer system inspection, cleaning, maintenance, rehabilitation, and capital improvement;
- Correlating grease control education and enforcement measures with expected reductions in the number, distribution, and severity of grease blockages;
- Establishing maximum hourly and monthly peak flow volumes;
- Establishing maximum emergency response time to emergency calls, tracking customer complaints and claims for private property restoration; and
- Performing cost-benefit analysis of key completed activities, taking into account expected vs. actual outcome, and budgeted vs. actual cost.

There are many available resources and guides that can be used to better manage the assets of a wastewater collection system. However, the managers and operators should manipulate the available resources to maximize their positive impacts on their specific systems.

2.8 Summary

The wastewater collection system is the first city-owned section of the wastewater system that transports wastewater from the customer to the treatment facilities. Hydrogen sulfide gas, and fats, oil, and grease (FOG) are two enemies of the collection system piping network that can cause failures and sanitary sewer overflows. The proper operation, maintenance, and rehabilitation of a collection system require joint effort between the customers, the city and the contractors.

3 Wastewater Lift Stations

3.1 Introduction

A wastewater service area with flat terrain without substantial elevation changes will require the construction of wastewater lift stations to eliminate the need for deep gravity sewer pipes. Lift stations are used to move wastewater from lower to higher elevations, particularly where the elevation of the source is not sufficient for gravity flow and/or when the use of gravity conveyance will result in excessive excavation depths and high sewer construction costs (U.S. Environmental Protection Agency July 2010a).

Dry wells and submersible lift stations are the two main types used in the wastewater industry. The proper operations of lift stations demand a routinely scheduled maintenance and operations program that is enhanced by control devices that are monitored remotely from a Supervisory Control and Data Acquisition (SCADA) or telemetry system. The maintenance and operations program is diverse, including daily general cleaning, availability of ventilation, cooling and heating devices, odor control, adequate power supply, and efficient pump and motor performance to optimize capacity. Although the use of sanitary sewer lift stations is mandated by the terrain, the wastewater system will benefit from their advantages and suffer from their disadvantages. Therefore, to capitalize on the use of sanitary sewer lift stations, an asset management program is needed.

"Sewage pumps are almost always end-suction centrifugal pumps with open impellers and are specially designed with a large open passage so as to avoid clogging with debris or winding stringy debris onto the impeller. A four pole or six pole AC induction motor normally drives the pump. Rather than provide large open passages, some pumps, typically smaller sewage pumps, also macerate any solids within the sewage breaking them down into smaller parts which can more easily pass through the impeller" (Grundfos Commercial Building Services 2002).

The interior of a sewage pump station is a very dangerous place. Poisonous gases such as methane and hydrogen sulfide can accumulate in the wet well; an unequipped person entering the well would be overcome by fumes very quickly. Any entry into the wet well requires the correct confined space entry method for a hazardous environment. To minimize the need for entry, the facility is normally designed to allow pumps and other equipment to be removed from outside the wet well (Grundfos Commercial Building Services 2002)

The discharge of untreated wastewater is an environmental and health hazard. Causes for/or undersized force mains, pumps not working as designed, clogged impellers, disconnected pipes, electrical outages, disconnected or non-functioning backup generators, vandalism, and sewage flows that are greater than anticipated (Malone II 2008).

3.2 Types of Lift Stations

Raw wastewater travels through a gravity piping network from residential, commercial, and industrial customers to a sanitary sewer lift station. In general, a sanitary sewer lift station stores raw sewage in a wet well which will be lifted by pumps and discharged into another gravity system. The larger and flatter the size of the service area, the more times this process has to be repeated for the raw sewage to reach the wastewater treatment plant without needing to install deep gravity sewer pipes. To prevent overflows from sanitary sewer lift stations, wet wells are remotely monitored by level sensors. The size of the wet well and service area of the sanitary sewer lift station will determine the setting of the level sensors and the number of pumps that will turn on to provide uninterrupted service to the customers. "By this method, pumping stations are used to move [wastewater] to higher elevations. In the case of high sewage flows into the well, during peak flow periods and wet weather, additional pumps will be used. If this is insufficient, or in the case of failure of the pumping station, a backup in the sewer system can occur, leading to a sanitary sewer overflow" (Wikipedia 2010a). The common types of wastewater lift stations are the dry-well and submersible lift stations.

3.2.1 Dry-Well Lift Stations

In dry-well lift stations (Figure 3.1), the pumps and valves are located in a pump room where they do not come in direct contact with the raw sewage in the wet well. This construction method is used to minimize the exposure of the equipment to sewer gases and prolong its life expectancy. Dry-well lift stations allow easy access for routine visual inspection that will identify required maintenance. In general, the installation of the equipment separate from the wet well provides a safer environment to repair and/or replace pumps and related equipment.

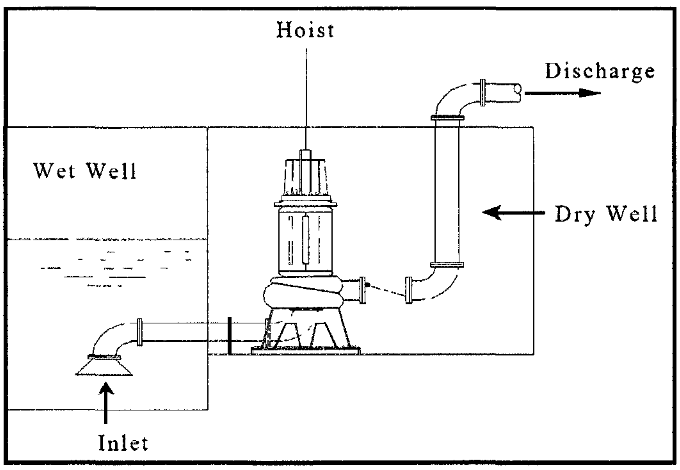

Figure 3.1 Dry-Well Pump

Source: (Qasim 1994)

3.2.2 Submersible Lift Stations

Submersible lift stations compact the pumps, motors, and wet wells in the same structure (Figure 3.2). Lift station header piping, valves (Figure 3.3), flow meters, electrical and process controls (Figure 3.4), are located in a separate dry area to protect the equipment from sewer gases and provide operational accessibility. The pumps used in submersible lift stations are in direct contact with raw sewage inside the wet well (Figure 3.5). The removal of the pumps for maintenance is made easier through the use of guide rails and a hoist system that are usually part of the design of a submersible lift station.

Submersible lift stations cost less than dry-well stations and usually operate with minimal pump maintenance. In addition, submersible lift stations are more acceptable by customers when installed in residential neighborhoods since they are mainly located below ground level.

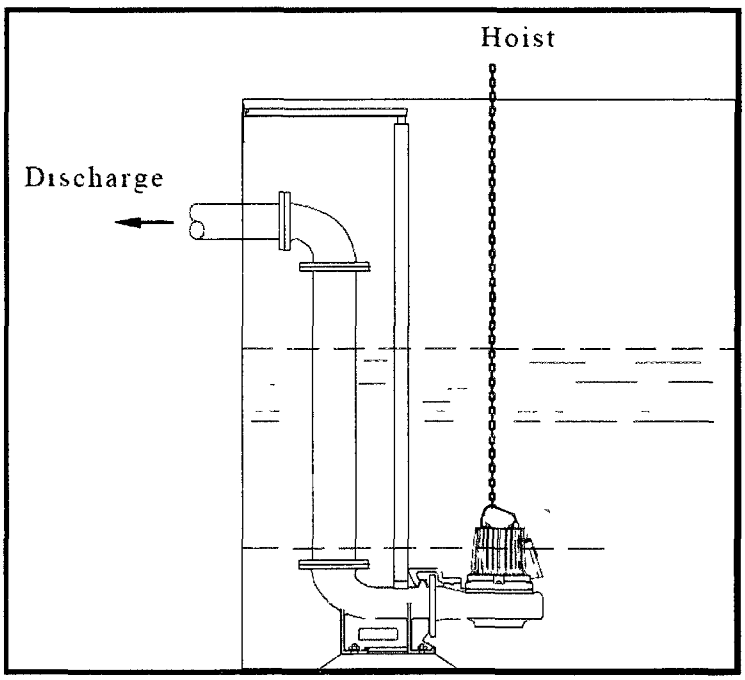

Figure 3.2 Wet-Well Submersible

Source: (Qasim 1994)

Figure 3.3 Submersible Lift Stations – Header Piping and Associated Valves

Source: (City of Beaumont-Water Utilities Department)

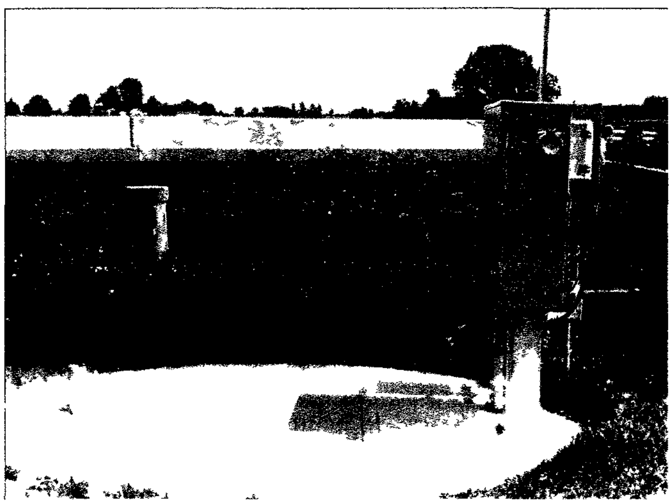

Figure 3.4 Submersible Lift Stations - Above Ground Electrical System

Source: (City of Beaumont-Water Utilities Department)

Figure 3.5 Submersible Lift Stations – Wet Well

Source: (City of Beaumont-Water Utilities Department)

3.3 Design Criteria

The Environmental Protection Agency (EPA) and the Texas Commission on Environmental Quality (TCEQ) in the State of Texas provide minimum design criteria for public wastewater lift stations to be used by the design engineers. "However, the design engineers shall seize the wastewater lift stations based on the given criteria as well as his/her experience and knowledge of the service area, population, and industry that will be served" (City of Houston 2010).

"Sewage pumping stations are typically designed so that one pump or one set of pumps will handle normal peak flow conditions. Redundancy is built into the system so that in the event that any one pump is out of service, the remaining pump or pumps will handle the designed flow. In these days there are a lot of electronic controllers in the market designed especially for this application. The storage volume of the wet well between the 'pump on' and 'pump off' settings is designed to minimize pump starts and stops, but is not so long a retention time as to allow the sewage in the wet well to go septic" (Texas Secretary of State 2008).

"In the selection of a site for a lift station, consideration shall be given to accessibility and potential nuisance aspects. The station shall be protected from the 100-year flood and shall be accessible during a 25-year flood. All lift stations shall be intruder-resistant with a controlled access. Lift stations should be located as remotely as possible from populated areas" (Texas Secretary of State 2008).

"Lift stations designed for a discharge capacity of less than 100 gallons per minute shall be used only for institutional use or other locations where it is necessary to pump the sewage from a single building, school, or other measurable source establishment into the sanitary sewer lines. Whenever a lift station handles waste from two or more residential housing units, or from any public establishment, standby pumps shall be provided. Grinder pumps should be used for all small installations" (Texas Secretary of State 2008).

"The following design considerations shall be addressed in providing dry well sump pumps. Two separate sump pumps should be provided for removal of leakage or water from the dry well floor. The discharge pipe level from the sump pumps shall be above the maximum liquid level of the wet well. A check valve should be installed on the discharge side of each sump pump. All floor and walkway surfaces shall have an adequate slope to a point of drainage with sufficient measures taken to maximize traction and safety. Motors to drive sump pumps shall be located above the height of the maximum liquid level in the wet well. As an alternate, sump pumps may be of the submersible type" (Texas Secretary of State 2008).

"All lift stations shall have automatically operated pump control mechanisms. Pump control mechanisms shall be located so that they will not be affected by flow currents in the wet well. Provisions shall be made to prevent grease and other floating materials and rags in the wet well from interfering with the operation of the controls. The circuit breakers, indicator lights, pump control switches, and other electrical equipment should be located on a control panel at least three feet above ground surface elevation. If controls are located in a dry well, the dry well shall be protected from flooding" (Texas Secretary of State 2008).

"Wet wells and dry wells, including their superstructure, shall be separated by at least a watertight and gastight wall with separate lockable entrances provided to each.

Based on design flow, wet well capacity should provide a pump cycle time of not less than six minutes for those lift stations using submersible pumps and not less than 10 minutes for other nonsubmersible pump lift stations" (Texas Secretary of State 2008).

"All influent gravity lines into a wet well shall be located where the invert is above the "off" setting liquid level of the pumps, and preferably should be located above the lead pump "on" setting" (Texas Secretary of State 2008).

"Ventilation shall be provided for lift stations, including both wet and dry wells. All mechanical and electrical equipment in wet wells should be explosion-proof and spark-proof construction if mechanical ventilation is not provided" (Texas Secretary of State 2008).

"The bottom of wet wells shall have a minimum slope of 10% to the pump intakes and shall have a smooth finish. There shall be no projections in the wet well which will allow deposition of solids under ordinary operating conditions. Antivortex baffling should be considered for the pump suctions in all large sewage pumping stations (greater than five mgd firm pumping capacity)" (Texas Secretary of State 2008).

"Drains from dry wells or valve vaults to the wet well shall be equipped with suitable devices to prevent entry of potentially hazardous gases.

All raw sewage pumps shall be of a non-clog design, capable of passing 2 1/2 inch diameter spheres, and shall have no less than three-inch diameter suction and discharge openings" (Texas Secretary of State 2008).

"The firm pumping capacity of all lift stations shall be such that the expected peak flow can be pumped to its desired destination. Firm pumping capacity is defined as total station maximum pumping capacity with the largest pumping unit out of service.

Only self-priming pumps or pumps with acceptable priming systems, as demonstrated by a reliable record of satisfactory operation, shall be used where the suction head is negative" (Texas Secretary of State 2008).

"All raw sewage pumps, other than submersible pumps without "suction" piping and self-priming units capable of satisfactory operation under any negative suction heads anticipated for the lift station under consideration, shall be positioned such that the pumps always experience, during their normal on-off cycling, a positive static suction head" (Texas Secretary of State 2008).

"Full closing valves shall be installed on the discharge piping of each pump and on the suction of all dry pit pumps. A check valve shall be installed on the discharge side of each pump, preceding the full closing valve. Butterfly valves, tilting disc check valves, or other valves with a pivoted disc in the flow line are not allowed" (Texas Secretary of State 2008).

"Flanged pipe and fitting or welded pipe shall be used for exposed piping inside of lift stations. A flexible or flanged connection shall be installed in the piping to each pump so that the pump may be removed easily for repairs. Piping should normally be sized so that the maximum suction velocity does not exceed five feet per second and the maximum discharge velocity does not exceed eight feet per second" (Texas Secretary of State 2008).

"Force mains shall be a minimum of four inches in diameter. In no case shall the velocity be less than two feet per second with only the smallest pump operating, unless special facilities are provided for cleaning the line at specified intervals or it can be shown that a flushing velocity of five feet per second or greater will occur one or more times per day. Pipe specified for force mains shall be of a type having an expected life at least as long as that of the lift station and shall be suitable for the material being pumped and the operating pressures to which it will be subjected. All pipe and fittings shall have a minimum working pressure rating of 150 pounds per square inch. Minimum test pressure shall be 1.5 times the maximum design pressure for all installed force mains. Air release valves or combination air release/vacuum valves suitable for sewage service shall be provided at all peaks in elevation" (Texas Secretary of State 2008).

"Lift stations shall be designed such that there is not a substantial hazard of stream pollution from overflow or surcharge onto public or private property with sewage from the lift station. Options for a reliable power source may include reliable commercial power service, emergency power supply or a detention facility shall be provided" (Texas Secretary of State 2008).

"An audiovisual alarm system (red flashing light and horn) shall be provided for all lift stations. These alarm systems should be telemetered to a facility where 24-hour attendance is available. The alarm system shall be activated in case of power outage, pump failure, or a specified high water level" (Texas Secretary of State 2008). For more information, see the TAC - *Rule 317.3, Lift Stations.*

3.4 Maintenance Requirements

3.4.1 General Maintenance

Through the use of SCADA, the operators of wastewater systems continuously monitor the operations of the sanitary sewer lift stations and immediately detect any interruptions in services. The SCADA has the capabilities to monitor and control pumps, level sensors, alarms, and power supply. The twenty-four hour monitoring of the lift stations can reduce the number of hours required by personnel while providing up to the minute information. Regular preventative maintenance can save the lift station owners costly repairs. The following maintenance items will insure continuous operations at a minimal cost:

1. A cleaning schedule of the wet well should be established based on the service area and type of waste discharged to the sanitary sewer lift station. A minimum of two cleanings a year is recommended for continuous operations. However, a weekly cleaning may be necessary to prevent solids and grease build-up. Build-up of solids can create odors and damage the pumps.
2. Submersible pumps and motors including impellers should be inspected quarterly or as needed if performance standards are not met. The

inspections would assure that the impeller is free of debris, and the motor and pump seals are in good condition.

3. Dry pit pumps and motors should be inspected daily for vibrations and quarterly for efficiency.

4. The check valves used to prevent backflow from the force main into the sanitary sewer lift station must be inspected semi-annually. The valves should provide a complete seal to be able to isolate the force main from the lift station's wet and/or dry well.

5. It is essential to keep the raw sewage from overflowing outside of the wet well. When floats are used to accomplish this task, they should be inspected weekly and cleaned as needed. The most common problem for floats is the buildup of grease which prevents them from working properly.

6. Every sanitary sewer lift station should have an audible and visual alarm system that will immediately alert the operators in case of a failure. Inspection of the light and horn should be performed weekly.

7. Regulations require the wastewater operators to keep records of the flows pumped from a sanitary sewer lift station. To ensure the integrity of the data collected, hour meters must be installed on each motor to provide an accurate record of the number of hours the motors are operating and cycling from which the flow is determined. The hour meters should be checked during routine inspections to make sure they are working.

8. The amp readings can provide the operators with valuable information regarding the efficiency of the system. If the amp readings do not match with the manufacturer's recommendation, it can be caused by debris lodged in the impeller or water leakage into the motor and wiring system.
9. Electrical motor control and SCADA equipment must be inspected semi-annually. Tightening of lose connections and replacement of deteriorated parts will increase the efficiency, improve reliability of the lift station, and reduce the operating cost.

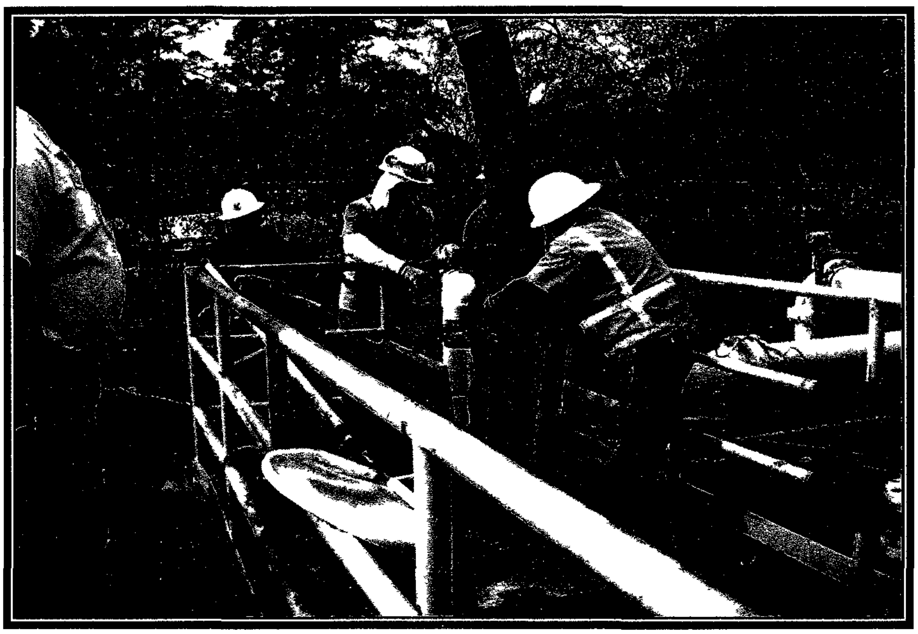

Figure 3.6 Lift Stations Maintenance Crew

3.4.2 Grease Removal

Fifty to seventy-five percent of wastewater collection system blockages and lift station failures are related to fat, oil, and grease (FOG). Grease blockages in the wastewater collection system and grease buildup in lift stations will cause sanitary sewer backups in homes and businesses and raw sewage discharges in ditches and waterways. The increasing number of fast food restaurants and apartment complexes in service areas contributes to an increase in the volume of grease discharged into the collection system which is transported to the lift stations.

Once grease enters the collection system, it solidifies and clings to the pipe, decreasing its capacity. "Grease in a warm liquid may not appear harmful. But, as the liquid cools, the grease or fat congeals and causes nauseous mats on the surface of settling tanks, digesters, and the interior of pipes and other surfaces which may cause a shutdown of wastewater treatment units" (Environmental Leverage, Inc. 2003).

A pipe cleaning program will have to be established and implemented to restore and maintain the design capacity of the piping network. In addition, grease discharged from restaurants must be regulated by the wastewater system operators. "Problems caused by wastes from restaurants and other grease-producing establishments have served as the basis for ordinances and regulations governing the discharge of grease materials to the sanitary sewer system. This type of waste has forced the requirement of the installation of preliminary treatment facilities, commonly known as grease traps or interceptors. Recently, the federal government raised the required temperatures for restaurants from 180 degrees to 210 degrees. The impact on this is that the grease now does not cool down in the grease traps, but later in the pipes or lift stations" (Environmental Leverage, Inc. 2003).

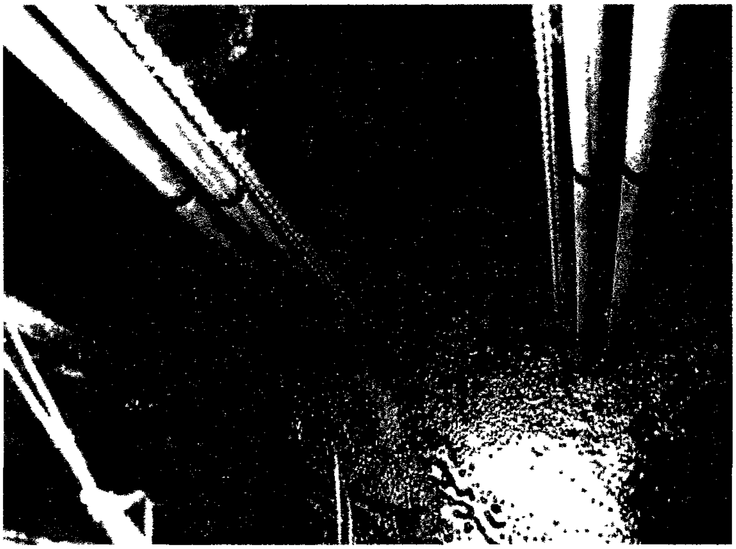

Figure 3.7 Scum Layer on Sidewalls and Piping System of Lift Station

Source: (Environmental Leveraage, Inc. 2003)

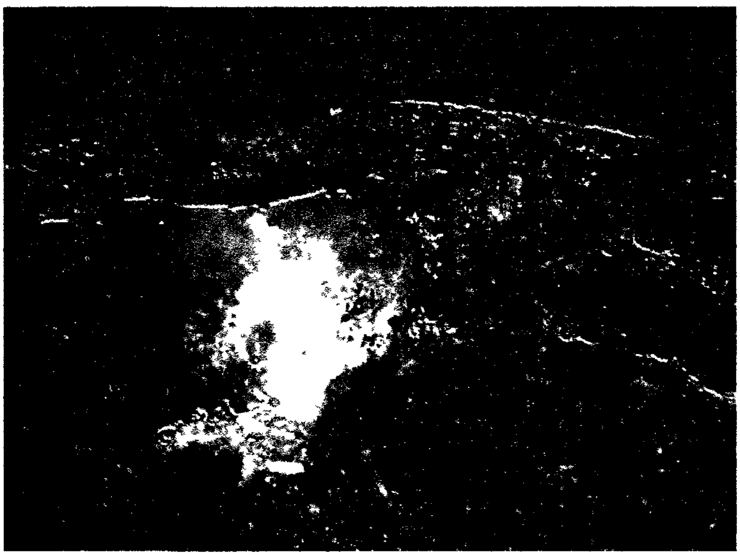

Figure 3.8 Mats of Grease in Wet Well of Lift Station

Source: (Environmental Leveraage, Inc. 2003)

3.4.3 Ventilation

The safety of the personnel accessing the lift stations is a priority to the managers of wastewater systems. A sophisticated monitoring system ensuring proper ventilation should be part of the operating components because of the poisonous nature of the gases discharged from the collection system and accumulated in the lift stations. "Ventilation is required if the lift station includes an area routinely entered by personnel. Ventilation is particularly important to prevent the collection of toxic and/or explosive gases. According to the Nation Fire Protection Association (NFPA) Section 820, all continuous ventilation systems should be fitted with flow detection devices connected to alarm systems to indicate ventilation system failure. Dry-well ventilation codes typically require six continuous air changes per hour or 30 intermittent air changes per hour. Wet-wells typically require 12 continuous air changes per hour or 60 intermittent air changes per hour. Motor control center (MCC) rooms should have a ventilation system adequate to provide six air changes per hour and should be air conditioned to between 13 and 32 degrees Celsius (55 to 90 degrees F). If the control room is combined with an MCC room, the temperature should not exceed 30 degrees C or 85 degrees F. All other spaces should be designed for 12 air changes per hour. The minimum temperature should be 13 degrees C (55 degrees F) whenever chemicals are stored or used" (U.S. Environmental Protection Agency June 2010).

3.4.4 Odor Control

Odor control is required for lift stations especially when located in residential areas. Several methods can be used for odor control such as reduction of turbulence in the piping network and wet well, collection of gases producing odors at the lift stations and running them through scrubbers or bio-filters, and the addition of odor control chemicals to the sewer upstream of the lift station. "Chemicals typically used for odor control include chlorine, hydrogen peroxide, metal salts (ferric chloride and ferrous sulfate) oxygen, air, and potassium permanganate. Chemicals should be closely monitored to avoid affecting downstream treatment processes, such as extended aeration" (U.S. Environmental Protection Agency June 2010).

3.4.5 Power Supply

"The reliability of power for the pump motor drives is a basic design consideration. Commonly used methods of emergency power supply include electric power feed from two independent power distribution lines; an on-site standby generator; an adequate portable generator with quick connection; a stand-by engine driven pump; ready access to a suitable portable pumping unit and appropriate connections; and availability of an adequate holding facility for wastewater storage upstream of the lift station" (U.S. Environmental Protection Agency September 2000).

3.4.6 Performance

"The performance of the pumps and the reliability of the force main determine the efficiency of a lift station. The performance of a pump depends on its capacity, head, power, and overall efficiency. Capacity is measured in gallons per minute (gpm) or million gallons per day (mgd). Head is the energy supplied to the wastewater per unit weight, measured in feet of water. Power is the energy consumed by a pump per unit time, measured as kilowatt-hours. Overall efficiency is the ratio of useful hydraulic work performed to actual work input. Efficiency reflects the pump relative power losses and is usually measured as a percentage of applied power" (U.S. Environmental Protection Agency September 2000).

"Pump performance curves [Figure 3.9] are used to define and compare the operating characteristics of a pump and to identify the best combination of performance characteristics under which a lift station pumping system will operate under typical conditions (flows and heads). Pump systems operate at 75 to 85 percent efficiency most of the time, while overall pump efficiency depends on the type of installed pumps, their control system, and the fluctuation of influent wastewater flow" (U.S. Environmental Protection Agency September 2000).

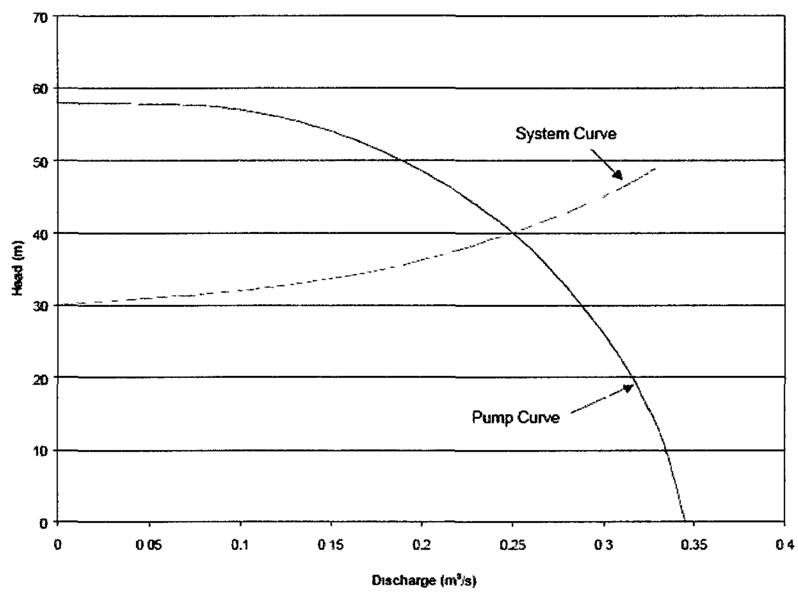

Figure 3.9 Pump Performance Curve

Source: (Qasim 1994)

"Performance optimization strategies focus on different ways to match pump operational characteristics with system flow and head requirements. They may include the following options: adjusting system flow paths; installing variable speed drives; using parallel pumps; installing pumps of different sizes; trimming a pump impeller; or putting a two-speed motor on one or more pumps in a lift station. Optimizing system performance may yield significant electrical energy savings" (Qasim 1994).

3.5 Operation and Maintenance

The effective operation of lift stations requires a planned preventative maintenance program. The operators should be trained and licensed to meet TCEQ and EPA regulations. The operators should have extensive knowledge of the lift stations and operating components. Any deviation from the regular daily operations of the pumps, motors, and discharge volumes should be easily detected by the operators.

Although SCADA controls provide monitoring of the lift station operations, it cannot perform inspections that should be conducted by the operators. Routine inspections are necessary to identify and address problems such as debris in the wet well that can cause major damage to the equipment and interruption in services if not physically removed. Similarly, pump vibrations, leaky seals, proper switch positions, evaluation of pump discharge rates, and studying pump curves for efficiency measures can only be detected and performed by the operators.

The operators of sanitary sewer lift stations should develop a different maintenance program for every lift station based on the size, capacity, age, and service area.

Asset management should be a main part of the maintenance program of lift stations. Identifying assets and projecting their life expectancy is used for determining maintenance schedules and needs. "The ultimate purpose of an asset management plan is to ensure that assets are operated and maintained in a sustainable and cost effective manner, so that they provide the required level of service for present and future customers" (Carterton District Council 2007).

3.6 Advantages

Lift stations are mainly used in flat terrains where the use of gravity sewer pipes will require the construction of pipes deeper than what is feasible for operations, cost and maintenance.

"Lift stations are used to reduce the capital cost of sewer system construction. When gravity sewers are installed in trenches deeper than ten (10) feet, the cost of sewer line installation increases significantly because of the more complex and costly excavation equipment and trench shoring techniques required. The size of the gravity sewer lines is dependent on the minimum pipe slope and flow. Pumping wastewater can convey the same flow using smaller pipeline size at shallower depth, and thereby, reducing pipeline costs" (U.S. Environmental Protection Agency September 2000).

Providing storage capacity in the collection system reduces the potential of overflows during brief service interruptions. In addition, the lift stations can be used to control the flow to the wastewater treatment plant. As an example, prior to a rain event the lift stations can be used to pump the collection system down allowing for additional storage capacity in the collection system. Keeping the wastewater contained in the collection system help meet TCEQ and EPA regulations and protect the environment from illegal discharges.

3.7 Disadvantages

Sanitary sewer lift stations are associated with operational costs unlike gravity sewer pipes. In addition, the operation of sanitary sewer lift stations is dependent on other entities such as power supply companies, pump and motor manufacturers, and repair crews. The operators of the wastewater system may not be in control of the lift station's ability to operate under certain circumstances disrupting the services. This interruption in services can affect the customers in the area as well as the downstream wastewater treatment facilities.

Odors and noise, especially if the lift station is located in a residential area, will generate customer complaints. Such situations can create a negative public image of the wastewater system, however, eliminating noise and odor can be expensive.

3.8 Summary

Lift stations are essential in areas with flat terrain to avoid the construction of deep gravity sewer pipes. The design, construction, maintenance, and operation of sanitary sewer lift stations are regulated by the EPA and the TCEQ. Sanitary sewer lift stations can act as a problem to the operators if not maintained properly or as an asset to prevent overflows if utilized in the flow management program.

4 Wastewater Treatment Plants

4.1 Introduction

The first step in designing a wastewater treatment plant involves collecting, testing, and analyzing the type of raw sewage that will be received in order to determine the type of treatment that will be required. The concentrations of biological oxygen demand (BOD) total suspended solids, ammonia, phosphates, and other contaminating constituents of the raw sewage that will be harmful to the environment if discharged in the waterways will dictate the required removal methods. The principle objective of a wastewater treatment plant is to produce an effluent that can be discharged without causing environmental impacts (Kaliappan 2009). Usually the contaminants in raw wastewater require more than one type of process to produce treated water that will not be harmful to the environment. The different processes include conventional, primary, secondary, or tertiary treatments. Part of the treatment process also includes the removal of sludge that must be disposed of properly. Regardless of the wastewater treatment method used, new technologies must be investigated to ensure the most efficient approach is used. Minimum design criteria are provided by the EPA and the TCEQ, and they set discharge permit limits based on the type of facility and receiving stream. However, these criteria should be used as a guideline and not a law. Once built and in operation, Wastewater Treatment Plants in the United States are regulated by the Environmental Protection Agency (EPA).

In most cases, the existing wastewater treatment plants were built for a different type of waste that is received today. As an example, the cleaning ingredients used today in households are completely different from those used 25 years ago. In addition, inflow and infiltration problems associated with the collection system drastically increase the volume of raw wastewater delivered to the plant during wet weather events and change the characteristics of the raw wastewater from that during regular daily operations. Therefore, to protect the integrity of the wastewater treatment plant and the environment, a management plan must be designed and implemented. The main objective should be to protect the waterways.

"Good water quality is necessary for protecting public health and sustaining a growing economy. Maintaining and improving the quality of our nation's waterways has long been a national priority. The Federal Water Pollution Control Act of 1972 (commonly referred to as the Clean Water Act) calls for all waterways to ultimately be 'fishable and swimmable'. Its principal goal is to 'restore and maintain the chemical, physical, and biological integrity of the Nation's waters' which 'provides for the protection and propagation of fish, shellfish, and wildlife'..." (Chicago Metropolitan Agency for Planning 2010).

4.2 Wastewater Treatment Process

Physical, chemical, and biological processes can be used to remove pollutants from raw sewage and meet permit limits set by the EPA and the TCEQ. The first step in treating raw sewage usually includes solids removal through a screening process. The screen openings will vary in size based on the type of solids the wastewater treatment plant receives and the type of treatment processes past the screens. Then the treatment can be conventional, requiring primary and secondary treatment or advanced, dictating the need for tertiary treatment to remove all the pollutants that cannot be treated by conventional methods and are harmful to the environment.

The features of wastewater treatment systems are determined by (1) the nature of the municipal and industrial wastes that are conveyed to them by sewers, and (2) the amount of treatment required to preserve and/or to improve the quality of the receiving bodies of water (Viessman and Hammer 1998). As shown in Figure 4.1 and Figure 4.2, surface aerators and fine bubble diffusers are used to aerate wastewater in a treatment process unit. Aeration supports biological and other treatment processes. With water conservation regulations becoming more stringent, recycling of the treated wastewater is becoming more desirable. Recycling may be in the form of reuse for irrigation or treatment for usage as potable water.

Figure 4.1 Surface Aerators Used to Aerate Wastewater

Source: (Viessman and Hammer 1998)

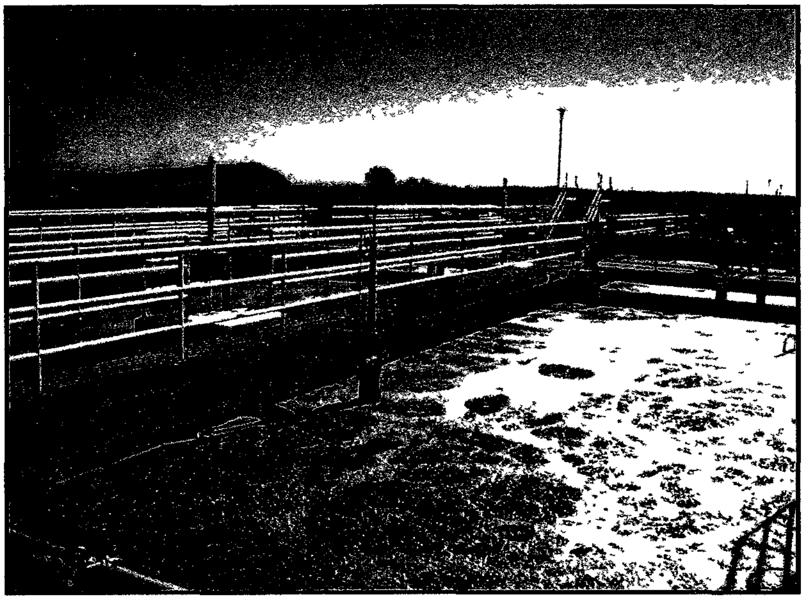

Figure 4.2 Fine Bubble Diffusers Used to Aerate Wastewater

Source: (Viessman and Hammer 1998)

"Stream classification documents, published by each state as required by the U.S. Clean Water Act of 1977, categorize surface waters according to their most beneficial present or future use, such as for drinking-water supplies, body-contact recreation, and so on. These publications also incorporate stream standards that establish maximum allowable pollutant concentrations for a given stream under defined flow conditions. Effluent standards under the Clean Water Act's National Pollutant Discharge Elimination System (NPDES) are used for regulatory purposes to achieve compliance with these stream standards. NPDES permits are issued to cities or other facilities that regulate the volume of discharge, contaminant concentrations, and timing of discharge so as to protect water quality in the receiving waterbody" (Viessman and Hammer 1998). The treatment process should ensure the wastewater system meets or exceeds the set permit limit requirements.

4.3 Conventional Treatment

The conventional wastewater treatment process is usually an approach used to treat the wastewater from residential areas that includes commercial and light industry. Conventional treatment will include the screening process, primary and secondary treatment, while excluding tertiary treatment. To produce treated water that will not harm the environment when discharged into the waterways, sludge removal is necessary. Once the sludge is separated from the wastewater, based on its type, it can be disposed of at a landfill or used to make fertilizer.

4.4 Primary and Secondary Treatment

The coarse screens at the head of the wastewater treatment plant can have openings small enough to remove solids that are as small as a penny. However, raw wastewater contains suspended solids that cannot be removed through the use of a coarse screen. At that point, the raw wastewater is transferred to the primary clarifiers for primary treatment that consists of a sedimentation process (Figure 4.3). Sedimentation is achieved through settling which will remove thirty to fifty percent of the suspended solids from the wastewater. Once the primary treatment is completed, the secondary treatment will start through an activated sludge or trickling filters process. Although secondary treatment can be accomplished through different processes they all include the biological removal of contaminants through the use of microorganisms that digest the organic materials in the wastewater in the presence of oxygen. In an activated sludge process, the oxygen is provided mechanically through blowers (Figure 4.4). For a trickling filters process, oxygen is provided naturally.

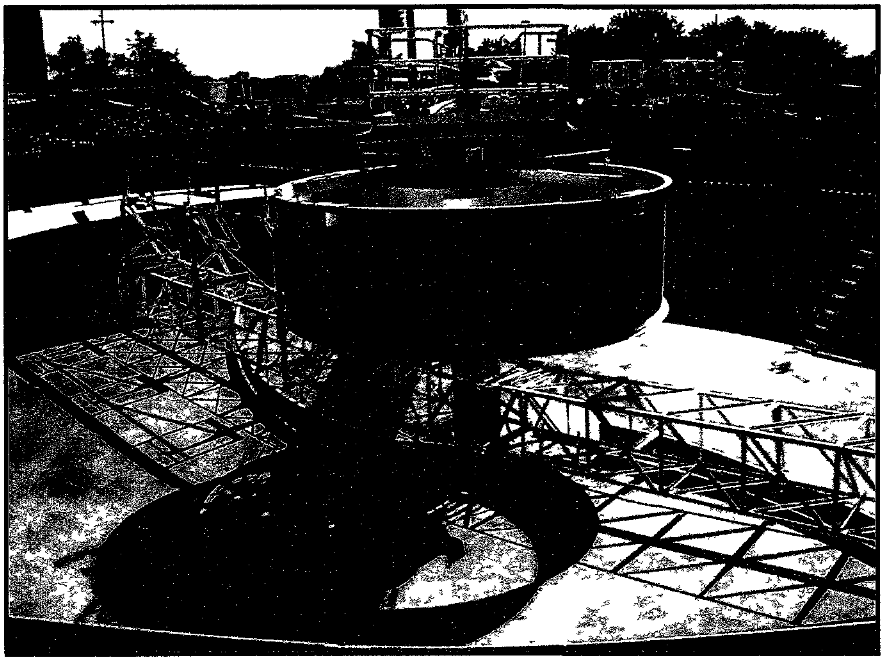

Figure 4.3 Filter Unit Under Construction

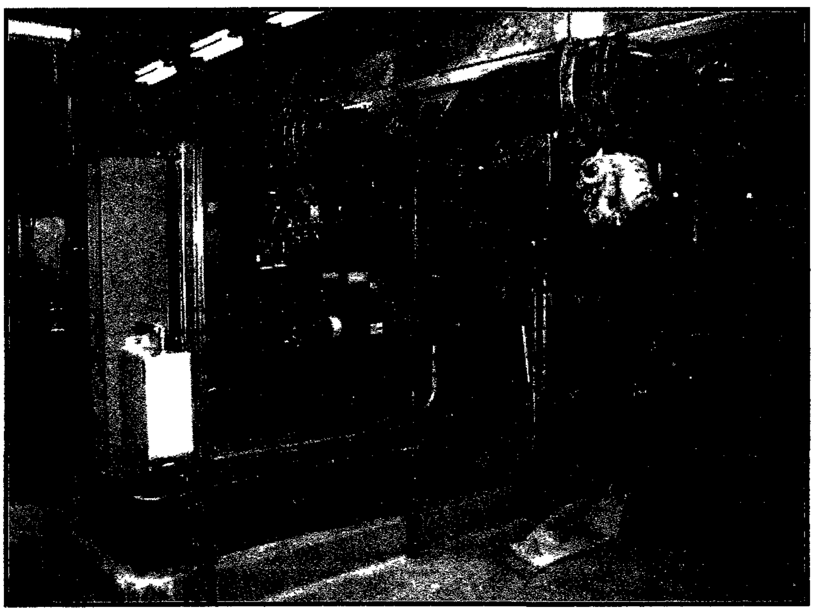

Figure 4.4 Blower Units

4.5 Tertiary Treatment

Tertiary treatment is usually required in wastewater systems that serve heavy industrial customers who discharge contaminants that cannot be treated by primary and secondary processes. Iron is a heavy metal that will require tertiary treatment for its removal. Another example is "phosphorus whose removal may be needed for wastewater that is discharged to receiving waters that are likely to become eutrophic, or enriched with nutrients. (Cultural or human-enhanced eutrophication often is associated with nitrogen and phosphorous in effluent)" (Viessman and Hammer 1998).

4.6 Sludge Processing and Disposal

The solids that cannot be removed through the use of mechanical screens and are mainly removed through the primary treatment process and the organics that are removed by the secondary treatment process make the sludge. Although the volume of sludge produced is a fraction of the volume of wastewater processed, handling the sludge is a major part of the wastewater treatment operation, the budget, and the permitting process. "Methods for processing raw sludge include anaerobic (biological) digestion and mechanical dewatering by either belt-filter pressing or centrifugation. Conventional methods of disposal are application as a fertilizer or soil conditioner on agricultural land, landfilling in a dedicated disposal site, or codisposal with municipal solid waste" (Viessman and Hammer 1998).

4.7 Wastewater Treatment Technology

New wastewater treatment technologies evolved with the advancement in biology and chemistry that provided a better understanding of the nature of the wastewater that needs to be treated, and the status of the receiving streams and what is required to improve their quality. Better understanding of the needs to protect the environment and the public health lead to chemical, biological, and mechanical inventions that improved the wastewater treatment process.

An example of innovative technologies "is the Membrane BioReactor (MBR) which falls under the category of biological treatment processes, 'systems that use microorganisms to degrade organic contaminants from wastewater'. MBR systems offer capital and operational cost savings due in part to reduced energy consumption, smaller footprints, and better effluent quality. In conjunction with Biological Nutrient Removal systems, MBRs have proven to reach nitrogen levels below 4.0 mg/L and phosphorus levels under 0.5 mg/L" (U.S. Environmental Protection Agency February 2008).

"Village of Pingree Grove conducted a pilot study to evaluate utilizing an MBR system in its wastewater treatment process. The study revealed significant improvement in the effluent water quality. The Village will utilize this system during the second phase of its wastewater treatment plant expansion (U.S. Environmental Protection Agency February 2008).

"Another example of effective wastewater treatment technology is nanofiltration. This process is used by many municipalities to remove organic pollutants, remove total suspended solids (TSS) and total dissolved solids (TDS), and to disinfect and soften wastewater for reuse. Though nanofiltration consumes relatively more energy than other processes, it is more effective than ultrafiltration in the removal of TSS, TDS, and other pathogens. This system has a small footprint and is convenient for retrofitting wastewater treatment facilities" (U.S. Environmental Protection Agency February 2008).

A growing wastewater treatment method is the use of constructed wetlands that utilize a natural process to treat wastewater with plants and bacteria. However, it requires large areas of land which is not available in an urban setting. In addition, relying on natural processes as a treatment method will limit the operator's control.

Wastewater vacuum system is also available. This approach uses differential pressure, vacuum valves and vacuum lift stations. The system is effective if pipe sizes can be kept below twelve inches in diameter, the pipes are sealed, and when sandy soil conditions and high water table cannot support a gravity system.

4.8 Design Criteria

"The design criteria are provided by the EPA and TCEQ and must be used as a minimum requirement by the design engineer. The following cover the design requirements for a wastewater treatment plant processes such as raw sewage data, design and peak flows, design loadings, overflow rate, clarifiers, trickling filters and aeration. The design criteria are in Texas Administrative Code - Rule 317.4 Wastewater Treatment Facilities" (Texas Secretary of State 2008).

"Whenever possible, existing data of flows and raw waste strength from the same plant or nearby plants with similar service areas should be used in design of treatment facilities. When using such data for design purposes, the variability of data should be considered and the design based on the highest flows and strengths encountered during normal operating periods taking into consideration possible inflow/infiltration. In the absence of existing data, [Figure 4.5] lists generally acceptable parameters to which must be added appropriate allowances for inflow and infiltration into the collection system to obtain plant influent characteristics" (Texas Secretary of State 2008).

Source	Remarks	Daily Wastewater Flow – Gallons Per Person	Wastewater Strength mg/L BOD_5
Municipality	Residential	100	200
Subdivision	Residential	100	200
Trailer Park (Transient)	2 ½ persons per trailer	50	300
Mobile Home Park	3 persons per trailer	75	300
School with Cafeteria	With Showers	20	300
	Without Showers	15	300
Recreational Parks	Overnight user	30	200
	Day user	5	100
Office Building or Factory		20	300
Motel		50	300
Restaurant	Per Meal	5	1000
Hospital	Per Bed	200	300
Nursing Home	Per Bed	100	300

Figure 4.5 Generally Acceptable Parameters for Inflow and Infiltration

Source: (Texas Secretary of State 2008)

"Wastewater treatment plants shall be designed to consistently meet the effluent concentration and loading requirements of the applicable waste disposal permit. The design flow of a treatment plant is defined as the wet weather, maximum 30-day average flow. The design basis shall include industrial wastewaters which will enter the sewerage system. It is the intent of these design criteria that the permit conditions not be violated.

The engineering report shall list the design influent flow, concentration of BOD_5, TSS, or other parameters for the following" (Texas Secretary of State 2008):

- Dry weather 30-day average (Q_D W);
- Wet weather maximum 30-day average (Q_D W); and
- Two-hour peak flow (Q_p W).

"The piping within all plants shall be arranged so that when one unit is out of service for repairs, plant operation will continue and emergency treatment can be accomplished. Valves and piping shall be provided and sized to allow dewatering of any unit, in order that repairs of the unit can be completed in as short a period of time as possible" (Texas Secretary of State 2008).

"For treatment unit design purposes, peak flow is defined as the highest two-hour average flow rate expected to be delivered to the treatment units under any operational condition, including periods of high rainfall (generally the two-year, 24-hour storm is assumed) and prolonged periods of wet weather. With pumped inflow, clarifiers shall have the capacity of all pumps operating at maximum wet well level unless a control system is provided that will limit the pumping rate to the firm capacity. This flow rate may also include skimmer flow, thickener overflow, filter backwash, etc. All treatment plants must be designed to hydraulically accommodate peak flows without adversely affecting the treatment processes" (Texas Secretary of State 2008).

"The need for auxiliary power facilities shall be evaluated for each plant and discussed in the preliminary and final engineering reports. Auxiliary power facilities are required for all plants, unless dual power supply arrangements can be made. Acceptable alternatives to auxiliary power include the ability to store influent flow or partially treated wastewater during power outage" (Texas Secretary of State 2008).

"There shall be no water connection from any public drinking water supply system to a wastewater treatment plant facility unless made through an air gap or a backflow prevention device" (Texas Secretary of State 2008).

"The need for odor control facilities shall be evaluated for each plant. Factors to be considered are the dissolved oxygen level of the incoming sewage and the type of treatment process proposed" (Texas Secretary of State 2008).

"Bar screens should be provided at all plants. Manually cleaned bar screens shall be constructed having a 30-degree to 60-degree slope to a horizontal platform which will provide for drainage of the screenings. Bar screen openings shall not be less than 3/4 inch for manually cleaned bar screens and 1/2 inch for mechanically cleaned bar screens. The channel in which the screen is placed shall allow a velocity of two feet per second or more at design flow. Velocity through the screen opening should be less than three feet per second at design flow" (Texas Secretary of State 2008).

"Grit removal facilities should be considered for all wastewater treatment plants. Grit washing facilities shall be provided unless a burial area for the grit is provided within the plant grounds, or the grit is handled otherwise in such a manner as to prevent odors or fly breeding. Plants which have a single grit collecting chamber shall have a bypass around the chamber. All grit collecting chambers shall be designed with the capability to be dewatered" (Texas Secretary of State 2008).

"Fine screens, if used, shall be preceded by a bar screen. Fine screens shall not be substituted for primary sedimentation or grit removal; however, they may be used in lieu of primary treatment if fully justified by the design engineer. A minimum of two fine screens shall be provided, each capable of independent operation at peak flow" (Texas Secretary of State 2008).

"Equalization should be considered to minimize random or cyclic peaking of organic or hydraulic loadings. Equalization units should be provided after screening and grit removal" (Texas Secretary of State 2008).

"Aeration may be required for odor control. When required, air supply must be sufficient to maintain 1.0 mg/liter of dissolved oxygen in the wastewater" (Texas Secretary of State 2008).

"A means for measuring effluent flow shall be provided at all plants. Consideration should be given to providing a means to monitor influent flow. All plants shall be provided with a readily accessible area for sampling effluent" (Texas Secretary of State 2008).

"Clarifier inlets shall be designed to provide uniform flow and stilling. Vertical flow velocity through the inlet stilling well shall not exceed 0.15 feet per second at peak flow. Inlet distribution channels shall not have deadened corners and shall be designed to prevent the settling of solids in the channels. Inlet structures should be designed to allow floating material to enter the clarifier" (Texas Secretary of State 2008).

"Scum baffles and a means for the collection and disposal of scum shall be provided for primary and final clarifiers. Scum collected from final clarifiers in plants utilizing the activated sludge process and aerated lagoons may be discharged to aeration basin(s) and/or digester or disposed of by other approved methods. Scum from all other final clarifiers and from primary clarifiers shall be discharged to the sludge digester or other approved method of disposal. Discharge of scum to any open drying area is not acceptable" (Texas Secretary of State 2008).

"Effluent weirs shall be designed to prevent turbulence or localized high vertical flow velocity in the clarifiers. Weirs shall be located to prevent short circuiting flow through the clarifier and shall be adjustable for leveling. Weir loadings shall not exceed 20,000 gallons per day peak design flow per linear foot of weir length for plants with a design flow of 1.0 mgd or less. Special consideration will be given to weir loadings for plants with a design flow in excess of 1.0 mgd, but such loadings shall not exceed 30,000 gallons per day peak flow per linear foot of weir" (Texas Secretary of State 2008).

"Means for transfer of sludge from primary, intermediate, or final clarifiers for subsequent processing shall be provided so that treatment efficiency will not be adversely affected. Gravity sludge transfer lines shall not be less than eight inches in diameter" (Texas Secretary of State 2008).

"Overflow rates are based on the surface area of clarifiers. The surface areas required shall be computed using the following criteria. The actual clarifier size shall be based on whichever is the larger size from the two surface area calculations (peak flow and design flow surface loading rates). The final clarifier solids loading for all activated sludge treatment processes shall not exceed 50 pounds of solids per day per square foot of surface area at peak flow rate. The following design criteria for clarifiers are based upon a side water depth of 10 feet and shall be considered acceptable" (Texas Secretary of State 2008).

For additional design information and requirement for wastewater treatment facilities in Texas, please refer to Texas Administrative Code - Rule 317.4.

4.9 Maintenance Requirements

The maintenance of a wastewater treatment plant is essential for its proper operations, adequate treatment, and to extend its life expectancy. Capacity, management, operation, and maintenance programs established and promoted by the EPA can be used as a tool by wastewater system operators to maximize the maintenance efforts.

4.9.1 Purpose of CMOM Programs

Wastewater treatment facilities operate within a fixed budget. The budget includes the cost of labor, materials, chemicals, electricity, and scheduled and unscheduled repairs. The CMOM program will assist the wastewater treatment operators to minimize expenditures and maximize productivity utilizing the available funds. "Routine regular maintenance is an essential component in prolonging the life of infrastructure and equipment. In particular, the development and the implementation of a preventive maintenance program is necessary for the better management of infrastructure facilities" (Karaa 1989). CMOM programs attempt to accomplish their objectives while taking into consideration permit limits and uninterrupted customer service. The elements of the CMOM program include (U.S. Environmental Protection Agency January 2005):

- Physical Inspection Program
- Plant Management
- Plant Operation
- Plant Maintenance.

A CMOM program can be successful if it is designed to accommodate the plant's design capacity while taking into consideration high flows during wet weather events. A maintenance plan for average daily flows should be modified when the plant receives double its design capacity. Another main component of CMOM is equipment maintenance and continuous operations through redundancy. Since operations at a wastewater system cannot be interrupted for long periods of time, equipment should always be in perfect condition. On average, the cost to build a new wastewater plant is six to eight dollars per gallon. A 50 MGD plant to serve approximately 250,000 residences will cost approximately $300,000,000. Therefore, a wastewater treatment plant is a major expense to a wastewater system and an asset that must be maintained to prolong its life. A CMOM program will accomplish this goal.

The EPA and TCEQ will audit the CMOM programs and evaluate their effectiveness. "The most valuable tool the auditor can use while conducting a CMOM evaluation is the plant Operations and Maintenance manual (O&M manual). The plant O&M manual provides detailed data and information regarding every aspect of the treatment plant, including procedures for management, operation, maintenance, and other programs designed to ensure the safe and compliant operation of the plant. The evaluation conducted to determine the effectiveness of a CMOM program is more than a paperwork exercise. To fully determine the value and effectiveness of the CMOM program, an auditor must be prepared to interview staff at all levels of the organization. Staff interviews will provide valuable insight into whether the CMOM program is purely paper, or if it is truly in practice. The auditor will also want to take a tour of the facility to observe how it is operated" (U.S. Environmental Protection Agency January 2005).

4.10 Impact of Inflow/Infiltration on Wastewater Treatment Plants

A typical wastewater treatment plant is designed to treat a wastewater volume for a specific population with room for growth and expansion. Since the construction and treatment costs can negatively impact the wastewater system's budget, it is important to size the treatment facilities accordingly. However, a deteriorated collection system will induce large volumes of storm water into the piping network during wet weather events exposing the plant to unforeseen conditions during the design. The solution for inflow and infiltration of storm water into the collection system is not to upsize the wastewater treatment plant, but rather rehabilitate the collection system and construct storage areas that the raw wastewater can be contained in until the rain event is over and the additional flow is transported to the wastewater treatment plant.

"According to a recent AMSA survey, inflow and infiltration (along with stormwater that goes to the plant) comprise almost 25 percent of total flows. This figure represents an average; values for specific plants are substantially higher" (U.S. Environmental Protection Agency 1998).

Flow Type	**Flow (MGD)**	**Percent of Total**
Inflow/Infiltration	2,423	20.2%
Combined Stormwater	502	4.2%
Total Wet Weather to Plant	2,925	24.4%
Residential	6,826	56.7%
C&I	2,253	18.8%
Total to Plants	12,005	100.0%

Figure 4.6 Aggregate Flows of 107 POTWS

Source: (U.S. Environmental Protection Agency 1998)

A study conducted in Lower Paxton Township Authority in Pennsylvania showed that the cost of adding capacity at the wastewater treatment plant is too high compared to rehabilitating the components of the collection system such as replacing pipes, rehabilitating manholes, and replacing lateral service lines. The study also shows that building holding basins or tanks to contain wastewater within a storm event is also more economical than increasing the plant's capacity.

Control Approach	**I/I Contribution (%)**	**I/I Control Costs ($/gallon removed)**
Remove Sump Pumps	19	$0.04 - $0.27
Grout Manholes	25	$0.04 - $0.30
Grout Sewers	15	$0.05 - $0.36
Mainline Replacement	<1	$0.16 - $2.22
Lateral Repairs	42	$0.20 - $3.72
Equalization Basins	N/A	
- Above ground tank		$0.98
- Below ground tank		$1.32 - $4.80
Convey and Treat	N/A	
- Additional capacity at existing plant		$6.16
- Construct new plant		$3.81 - $18.80

Figure 4.7 Inflow and Infiltration Control in Lower Paxton Township Authority, PA

Source: (U.S. Environmental Protection Agency 1998)

Regardless of the approach the wastewater system chooses to resolve the inflow and infiltration problems, it is going to be costly and funding will be required. Ideally, the customers in areas with highest inflow and infiltration problems should be charged their share of the cost. However, usually water and wastewater rate increases throughout the wastewater system's boundaries are applied evenly to fund the required capital improvement projects.

4.11 Permitting and Inspection

Wastewater treatment plants are permitted by the EPA and TCEQ. Permits are renewed every three to five years based on the type of facility, quality of discharge stream, and history of compliance. The discharge limits set by the permit are mainly contingent on the environmental needs and protecting public health. The TCEQ conducts yearly inspections of the wastewater treatment plants to ensure compliance with permit limits, inspect the physical condition of the facility, and review the applicability of the CMOM program.

A permit writer uses "Section 303(c) of the CWA that requires every state to develop water quality standards applicable to all water bodies or segments of water bodies that lie within the state. Once standards are developed, EPA must approve or disapprove them. Water quality standards should (1) include provisions for restoring and maintaining the chemical, physical, and biological integrity of state waters, (2) provide, wherever attainable, water quality for the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water ("fishable/swimmable"), and (3) consider the use and value of state waters for public water supplies, propagation of fish and wildlife, recreation, agriculture and industrial purposes, and navigation. Currently, states are required to review their water quality standards at least once every three years and revise them as necessary. When writing a permit, the permit writer must use the most current state water quality standards" (U.S. Environmental Protection Agency 1991).

4.12 Summary

Wastewater treatment plants' design, operations, and maintenance are regulated by the EPA and the TCEQ. The main objective of a treatment facility is to remove the contaminants from wastewater so that the discharge into the waterways will meet permit TPDES limits. The treatment process can be as simple as the use of trickling filters or as involved as an activated sludge plant, as long as the objective is met.

5 State and Federal Regulations

5.1 Introduction

It is the responsibility of wastewater system operators to ensure their system's continuous operation with optimized efficiency. Wastewater illegal discharges should never occur intentionally or from poor maintenance of the collection system or wastewater treatment facilities. Although wastewater system operators understand the importance of protecting the environment and public health, funding may deter them from accomplishing these tasks. Therefore, the state and federal government determined the need to set and ensure the implementation of wastewater regulations to govern wastewater systems. The Federal Water Pollution Control Act of 1972, as amended by the Clean Water Act (CWA or the Act) of 1977 and the Water Quality Act of 1987, gives EPA the authority to regulate the discharge of pollutants to waters of the United States (Probe International n.d.).

These regulations provide the wastewater system operators with the tools they need to obtain funding and construct needed expansion and rehabilitation projects. The state and federal government established guidelines for treated wastewater discharge limits that are set in the permitting process of the wastewater system authorized by the Clean Water Act and known as the National Pollutant Discharge Elimination System (NPDES). In most cases, the NPDES permit program is administered by authorized states. Since its introduction in 1972, the NPDES permit program is responsible for significant improvements to our nation's water quality (National Pollutant Discharge Elimination System (NPDES) Permits Program 2010).

The Clean Water Act (CWA) enacted in 1977, prohibits any person or entity from discharging pollutants, such as sewage, from a point source into waterways unless a permit is obtained. The NPDES program was designed to control "water pollution sources by regulating point sources that discharge pollutants into waters of the United States" USEPA, Office of Wastewater Management (Chicago Metropolitan Agency for Planning 2010).

In the State of Texas, the Texas Pollutant Discharge Elimination System is used to regulate wastewater systems. Hundreds of acts, regulations, and policies have been created by federal, state, and local government to help protect the environment. Regulatory agencies, such as the Environmental Protection Agency (EPA) and the Texas Commission on Environmental Quality (TCEQ), are authorized to create and enforce regulations that help put the acts or laws into effect (3 Rivers Wet Weather 2010).

Once permits are underwritten, the responsibility of complying by the permit limits resides in the hands of the wastewater system operators. The state and federal government performs inspections of the wastewater facilities to ensure that the operators are licensed to perform their duties, the documentation of data and analysis results is appropriate, and the equipment and structures are in good operating conditions. The purpose of the inspections is not to fine the facilities but rather provide direction. However, continuous noncompliance may lead to fines.

5.2 TPDES Domestic Wastewater Permits

The discharge of treated wastewater into the waterways is regulated by the state and federal government and cannot legally take place without a Pollutant Discharge Elimination Systems permit issued by the state. Under Section 402 of the Act, point source dischargers of pollutants (e.g., municipal wastewater treatment plants, industries, animal feedlots, aquatic animal production facilities, and mining operations) facilities must apply and receive a permit that set specific limits and operating conditions to be met by the permittee (U.S. Environmental Protection Agency July 2002).

Different states have different permitting processes and requirements. However, they should all follow the guidelines set by the EPA. In Texas, the discharge of treated domestic wastewater into or adjacent to water in the state must be authorized by the TCEQ. Domestic facilities that dispose of treated effluent by discharge into waters of the state are required to obtain a Texas Pollutant Discharge Elimination System (TPDES) permit (Texas Commission on Environmental Quality August 2010).

In the State of Texas, the TCEQ provides field and technical support to wastewater systems for the permitting process. The permit limits will be determined by several factors, such as concentrations of pollutants in the untreated wastewater, the type of wastewater system and its pollutants removal percentages, and the water quality in the receiving stream. The State of Texas divided the receiving streams into different sections based on water quality and ranked them based on their ability to meet their intended use purposes such as fishing and recreation. Discharges that will degrade the water quality of the receiving stream will not be authorized and the wastewater system will have to modify its treatment process to meet stringent permit limits set by the TCEQ. The Texas Water Quality Inventory and 303(d) List describe the status of the state's waters on historical surface and groundwater quality data (the Inventory) and identify water bodies that are not meeting standards set for their use (the List). The List must be approved by the Environmental Protection Agency (EPA) before it is considered final (Texas Commission on Environmental Quality August 2010).

Once the TCEQ is consulted and the permit needs are determined, an application must be completed and submitted. Different states have different time limitations for the application. However, all states prohibit any discharges of treated wastewater prior to the issuance of the permit.

The following instructions and forms are needed to complete the permit application package (Texas Commission on Environmental Quality 2006):

- Completing the Domestic Wastewater Permit Application
- Domestic Administrative Report
- Domestic Technical Report
- Instructions for Completing Sewage Sludge Technical Reports
- Sewage Sludge Technical Report

The submittal of the application is the tool the wastewater system's operator has to inform the state of the system's discharge intentions. The administrative and technical reviews are tools used by the states to evaluate and approve the application.

The administrative review consists of a detailed review of the application to make sure required information is complete. The application should have information, such as address of treatment facility, type and capacity of treatment components, total treatment capacity, location maps, and proposed discharge limits. The application will be rendered incomplete if any of the required information is not provided and TCEQ will issue a Notice of Deficiency letter that must be responded to within a certain time period. The TCEQ will not proceed with the application process unless the application is complete.

Since the discharge of treated wastewater may affect different entities downstream of the discharge point, all permit applications must be advertised to give everyone that may be affected by the permit issuance the opportunity for comments. The Notice of Receipt of Application and Intent to Obtain Permit or NORI must be published after the administrative review is complete. After TCEQ receives the application, it will go through an administrative and technical review (Texas Commission on Environmental Quality 2006):

- **Technical Review**

  Once the administrative review is complete and public comments are addressed, the Technical Review phase will start. The main objective of the Technical Review is to analyze collected data and approve the proposed permit limits or modify them as needed to improve the quality of the receiving stream. Upon the completion of the Technical Review, a draft permit is prepared and issued. At that point, a second publication is required, Notice of Application and Preliminary Decision or NAPD, for public input and comments (Texas Commission on Environmental Quality 2006).

- **Comments from the Applicant**

  The wastewater system provides all the information needed and permit limits proposed during the permit application process. Once the TCEQ issues a draft permit, the wastewater system will be given the opportunity to review and comment. The wastewater system has the right to challenge and seek clarification of TCEQ's changes to the original permit submittals (Texas Commission on Environmental Quality 2006).

- **Public Comments**

  The main objective of the TCEQ is to protect the environment and the waterways to provide the citizens with safe potable water sources and public recreational areas. Therefore, the TCEQ considers the public's input an essential element in the permitting process and their comments and concerns must be evaluated and addressed as needed. In addition to responding to the comments in writing, the TCEQ will hold a public hearing (Texas Commission on Environmental Quality 2006).

- **Final Action on the Application**

  Modifications to the draft permit as proposed by the public and the TCEQ are made prior to the issuance of a final permit by the TCEQ. Once the permit is finalized, the wastewater system must comply with all its provisions, including but not limited to, discharge limits, sampling, maintenance, monitoring, and sludge disposal. An annual fee will also be paid to the TCEQ based on the treatment plant capacity (Texas Commission on Environmental Quality 2006).

5.3 Annual Inspection

5.3.1 Purpose and Objectives

The operators of wastewater systems should conduct regular daily inspections of their facilities to ensure proper operations and perform required maintenance regardless of their permit requirements. The objectives of the TCEQ's yearly inspections is to determine compliance status with regulations, permit conditions, and other program requirements, verify the accuracy of information submitted by permittees and verify the adequacy of sampling and monitoring conducted by the permittee (U.S. Environmental Protection Agency July 2002). These objectives should be part of the wastewater system operator's daily mission. The goals should be part of the standard operational manuals.

For wastewater systems that are not complying with their permit requirements and/or are under enforcement, the TCEQ uses the yearly inspections as a tool to identify the weaknesses and deficiencies of the system, gather data to support the enforcement order and educate the operators on necessary changes for compliance. For systems that are regularly in compliance, the inspections may be scheduled every two or three years.

5.3.2 Inspection Types

In general, wastewater systems perform their own monitoring, sampling and testing which requires inspection by the governing bodies to ensure that procedures are followed and data is accurately reported. The type and frequency of inspection performed by the TCEQ is dependent on the wastewater system's performance and history. Violations such as sanitary sewer overflows, repetitive customer complaints of odor, and service interruptions will trigger an inspection. The treatment process and history of compliance determines the type of inspection that may be performed by the TCEQ. The following is a description of typical types of inspections (U.S. Environmental Protection Agency July 2002):

Compliance Evaluation Inspection (CEI)

The CEI is a nonsampling inspection designed to verify permittee compliance with applicable permit self-monitoring requirements, effluent limits, and compliance schedules. Inspectors must review records, make visual observations, and evaluate treatment facilities, laboratories, effluents and receiving waters (U.S.

Environmental Protection Agency July 2002). During the CEI, the inspector must examine both chemical and biological self-monitoring, which form the basis for all other inspection types except the Reconnaissance Inspection.

Compliance Sampling Inspection (CSI)

During the CSI, NPDES permitted or unpermitted facilities, inspectors must take representative samples. Inspectors then verify the accuracy of the permittee's self-monitoring program and reports through chemical and bacteriological analysis; determine compliance with discharge limitations; determine the quantity and quality of effluents; develop permits; and provide evidence for enforcement proceedings where appropriate. In addition, the CSI includes the same objectives and tasks as a CEI (U.S. Environmental Protection Agency April 2002).

Performance Audit Inspection (PAI)

The inspector conducts a PAI to evaluate the permittee's self-monitoring program. As with a CEI, the PAI verifies the permittee's reported data and compliance through a records check. However, the PAI provides a more resource-intensive review of the permittee's self-monitoring program and evaluates the permittee's procedures for sample collection, flow measurement, chain-of-custody, laboratory analyses, data compilation, reporting, and other areas related to the self-monitoring program. In a CEI, the inspector makes a cursory visual observation of the treatment facility, laboratory, effluents, and receiving waters. In a PAI, the inspector observes the permittee performing the self-monitoring process from sample collection and flow measurement through laboratory analyses, data workup, and reporting. The PAI does not include the collection of samples by the inspector. However, the inspector may require the permittee to analyze performance samples for laboratory evaluation purposes (U.S. Environmental Protection Agency July 2002).

Compliance Biomonitoring Inspection (CBI)

This inspection includes the same objectives and tasks as a CSI. A CBI reviews a permittee's toxicity bioassay techniques and records maintenance to evaluate compliance with the biomonitoring terms of the NPDES permit and to determine whether the permittee's effluent is toxic. The CBI also includes the collection of effluent samples by the inspector to conduct acute and chronic toxicity testing to evaluate the biological effect of a permittee's effluent discharge(s) on test organisms (U.S. Environmental Protection Agency July 2002).

Toxics Sampling Inspection (XSI)

The XSI has the same objectives as a conventional CSI. However, it places increased emphasis on toxic substances regulated by the NPDES permit. The XSI covers priority pollutants other than heavy metals, phenols, and cyanide, which are typically included in a CSI (if regulated by the NPDES permit). An XSI uses more resources than a CSI because sophisticated techniques are required to sample and analyze toxic pollutants. An XSI may also evaluate raw materials, process operations, and treatment facilities to identify toxic substances requiring controls (U.S. Environmental Protection Agency July 2002).

Sewage Sludge Inspection

The objectives of a sewage sludge inspection are to determine compliance with Federal 503 sludge regulations for any facility engaged in a regulated sludge or disposal practice and to evaluate the permittee's compliance with sludge monitoring, recordkeeping and reporting, treatment operations, and sampling and laboratory quality assurance. The PCI, CEI, and PAI are the most likely vehicles for evaluating compliance with sludge requirements (U.S. Environmental Protection Agency July 2002).

Sanitary Sewer Overflow (SSO) Inspection

During an SSO inspection, the inspector evaluates compliance with SSO provisions present in the NPDES permit, an enforcement order, a consent decree, or another enforceable document. The inspector collects information to verify that the permittee is complying with the NPDES standard permit conditions (duty to mitigate and proper operation and maintenance) and the required notification procedures. The inspector also determines whether there have been any unpermitted discharges, or discharges from a location other than the discharge point specified in the permit, to waters of the United States (U.S. Environmental Protection Agency July 2002).

5.4 Summary

Permitting will not be required if entities will operate wastewater systems with the objective of protecting the public health and the environment. However, accomplishing this task requires money which in turn requires approval from political figures. Therefore, state and federal regulations can be used by wastewater system operators to acquire funding necessary for the needed improvements.

6 Inflow and Infiltration

6.1 Introduction

Wastewater collection systems are designed to transport wastewater from residential, commercial, and industrial customers to the wastewater treatment facilities. The piping network consists of service lines, laterals, small diameter pipes, and large interceptors that are made of different types of materials based on when they were installed. In the early 1950s concrete pipe was popular, in the early 1970s polyvinyl chloride pipe was used, and today, high density polyethylene is the most common sanitary sewer pipe used. Although sanitary sewer pipes are supposed to only transport wastewater, open pipe joints, defects, and deterioration of the pipe materials can provide a source for groundwater through infiltration and storm water through inflow to enter into the collection system. Inflow of storm water into the collection system may be intentional through directly connecting roof and driveway drains to the sanitary sewer piping network or indirectly through deteriorated pipe, open joints, and cracked manholes. Infiltration of ground water into the wastewater collection system depends on the elevation of the water table compared to that of the pipe, the number of canal, ditch, and river crossings in the system, and the ground saturation level above the pipe. Once ground or storm water enters and mixes with the raw sewage, it becomes part of the wastewater, and therefore, must be treated to meet permit limits prior to discharging it into the waterways.

The design engineer of a wastewater collection system should be able to calculate a design capacity that will be a balance between inflow and infiltration volumes entering the collection system during wet weather events and wastewater volumes generated during dry-weather flow. Over sizing a wastewater system to contain wet weather events volumes is very costly to construct and maintain. However, sizing wastewater facilities to only transfer and treat daily dry weather flows can generate more overflows and, hence, fines. Choosing a large event can incur significant capital costs, while too small of an event may lead to unacceptable overflow frequency and volume (Dent and Wright 2007). Aging systems may not have the hydraulic capacity to receive the increased flows because of a large volume of inflow and infiltration and lack of periodic maintenance. This may result in a Sanitary Sewer Overflow (SSO) to receiving waters (Sample, Bocarro, and Latallad 2005). To minimize the number of SSOs, while the system is being rehabilitated, sanitary sewer flow data must be analyzed to determine how to control and manage inflow and infiltration volumes.

6.2 Inflow and Infiltration Background

Wastewater collection systems are mainly installed below the ground surface and are not visible to the public. Most sewer pipe inventory for older cities pre-date World War II, and were installed with materials that were well beyond their expected service life (Global Water Instrumentation, Inc. 2010). In addition, aging and deteriorating pipes and manholes are not usually detected until a failure interrupts service. It is estimated that there are approximately 4.0 billion feet of sanitary sewer pipe in the United States with more being installed daily (Global Water Instrumentation, Inc. 2010). The hidden infrastructure combined with the high replacement and rehabilitation costs are the main reasons most wastewater systems are behind schedule on updating their systems. The older the sanitary sewer system, the larger the number of point sources for inflow and infiltration allowing storm and ground water to enter the system. Inflow and infiltration are the main causes of sanitary sewer overflows. The EPA requires any regulated agency with a NPDES permit to eliminate all wastewater overflows that reach the waters of the United States (Global Water Instrumentation, Inc. 2010). However, the EPA and the TCEQ understand the seriousness of the inflow and infiltration problems and the limitations the wastewater systems have on repairing and minimizing the number of overflows. Therefore, programs such as the Sanitary Sewer Overflow Initiative have been created to ensure available funding is directed towards rehabilitation and not fines. Initial efforts, in the 1970's, to reduce inflow and infiltration in sanitary sewer systems were typically unsuccessful in spite of substantial funding from the EPA's Construction Grants Program. Most inflow and infiltration control programs were reduced to emergency programs, in the late 1980's, that tried to resolve isolated issues in the sanitary sewer systems. During this time period several major sanitary sewer systems were evaluated in cities such as Nashville, Atlanta, and Houston. These evaluations raised public interest in the repair and replacement of sanitary sewer system infrastructure. Additionally, new and better sewer system technologies allowed for reduction or elimination of inflow and infiltration sources (Global Water Instrumentation, Inc. 2010).

For sanitary sewer systems that have not initiated a rehabilitation program, the inflow and infiltration problem will increase in magnitude increasing the volume of ground and storm water into the sanitary sewer collection system. The capacity of the collection system and treatment facilities is not designed to handle the additional volume resulting in overflows.

6.3 Impact of Inflow and Infiltration on the Wastewater System

Designing a wastewater collection system and treatment facility to accommodate volumes other than wastewater generated by residential, commercial, and industrial customers is economically unfeasible. Increasing the size of existing wastewater infrastructure to absorb inflow and infiltration volumes of storm and ground water is restricted with the inability to interrupt service and availability of space. Therefore, inflow and infiltration sources must be eliminated to solve the problem. Until the sources are eliminated, the storm and ground water entering the collection system must be treated and it is costly. Inflow and infiltration costs water treatment facilities and consumers large amounts of money in water treatment operating expenses. All water entering a water treatment facility must be treated as wastewater causing an increase in operating costs proportional to the amount of clean water entering the sanitary sewer system due to inflow and infiltration (Global Water Instrumentation, Inc. 2010).

During a rain event, wastewater treatment facilities may have to treat three to four times the volume treated during dry weather. Overflows that occur in the system must be reported to the TCEQ with a corrective action plan that includes cleanup and repairs that must be accomplished in a timely manner. Other impacts of inflow and infiltration on the wastewater system are increased operating cost, reduction in development availability, service interruptions, jeopardizing public health and safety, pipe and manhole failures from hydraulic loading, and potential fines. Although the overflows are the responsibility of the wastewater system, any damage to private property that is not caused by motorized equipment is considered an Act of God and the wastewater system will not be liable.

6.4 Management of Inflow and Infiltration

Funding is a limiting factor to resolving inflow and infiltration problems. Therefore a program should be established to prioritize the collection system's rehabilitation needs to generate the largest reduction of storm and ground water entering the collection system for the allocated cost.

The operator's extensive knowledge of the collection system should be utilized as the foundation for the rehabilitation program. The first step is a sanitary Sewer Evaluation System (SSES). An SSES will perform visual surface inspections of the ground on top of the pipes, manholes and pipes, install flow meters in strategic locations in the collection system to measure volumes of inflow and infiltration, televise the sanitary sewer pipes, smoke and dye test to identify failures, and direct stormwater connections.

The information collected in the field should be used in conjunction with the data gathered in the work management system of the maintenance department to identify the weakest links in the system. It is essential to quantify the volumes and identify the source of storm and ground water entering into the collection system in order to determine a method to manage them. Since resolving the cause of inflow and infiltration will require time and funding and since overflows jeopardize public health and safety, an immediate management plan should be implemented. Management of inflow and infiltration can be accomplished by transferring the storm and ground water from basins with poor pipe conditions to basins with minimal inflow and infiltration problems. Holding lagoons can be built to store storm and ground water during wet weather events after which the water is pumped to the treatment facility when the rain stops and plant capacity is available. Pumping the collection system down prior to a rain event will increase the storage capacity and reduce the number of overflows. An effective maintenance program can also play an important role in managing inflow and infiltration. Once a management program is established and implemented, a rehabilitation program should concentrate on replacing deteriorated pipes and replacing defective manholes and old service lines. After rehabilitating wastewater infrastructure in a basin, flow monitoring should be performed to determine the effectiveness of the program. The following "rules-of-thumb" may be used to determine a monitoring and evaluation strategy to adequately measure amount of inflow and infiltration in a sanitary sewer system. Parameters vary depending on the overall city or agency goals (Global Water Instrumentation, Inc. 2010):

- One flow meter for every 30,000 – 50,000 feet of sanitary sewer pipe;
- The flow meter recording should be set at 15-minute intervals;
- Flow meter capable of measuring surcharges;
- One rain gauge for every 2-4 flow meters;
- Minimum monitoring period – 45 days with 60 days being optima;
- Measurement of between 6-8 separate rainfall events; and
- The system should be monitored during a period of high seasonal groundwater.

6.5 Summary

Inflow and infiltration is every wastewater system operator’s nightmare. During wet weather events storm and ground water entering the collection system reduces the available capacity for wastewater and causes SSOs. Wastewater system operators must implement maintenance, rehabilitation, and flow diversion programs to reduce the number of SSOs.

7 Sanitary Sewer Overflow Initiative (SSOI)

7.1 Introduction

A perfect sanitary sewer collection system is designed to be completely sealed and to collect a certain volume of wastewater from residences, businesses, and industry. Once the wastewater enters the collection system, it should be totally transported to the treatment facilities. However, old deteriorated pipes, structurally unstable brick manholes, and broken service laterals are entry points for storm water during rain events and can also be discharge points of raw sewage into the environment. It is a violation of EPA and TCEQ regulations for any volume of raw wastewater to exit the collection system prior to reaching the treatment facilities. Such discharges, that are not usually controlled by the wastewater system operators, are known as sanitary sewer overflows (SSOs). The untreated sewage from these overflows can contaminate our waters, causing serious water quality problems (U.S. Environmental Protection Agency April 2010). A draft report for the Environmental Protection Agency obtained by U.S. News found that more than a million Americans become ill each year from sanitary-sewer overflows (Kiest and Flanery 2003). With the implementation of the Total Maximum Daily Load (TMDL) program and watershed protection program, SSO events have received increased attention from regulatory agencies (Sample, Bocarro, and Latalladi 2005). However, with more than 40,000 overflows a year in the United States, the EPA and the TCEQ understands that there is not an immediate solution for SSO. Therefore, the Sanitary Sewer Overflow Initiative was established to allow cities to plan and implement the rehabilitation of sanitary sewer infrastructure to systematically reduce the number of overflows in the collection system. The main objective of the program is to direct the cities funds towards reducing overflows and not paying fines.

7.2 Sanitary Sewer Overflow Initiative

7.2.1 Definition of the SSOI

A typical sanitary sewer collection system is designed to collect and transport a certain volume of raw sewage based on the current and projected population and industry in the service area. To design a collection system that can also contain storm water during a rain event from infiltration through deteriorated pipes and broken manholes would be expensive and unfeasible. Therefore, existing deteriorated collection systems get inundated with storm water during wet weather events causing illegal raw sewage discharges. The design of an effective rehabilitation plan that will reduce SSOs from a sanitary sewer collection system requires knowledge of the system's components. More importantly, the implementation of the plan is expensive and requires funding sources. For many years, the difficulties associated with acquiring the funding introduced to the operators a mentality of temporarily patching the failure points causing the SSOs in the collection system and/or just paying the fines implemented by the EPA and the TCEQ. To change these approaches as a solution to the SSOs, the EPA and the TCEQ introduced the SSOI as an incentive to rehabilitate the collection system instead of temporarily patching it or ignoring it. When the collection system operators design and implement a rehabilitation plan that mainly includes a certain footage of pipe, number of manholes, and service connections to be replaced yearly, the system will not be fined if SSOs occur. The plan should include a method to measure and prove that the rehabilitation is reducing the number of overflows in the system.

7.2.2 SSOI Allowed Participants

Participation in the sanitary sewer overflow initiative is open to any municipality, municipal utility district, and sanitary sewer system that have sanitary sewer overflow problems and is willing to fix the problem. Participation is voluntary at this time and the SSOI is purely designed to help sanitary sewer system operators reduce SSOs without being fined during the process. Sanitary sewer systems under enforcement can also participate in the SSOI if they submit a plan that will reduce SSOs.

The TCEQ Field Operations Division regional staff may identify some facilities that are good candidates for participation during on-site compliance investigations or file-review investigations. This identification will be based on:

- Self-reported data indicating violations of permitted flow limitations and significant noncompliance with other permitted effluent limitations;
- SSO history (the number and volume of overflows);
- Previous notices of violation (NOVs) for SSOs;
- SSOs occurring in impaired watersheds;
- SSOs with the potential to have an impact on human health, safety, and/or the environment;
- Repeated complaints regarding SSOs; and
- Corrective action for SSOs that will require longer than six months to complete (Texas Commission on Environmental Quality April 2010).

7.2.3 SSOI Benefits

The benefits to a wastewater system from entering into a SSOI with the TCEQ are designed towards minimizing the number of overflows in the collection system. The

SSOI plan eliminates potential formal enforcement that usually leads to fines that can be up to $10,000 per violation per day. However, the SSOI does not eliminate the EPA and TCEQ rights to execute enforcement actions for SSOs. The EPA and TCEQ retain that right in case the wastewater system ignores the regulations intentionally or does not act effectively to eliminate repetitive overflows. The SSOI eliminates fines, freeing funding to repair the causes of SSOs. Also, repetitive SSOs will not be included on the wastewater system's compliance history. The participation in the SSOI plan will improve the relationship between the wastewater system and the TCEQ, and allow them to work closer together to resolve a common problem that could jeopardize public health and safety. However, participation in the SSOI does not eliminate the TCEQ and EPA reporting requirements of SSOs.

7.2.4 TCEQ's Role in the SSOI

Wastewater systems facilities including collection system, sanitary sewer lift stations, and wastewater treatment plants are subject to a yearly inspection by the TCEQ and/or the EPA. If the TCEQ and/or EPA inspectors detect an increasing number of SSOs that can lead to notice of violations and fines, they can propose to the wastewater system's operators to participate in the SSOI. In addition, a wastewater system that is under enforcement from SSOs could be allowed to participate in the SSOI in order to eliminate the fines and spend the available funds to fix the causes of the SSOs. The TCEQ provides assistance to wastewater systems through the Small Business and Environmental Assistance Division (SBEA). The SBEA can assist in developing a plan, finding funding sources, helping establish fats, oil, and grease (FOG) programs, and implementing a Capacity, Management, Operation, and Maintenance (CMOM) program.

The TCEQ will provide the wastewater system's operators with the information required to participate in the SSOI and how to develop a plan. The participation will be dependent on the facility operator's willingness to conduct a sanitary sewer system evaluation of the wastewater system in order to determine the scope of the problem and to develop a plan for improving, updating, and repairing the wastewater collection system.

If the facility does not elect to participate in the initiative, the TCEQ will not afford it protection from formal enforcement for SSOs and will issue a notice of violation for any SSO violations noted during the investigation (Texas Commission on Environmental Quality April 2010).

7.2.5 SSOI's Plan

The objective of the SSOI plan is to efficiently reduce the number of SSOs in the collection system by utilizing all available resources and funds to the wastewater system. It is the wastewater system's responsibility to measure the effectiveness of the plan and modify it as needed to optimize its capabilities. The plan should include:

- A description of the cause of the SSOs and interim measures the facility will take to mitigate the effects of continuing SSOs;
- A comprehensive evaluation of the sewer system;
- A description of specific corrective measures, with milestones for addressing continuing SSOs;
- The time line for completing each corrective action;

- Provisions for the development and implementation, or the improvement, of an operations and maintenance program to ensure continued permit compliance;
- A description of all funding sources; and
- A statement describing how the facility will evaluate the effectiveness of the improvements (Texas Commission on Environmental Quality April 2010).

7.2.6 SSOI Plan Evaluation

The initial evaluation of the SSOI plan should be performed by the wastewater system's operators to ensure that all their resources are being utilized to maximize the productivity of the plan. Then, the plan is submitted to the regional TCEQ office for review and comments. The TCEQ staff will compare the submitted plan to the standard set of guidelines and request any missing information. In general, the TCEQ relies on the wastewater system's operators to submit reliable and comprehensive plans. Once all the requirements are met, a letter of approval will be sent from TCEQ to the Wastewater system.

7.2.7 Forfeiting the SSOI

The SSOI is designed to help wastewater systems organize their rehabilitation efforts to reduce SSOs in exchange for reduction or elimination of fines. However, the SSOI is not a free pass for wastewater systems and it can be forfeited if SSOs are not reported as per the requirements. An SSOI can be forfeited if the plan is not submitted with all the required information, if the required reporting is not turned in, if an SSO continues to occur because of failure by the wastewater system's operators to correct the problem, and if the harm to the environment and public health increases after the SSOI is implemented.

7.3 Summary

The SSOI is the EPA and TCEQ's way of letting the wastewater system operators know that they understand the magnitude of the problem generated by SSOs and that there is no immediate solution. Therefore, an SSOI is made available to the wastewater systems to avoid fines as long as they are willing to exhort all efforts and funding available on the rehabilitation programs.

8 Utility Management

8.1 Introduction

Regulations imposed by the EPA and the TCEQ in conjunction with operators' new mentality of rehabilitation rather than patch and spot repair of wastewater systems infrastructure, started a new era of wastewater system projects. Since the late 1970s, operators of wastewater systems initiated pipe replacement projects including all related appurtenances, wastewater treatment plant, sanitary sewer lift stations rehabilitation and expansion. Since the approval of the Clean Water Act in 1972, the City of Houston invested over four (4) billion dollars for wastewater infrastructure improvements. During this period, approximately forty-two (42) percent of the sewer pipes have been rehabilitated, seventy (70) percent of which are older than fifty (50) years. However, the Peak Wet Weather Flow (PWWF) in the collection system is gradually increasing and has become a great concern for the operators (Rabbi 2007)

Although the rehabilitation efforts are essential to upgrade the collection and treatment systems, operators realized that managing wastewater in the collection system in parallel with the rehabilitation efforts can reduce the number of overflows and protect public health and environment. Since the rehabilitation efforts can take years to be completed, and the public's health and environment must be protected today, management of wastewater systems became more popular. An extensive knowledge of the wastewater system, an inventory of all assets, minute to minute monitoring of the collection system, written standard operating procedures for daily operations and emergency response, a strategic maintenance program, an evaluation of the physical and structural conditions of the piping network, and a flow monitoring study to identify point sources and volumes of inflow and infiltration are essential tools for the operator's to implement operational modifications that will keep the wastewater in the collection system. Once all the preliminary work is completed and the data is gathered, options such as utilizing the existing capacity in the piping network through passive control measures, diverting flow from one basin to another, upsizing pipes and wastewater treatment infrastructures, implementing new ordinances, modifying design criteria and requirements, and building holding lagoons are available for implementation.

8.2 Management of Wastewater Systems

Management of raw wastewater in a collection system ensures the treatment of all flows including inflow and infiltration volumes during wet weather events prior to discharging it into the waterways. The management process is complex and must include thorough knowledge of: the wastewater system, assets inventory, monitoring of the wastewater system, standard operating procedures, emergency response plan, maintenance program, condition of wastewater system, flow monitoring and hydraulic modeling, performance measures, and communication and outreach.

8.2.1 Knowledge of the Wastewater System

An effective wastewater management program is highly dependent on the knowledge of its operators. Through their many years of experience responding to citizen calls, operators can identify the areas contributing the most storm and ground water to the collection system. The operators maintaining the sanitary sewer lift stations can identify the areas that contribute large volumes of grease and the cleaning frequency required. The wastewater system operators should be involved in the planning of the evaluation of the sanitary sewer system as well as the establishment of the capital improvement program.

8.2.2 Assets Inventory

It is vital to know what components constitute the wastewater system in order to be able to manage the raw wastewater that it collects and treats. Knowing the size, type of materials and age of the pipe in the collection system will allow the operator to determine the rehabilitation needs and storage capacity. Having an inventory of the sanitary sewer lift stations including size of wet well, size of pumps, pumping capacity and efficiency will provide the operator with data needed to manipulate flows during wet weather events to minimize the number of overflows. Understanding the permit requirements and the capacities of the wastewater treatment facilities during dry and wet weather events can avoid illegal discharges. To efficiently manage the collection system, the wastewater agency needs to provide staff with suitable resources to enable effective collection, storage, evaluation, forecasting, and communication of data and information (APWA, ASCE, NACWA, Water Environment Federation 2010). A thorough knowledge of the assets of the wastewater system will allow the operators to respond effectively to customer complaints, operate the system and maintain it better, prepare a well planned replacement and rehabilitation program and project failures, and address them prior to their occurrence.

In the past, asset inventory was documented in writing and kept on a paper format. Today, available technologies such as geographic information system (GIS) integrated with other software programs can provide access to historical and current data within seconds and remotely in the field if computer access is available. The program can store maps, records of repair history, performance during wet weather events information, latitude and longitude coordinates of assets, and operator comments. The program is also capable of analyzing data and providing it in graphical and graph format as well as managing a maintenance program. Access to a computer can make this information available to the operator. Such information will allow the operator to make educated operational and repair decisions. Once data is gathered and organized it must be kept current by inputting daily changes to the wastewater system. When a wastewater agency wants to begin or improve their data management program, they must first understand the way data flows through their organization. Managers use data mapping to chart where or how data is generated, where it resides, and how it is used. Managers can also use this exercise to identify data gaps and internal and external needs (APWA, ASCE, NACWA, Water Environment Federation 2010). Different wastewater systems will require different methods of gathering and maintaining data based on the complexity of the system. The involvement of the operators at all levels is essential for the success of the program.

Since the physical characteristics of the wastewater system and the chemical and biological nature of the wastewater can change on a regular basis, daily analysis of the assets and flows especially during wet weather events should be performed for better operational decisions. Assets inventory also include maintenance records that can be made available to the operators to track customer complaints, repetitive problems, and performance before and after repairs or operational changes are implemented.

8.2.3 Monitoring of the Wastewater System

The daily monitoring of the wastewater system through physical inspections, SCADA, and the data analysis in the management program will provide the operators with information required to use all available resources efficiently. Knowing what is taking place in the system during dry and wet weather events will provide comparison tools that can be used to plan improvements. Identifying overflows on a map and tracking their sources can find a solution to eliminate them. Lift stations monitoring can provide information necessary for planning a maintenance program that will increase the life expectancy of the pumps. Measuring the flows during wet weather events may allow the diversion of flow from basins with high inflow and infiltration problems to less impacted basins. Monitoring the operations at the wastewater treatment facilities can provide treatment capacities and nutrients removal rates during different flow conditions. Monitoring also provides information that is essential for efficient operations.

8.2.4 Standard Operating Procedures

A Standard Operating Procedure is defined as: A set of instructions covering those features of operations which lend themselves to a definite or standardized procedure without loss of effectiveness also called SOP (Wikipedia 2010b). SOPs are written for different tasks by experienced individuals that have mastered the step by step process, generating accurate, dependable data, and high quality final product. SOPs describe both technical and fundamental programmatic operational elements of an organization that would be managed under a work plan or a Quality Assurance (QA) Project Plan [EPA Requirements for QA Project Plans (QA/R-5) (EPA 2001a)], or Chapter 5 of the EPA Quality Manual for Environmental Programs, (EPA Manual 5360 A) and under an organization's Quality Management Plan [EPA Requirements for Quality Management Plans (QA/R-2) (EPA 2001b)], or Chapter 3 of the EPA Quality Manual. This document is designed to provide guidance in the preparation and use of an SOP within a quality system (U.S. Environmental Protection Agency April 2007). An SOP can be written for a simple task such as installing a sanitary sewer service tap or a complicated laboratory experiment. Regardless as to why the SOP is written it should be detailed enough to follow with ease. Different certifications require different formatting of the SOPs and provide rules and regulations on how to develop them. Once established, staff must be trained on using the SOPs, and they should be made available to them at all times. It is the responsibility of the supervisors to ensure SOPs are updated as needed and meet state and federal regulations. The main objective of the SOP is to standardize the operation.

8.2.5 Emergency Response Plan

State and federal regulations require a wastewater system to establish an emergency response plan (ERP) that must be updated yearly. The ERP must encompass all aspects of the wastewater system whose failure can interrupt services and jeopardize public health. A plan to restore services in a timely manner for items such as power failure, chemical spills, natural disasters and terrorist attacks should be in a written procedural form and part of the ERP. Written procedures for assessing, notifying, containing, clearing the cause, documenting, estimating the volume, sampling and analysis, posting warning signs, and conducting necessary cleanup should be developed and implemented (APWA, ASCE, NACWA, Water Environment Federation 2010). An organizational chart indicating the persons in charge of the decision making with contact information must be included in the ERP. Employees responding to the emergency must be trained on the procedures and any changes implemented. The wastewater system should have equipment and materials to respond in a timely manner as well as emergency contracts with contractors that can provide immediate backup. A copy of the ERP must be placed at the wastewater facilities in an area that is accessible to all employees. A major component of managing the wastewater system includes minimizing sanitary sewer overflows. Any illegal discharge of wastewater into the environment must be addressed as an emergency and the response method should be documented in the ERP. The objective of the response to a SSO should be complete removal of the discharged wastewater and resolving the problem that caused the SSO in a timely manner. Illegal discharges into waterways, storm water ditches, and private property may require different response plans which should all be included in the ERP. To avoid fines by state and federal agencies the ERP should include the required reporting procedures mandated by the regulations. It is crucial for a wastewater system to avoid repetitive SSOs at the same location because of lack of appropriate corrective measures. A SSOI does not protect the wastewater system from fines if repetitive overflows take place.

8.2.6 Maintenance Program

Although a wastewater system should have a maintenance program designed around a priority list of the assets and their contribution to SSOs, proactive maintenance should also be performed on assets that do not require routine maintenance. The purpose of a maintenance program is to minimize the number of SSOs through continuous cleaning of pipes and wet wells, equipment servicing for uninterrupted services, restoring pipe, lift stations and treatment units rated capacity, protecting the public health and environment, and avoiding state and federal fines. The efficient operation and management of collection system assets is critical to minimizing performance failures and its potential effects. Proper maintenance of a collection system provides for the safe conveyance of wastewater to the treatment plant and mitigation of gases. Maintenance also monitors system flow performance with the design service capacity (APWA, ASCE, NACWA, Water Environment Federation 2010). The maintenance program should be designed to extend the life of the wastewater infrastructure. Sanitary sewer pipes including force mains and siphons should be flushed and cleaned once every seven to ten years. Solid, fats, oil, and grease must be vacuumed from lift station wet wells on a scheduled basis for every lift station based on volume contributed from the designated service area. Some lift stations may require weekly vacuuming while others need it monthly. In addition, ordinances regarding grease traps and their maintenance by the business owners should be enforced as part of the maintenance program. Equipment such as pumps and motors must be inspected daily and repaired immediately if operational deficiencies are detected. The maintenance of wastewater treatment units should be conducted as per manufacturer's recommendations and repairs performed as needed and in a timely manner to ensure continuous operations. An effective maintenance program will include measures that will prevent failures and the need for emergency response. This will require an extensive knowledge of the system based on historical data, prior failures, hydraulic capacity, inflow and infiltration volumes, and condition of system assets. The maintenance program should be developed with the objective of optimizing performance of the wastewater system at an affordable cost.

8.2.7 Condition of Wastewater System

The condition of the wastewater system must be evaluated through an extensive inspection program in order to prioritize the rehabilitation needs. The collection system can be inspected visually by looking inside manholes and checking for cavities on the ground surface over the sanitary sewer lines. However, sophisticated technologies are available, such as closed circuit television (CCTV), sonar, and x-ray that will provide a visual image of the interior pipe surface as well as depth of settled solids, wall thickness, and pipe diameter. This information will allow the operator to determine the structural integrity of the pipe, capacity, and required rehabilitation technique.

Sanitary sewer lift stations and treatment units must be placed out of service for a thorough inspection of the reinforced concrete structures, pipes, pumps, motors, and electrical equipment. The condition of the different components will determine the rehabilitation needs and the time frame required for maintenance and repairs.

8.2.8 Flow Monitoring and Hydraulic Modeling

The first step in managing the flow in a wastewater system is measuring the volumes during dry and wet weather. Permanent and temporary flow meters are installed in the collection system to record the data. Permanent flow meters are used for long range planning while temporary flow meters are used to support ongoing rehabilitation projects. The volumes measured must be compared to the system's capacity in order to design the measures needed to prevent SSOs. Hydraulic modeling can be used to determine the capacity of the existing collection system, the effect of inflow and infiltration volumes during wet weather events, implement maintenance measures, analyze, plan, and design future improvements required to reduce SSOs.

8.2.9 Performance Measures

The effects of rehabilitation, replacement, and maintenance efforts must be measured and evaluated to determine if they are improving efficiency, increasing capacity, and reducing SSOs. Measuring the performance of the wastewater system after an improvement to the collection system, lift stations, or treatment units will help optimize future design and rehabilitation projects. A well managed data collection program will automatically provide tabulated and graphed performance measures such as number of sanitary sewer overflows, number of customer complaints, number of TPDES violations, power consumption, chemical usage, flow volumes in the collection system and wastewater treatment plant, nutrients removal percentage at treatment units, and number of collapses of sanitary sewer pipes. Performance measures for different time periods can be compared to each other to determine the effectiveness of the improvements.

8.2.10 Communication and Outreach

The wastewater system is technically owned by the public. Getting the public to buy into this concept will make them part of the solution, not the problem. Once the public understands that the rehabilitation cost will be transferred to them through annual rate increases on their water and wastewater bills they will do their share to minimize the impact on the wastewater system. As an example, if the water customers in Beaumont, Texas, stop poring fats, oil, and grease down the sink pipe stoppage, overflows will be reduced by approximately forty-five percent (Tohme 2009). Similarly, removing roof drain pipes from the sanitary sewer service lines will reduce the inflow volumes during wet weather events. The public can be educated on matters related to the wastewater system through radio and television advertisements, billboards, pamphlets, and water bill inserts.

8.3 Wastewater Management Control Methods

Once the data is collected and analyzed, one or a combination of the following control methods can be implemented to ensure the wastewater remains in the collection system and gets treated prior to discharging it into the water ways.

8.3.1 Utilize Existing Capacity

The existing capacity of a wastewater system is usually designed for pipes to flow half full for the specified tributary area. Therefore, pumping the collection system down prior to a rain event will provide added capacity. This effort will require coordination between the wastewater treatment plants staff and the operators of the lift stations 24 to 48 hours prior to a rain event.

8.3.2 Divert Flow from Basin to Basin

The age of the pipes in a wastewater collection system varies from basin to basin. Younger basins will have less deteriorated pipes than older basins, hence, less inflow and infiltration. In addition, in a large city, rain events may not encompass the entire service area and will not affect the whole collection system. Therefore, diverting flow between basins will reduce the affect of a rain event on the part of the collection system that does not have the capacity for the inflow and infiltration volumes. This diversion will require the construction of high flow pump stations and force mains that will be operated only during rain events. Hydraulic modeling can be used in conjunction with flow monitoring to design the flow diversion system. Flow diversion is only a temporary fix until the collection system is rehabilitated and inflow and infiltration volumes are eliminated.

8.3.3 Upsize Wastewater Infrastructures

Upsizing wastewater infrastructure is usually performed if the capacity of the existing wastewater system is no longer adequate to serve the population in the tributary area. Under sized wastewater infrastructure may result in SSOs, interruption of services, limit growth, and adversely affect the economy of the area. Upsizing wastewater infrastructure, especially treatment facilities, for the purpose of inflow and infiltration control is not feasible and can increase daily operational cost.

8.3.4 Modify Ordinances

The wastewater system operators have the power to implement ordinances that will reduce the impact on the wastewater system. A grease trap ordinance can be used to regulate grease discharges by the restaurant industry. The ordinance can specify a minimum grease trap size, fats, oil, and grease discharge limits, and enforce a cleaning frequency to ensure that the fats, oil, and grease is collected and disposed of properly. The ordinance can also provide the wastewater system operators the ability to fine violators. Some cities have implemented a service line replacement ordinance requiring customers to replace deteriorated sanitary sewer service lines within a specific time frame. If the customers fail to abide by the ordinance, the wastewater system will perform the required repairs and bill the customer for its incurred cost. Therefore, ordinances can be used as a tool by the wastewater system operators to protect the public's investment.

8.3.5 Evaluate Design Criteria

The ground and a pipe's physical condition, as well as, the chemical nature of the wastewater change regularly. Hence, design criteria must be evaluated and modified to accommodate new conditions. Inflow and infiltration data gathered by the city of Houston was used to change several design criteria. In the early 1990s, the design criteria for sanitary sewer collection systems was 4,000 gallons per acre per day (GPAD). It was increased to 7,500 GPAD in the late 1990s and is currently 10,000 to 20,000 GPAD for the majority of the city. In mid 2004, Houston began a 10-year Sanitary Sewer Overflow (SSO) program for the collection system. The program includes structural renewal of 950,000 linear feet of sewer pipes every year. Recent data indicates a steady reduction in the Inflow/Infiltration (I/I) volume, but no significant improvement for the PWWF (Rabbi 2007). PWWF may cause two-hour peak violations at the wastewater treatment plants.

8.3.6 Build Holding Lagoons

The expansion and construction of new treatment facilities is approximately $6 to $8 per gallon. Therefore, increasing the size of the treatment facilities for anything other than growth is proven to be an unnecessary cost. Holding lagoons can be used to store wastewater when the capacity of the wastewater treatment is reached. The holding lagoons can be constructed in the collection system if buffer zones are provided as required by the EPA or TCEQ or at the wastewater treatment facilities. Once the rain event ends and the treatment capacity at the wastewater treatment plant is restored, the stored volume in the holding lagoons can be diverted back into the collection system. The holding lagoons must be aerated and screens provided to remove large solids from the wastewater.

8.4 Summary

Managing the flow of wastewater in the collection system is a tool that has been proven effective in reducing SSOs. Since rehabilitating the deteriorated pipes and related appurtenances in a city the size of Beaumont will take thirty years, flow management can be utilized as a temporary fix for immediate relief.

9 Rehabilitation Methods

9.1 Introduction

Most municipalities wait until a wastewater pipe collapses before taking action, necessitating expensive emergency repairs. Renewal of aging underground infrastructure is a major challenge that municipalities face every day. Traditional replacement of underground utilities uses open-cut excavation methods that can be expensive, particularly in built-up areas. Open-cut methods have adverse impacts on the community, businesses, and commuters because of undesirable pollution and traffic disruptions. New cost effective methods have been developed for inspection and rehabilitation of wastewater systems, which have made the rehabilitation and maintenance a cost effective alternative to replacement/new construction because of the advancement in technology (Gokhale and Hastak 2003).

Trenchless technologies use new methods, materials, and equipment that require minimal excavation. These new methods are considered much more cost-effective. Trenchless technologies that are used to repair, upgrade, replace, or install underground infrastructure systems with minimum surface disruption offer a viable alternative to existing open-cut methods. Using trenchless methods could save municipalities millions of dollars in the renewal of their underground utilities systems (Gokhale and Hastak 2003).

"Sanitary sewer rehabilitation programs are generally triggered by the need for reducing inflow and infiltration, restoring structural integrity of the pipes and related appurtenances, and provide uninterrupted service to customers. Sewer pipes have been discovered in ancient ruins, and materials used throughout history varies from wood, clay, concrete, reinforced concrete, cast iron, ductile iron, polyvinyl chloride (PVC), and high density polyethylene. In the past, sanitary sewer manholes were made out of brick. Currently, they are made out of reinforced concrete, fiberglass, polyvinyl chloride, polymer resin and high density polyethylene" (Sever and Bradshaw 2009).

As sewers age, they deteriorate in many ways. Cracks appear and joints separate. Infiltration through these cracks and joints creates external voids, accelerates structural deterioration, and can overload collection systems and treatment plants (Kung'u 1999).

The primary goal of any sewer rehabilitation program is to target the areas with the highest source of inflow/infiltration. The size, type, and location of the pipe determine the rehabilitation method for fixing inflow/infiltration problems.

Trenchless technologies such as sliplinning, pipe bursting, and cured in place techniques have been used in the United States since the late seventies. The success of the rehabilitation method is highly dependent on the experience of the installer. The rehabilitation program usually starts with a sanitary sewer evaluation survey (SSES) that inspects the pipe, manholes, and service laterals and identifies the type and location of the failures in the collection system. The results of the SSES in combination with the ground conditions will determine the type of replacement pipe to use and rehabilitation technique. Certain conditions will require the use of different rehabilitation techniques within the project limits. SSES can be accomplished through the following methods: continuous flow monitoring, manhole inspection, smoke testing, flow isolation, dye-water testing, cleaning and television inspection, building inspection, and hydraulic modeling. It should be noted that trenchless technologies have not completely replaced excavation and replacement of defective sewers and manholes. There still remain circumstances where excavation and replacement is the best method to rehabilitate a segment of a sanitary sewer collection system (Kung'u 1999).

9.2 Methods Available

Excavation, removal, and replacement of existing deteriorated sanitary sewer pipe and related appurtenances was the only method of choice prior to the invention of trenchless technologies. The open cut method creates traffic disruptions and negatively impacts the economy of the area under construction. In addition, the open cut method creates surface destruction that requires time and money to replace. During the last twenty years technology developments created trenchless rehabilitation techniques that almost eliminated the use of open cut method for underground utilities construction. The speed and economical installation of sanitary sewer pipe using pipebursting, directional drilling, sliplinning and cured in place, and other trenchless methods have positive impacts on the environment, installers, municipalities and citizens.

9.3 Choosing the Right Rehabilitation Method

Choosing a rehabilitation technique that will replace the pipe economically is most effective. Most cities in the United States are behind schedule on rehabilitating an aging infrastructure. Funding availability and stringent EPA and TCEQ compliance requirements reduce the options available to the wastewater system operators. Deteriorated pipes, broken manholes, and defective service laterals provide a point of entrance of inflow and infiltration into the collection system. The result is an increasing number of sanitary sewer overflows (SSOs). To accommodate the lack of funds needed to replace large portions of a municipal sanitary sewer system, many managers are investigating techniques for extending the life of their collection system assets through pipe and manhole rehabilitation (Favre 2002). When considering rehabilitation methods, the system's structural repair needs, capacity requirements, and inflow and infiltration impact must be considered.

9.3.1 Chemical Grouting

If the structural integrity of the pipe is sound, chemical grouting can be used to fill cracks and leaky joints and reduce the migration of dirt around the exterior surface of the pipe into the collection system. Acryl Amide and Urethane are the most common grouts available, and various additives can increase/decrease setting times and increase strength, flexibility and durability. The grout travels outside of the joint or manhole wall into surrounding soils and bonds with those soils to create a seal collar of material around the leaking joint or wall defect (Figure 9.1). Pipes with significant soil voids behind leaking joints or those with pipe under-drains may be better suited to other rehabilitation techniques (Favre 2002).

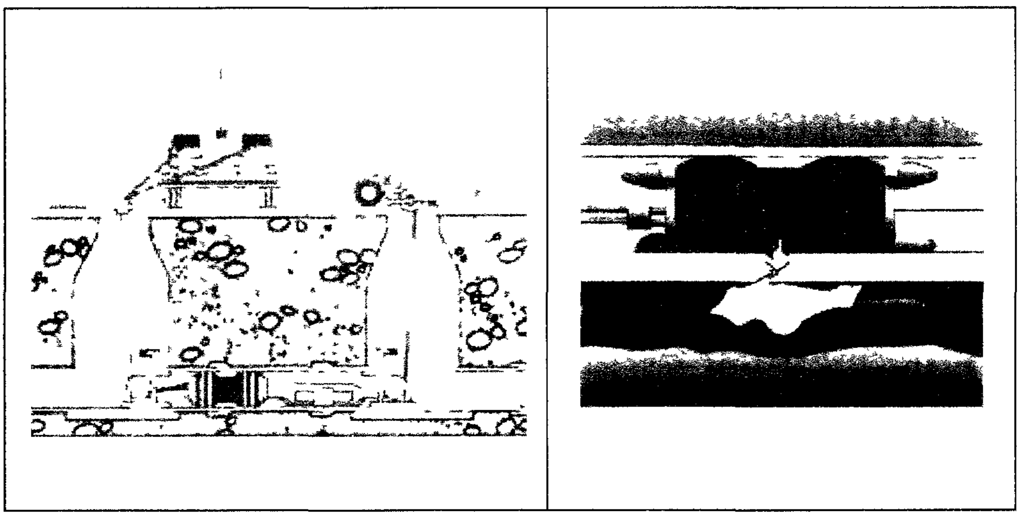

Figure 9.1 Chemical Grouting Process Units

Source: (Kembla Watertech PTY LTD 2005)

Chemical grouting can be used for pipes with 6 inch diameter and larger. However, a significant number offset joints and improperly installed taps may not allow the use of this method.

9.3.2 Sliplining

Sliplining can be used as a rehabilitation technique when the capacity of the pipe can be reduced because of reduction in flow. The technique involves pulling with a winch and/or pushing using a jack to install the new pipe into the existing pipe with minimal surface disruption (Figure 9.2). Pipe materials such as PVC, high density polyethylene, and reinforced fiberglass (Figure 9.3) can be used as a liner. Once the new pipe with a smaller inside diameter is sliplined into the existing pipe, the created annular space will have to be grouted using cement or chemical-based grout to fix the pipe in place to avoid any liner movement, provide additional structural strength, and stop inflow and infiltration. The slip liner pipe method is best suited for the rehabilitation of large diameter sewer pipes with few or no service connections and pipes where the wastewater flow is difficult to divert (Kung'u 1999).

Major deviations in the alignment of the existing pipe such as dropped joints, roots, and protruding taps will generate the need for additional excavations to remove the obstructions and allow the installation of the new liner. The need for bypass pumping depends on the size of pipe to be rehabilitated and volume of flow. Particularly deep installation may make the method less desirable because of increased costs. While relatively cost efficient in most instances, the installation can be disruptive because of the excavation required for the installation trench and lateral re-connection. Lack of access may make traditional sliplining impractical (Favre 2002).

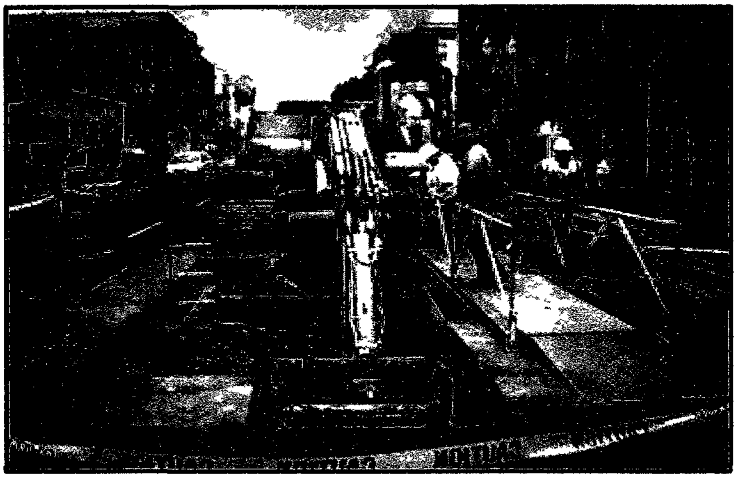

Figure 9.2 Insertion Pit

Figure 9.3 Sliplinning Existing RCP Pipe with Reinforced Fiberglass Pipe

9.3.3 Cured-in-Place Pipe (CIPP)

If closed circuit television inspection of the pipe indicates irregularities in the alignment of existing pipe, the cured in place pipe technique may be the most economical approach since sliplinning and pipebursting methods cannot be used in misaligned pipes with offseted joints. The cured-in-place liner pipe method is best suited for sewer pipes with high I/I and defects such as missing pipe segments, offset joints, and cracked pipes. It is also suited for sewers with multiple bends. The cured-in-place liner pipe method is probably one of the oldest and most effective methods for sanitary sewer collection system rehabilitation (Kung'u 1999).

The CIPP technique installs a polyester flexible sock or sleeve impregnated with resin that is inverted or winched into the existing pipe (Figure 9.4). Once winched into the pipe, hot water or steam is used to conform the liner around the existing inside surface area of the pipe. The required structural strength of the new pipe can be accomplished by varying the thickness of the resin inside the sock or sleeve.

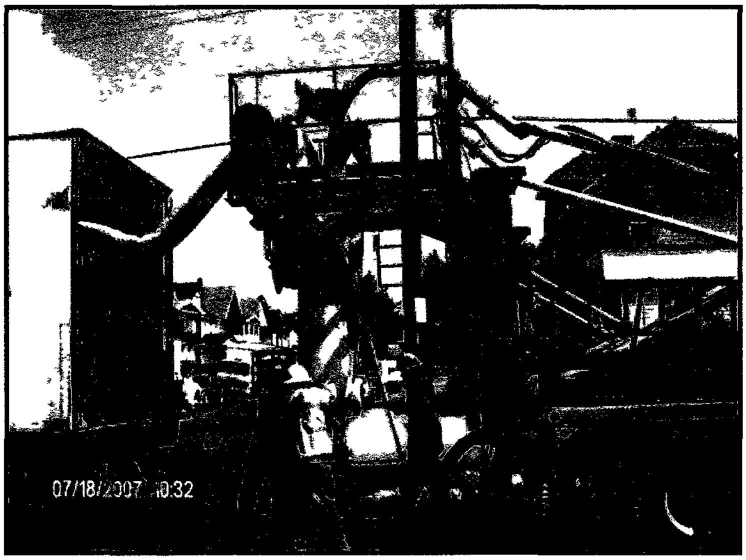

Figure 9.4 Cured-in-Place in Progress

Source: (AJP Engineering 2007)

No excavation is needed to accomplish the installation of a cured-in-place liner pipe. The resin-impregnated felt tube is inserted through existing manholes and service connections are reinstated remotely. The cured-in-place liner pipe bonds well with manhole rehabilitation products and hence reduces significant amounts of I/I at manhole connections (Kung'u 1999).

The CIPP method does not require grouting of the annular space because the liner is designed to fit on the internal surface of the existing pipe wall. Cured-in-place pipe can be economical for applications where accessibility is limited and access pits cannot be installed. However, for rehabilitation projects where pipe bursting can be utilized, cured-in-place pipe technique cannot compete.

9.3.4 Pipe Bursting

Pipe bursting is the most common rehabilitation trenchless method used for the replacement of utilities pipes such as sewer, water, and gas. Based on the material of the pipe to be rehabilitated, vitrified clay, cast iron, plain concrete, asbestos, or plastics require different bursting heads that will be pulled pneumatically, statically, or hydraulically to break the existing pipe and push it out of the way (Figure 9.5). At the same time, a new liner pipe mainly made out of high density polyethylene is pulled behind the bursting head to replace the old pipe that will act as bedding material.

Swags in the existing pipe and offset joints will not affect the pipe bursting technique. However, soil conditions are a deciding factor in the effectiveness of pipe bursting technique. The most favorable ground conditions for pipe bursting are soils that can be moderately compacted (reducing the lateral extent of outward ground movements), in which the expanded hole behind the bursting head does not cave in before the replacement pipe is installed (lowering the drag and the tensile stresses in the pipe during installation). Less favorable ground conditions involve densely compacted soils and backfills, soils below the water table and dilatants soils. Each of these soil conditions tends to increase the force required for the bursting operation and to increase the zone of influence of the ground movements. Special soils such as highly expansive soils or collapsible soils will also cause problems. For most soil conditions, it is simply necessary to provide the required power to effect the burst, displace the soil and pull the replacement pipe in over the length of the burst and to consider the potential effect of the ground displacements and vibrations on adjacent utilities and structure (Figure 9.6). When the soil provides a high friction drag on the pipe and the length of run is long enough to generate high tensile forces on the replacement pipe, bentonite or polymer lubrication muds may be injected into the annular space behind the bursting head to help keep the hole open and to reduce the frictional drag on the replacement pipe (Sterling 2001).

Insertion and access pits are required for pipe entry and winch pulling locations, respectively. During the pipe bursting process, the liner pipe may be stretched because of the pulling force. The lateral service connections should not be installed before allowing the new liner to relax for twenty-four hours so that the tap connection does not separate as the pipe retracts to its original length. Therefore, lateral service connections must be excavated prior to pipe bursting to provide the customer relief until the pipe bursting process is completed.

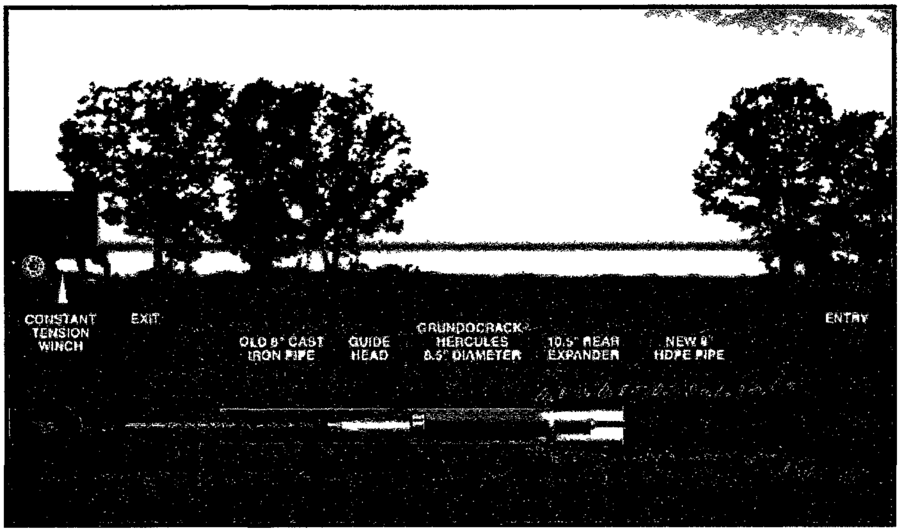

Figure 9.5 Trenchless Technology: Rehab Showcase, Spring 2002

Source: (TT Technologies, Inc. 2002)

Although the pipe bursting technique has no limit on the size pipe it can be used for, it is commonly used to replace existing pipes ranging in diameter from 6 to 36 inches A typical pipe bursting installation is usually 200 to 300 feet in length. However, if the ground conditions and structural integrity of the existing pipe are favorable, 2000 feet pulls can be accomplished. Cost is the main factor that will determine the applicability of the pipe bursting technique.

The pipe bursting technique is the only method that can increase the size by two pipe diameters, and hence, hydraulic capacity of the existing pipe with minimal surface disruption. However, disadvantages to be considered include uplifting of the surface for shallow installations, inability to burst through point repairs where stabilized sand was used, and possible damage to utilities and structures close to the existing pipe being rehabilitated.

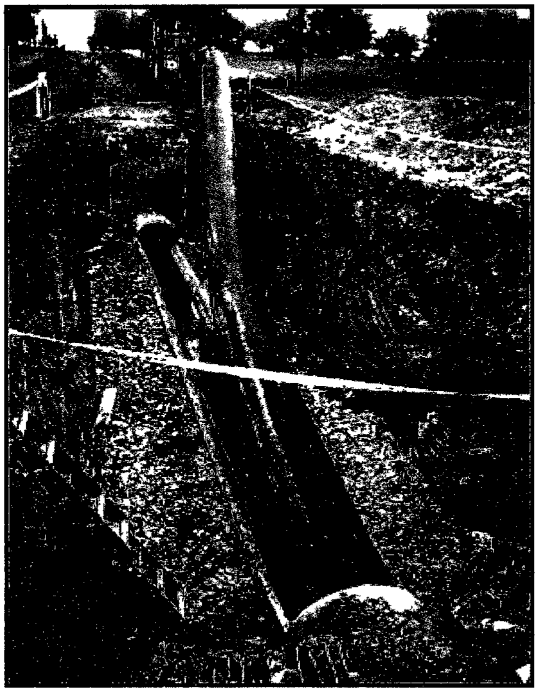

Figure 9.6 Pipe Bursting in Progress

9.3.5 Fold-and-Formed Pipe

Fold-and-formed pipe method is similar to the CIPP method. However, the pipe used is folded polyvinyl chloride pipe in its solid state rather than its resin state. Once the solid folded pipe is pulled inside the existing pipe being rehabilitated using a wench, it is pressurized into its circular shape using hot water or steam to fit the inside surface of the existing pipe like a glove. Grouting of the annular space is usually not required because of the close fit of the new pipe to the old. Laterals may be reconnected internally or by excavation. As with CIPP, laterals may require sealing or lining in order to eliminate migration of I/I. By-pass pumping is usually required (Favre 2002).

The fold-and-formed liner pipe method requires minimal excavation and surface disturbance. However, it cannot be used for pipe rehabilitation with bends, offset joints, and curvilinear pipe sections. In addition, the fold and formed liner pipe can go back to its original folded shape after being pressurized causing loss of hydraulic capacity that may cause sanitary sewer overflows.

9.3.6 Microtunneling

Microtunneling utilizes specialized equipment to install new pipes after removing the virgin dirt. Water is used to convert the soil into mud for easier removal. The entire process does not require utilization of manpower inside the tunnel. Microtunneling is used to install pipes ranging in diameter from 18 inches to 54 inches and in depth from 40 feet to 50 feet. This technique is mainly used in areas where the surface cannot be disturbed.

Microtunneling is particularly effective in below-groundwater conditions and unconsolidated soils and where above- and below-ground obstructions exist (Insituform Technologies, Inc. 2010).

9.3.7 Tunneling

Tunneling is a trenchless technique that utilizes manpower to construct tunnels for pipe installation ranging in diameter from 5 feet to 26 feet. Tunneling can be used in any ground conditions if the appropriate equipment is available. Tunnels can increase the capacity of the collection system and allow the transportation of large volumes of raw sewage from the source to the treatment facilities because of the large size of the tunnels.

9.3.8 Pipe Jacking

The pipe jacking technique can be used to install new pipe or rehabilitate existing pipe ranging in diameter from 54 inches to 120 inches. Unlike microtunneling, the pipe jacking method requires the usage of manpower to excavate the tunnel using the new liner. As the jacks are used to push the new liner into virgin soil, manpower will remove and dispose of the displaced soil.

"Pipe jacking is an economical alternative to and much less disruptive than using open-cut construction to install new underground pipes. Because it is performed with a closed system, pipe jacking decreases the risk of environmental contamination during construction" (Insituform Technologies, Inc. 2010).

9.3.9 Shotcrete

"For pipes ranging in diameter from 6 feet to 20 feet, the shotcrete technique may be the most economical if the structural integrity of the pipe can accommodate the sprayed concrete mix which is applied to the interior surface. This technique can also be used to restore the structural integrity of manholes, sanitary sewer lift stations, and other structures. New enhanced concrete mixes and polymer materials that are designed to resist corrosive gases can be used and will prolong the life expectancy of the pipe" (Insituform Technologies, Inc. 2010).

9.4 Manhole Rehabilitation

When replacing sanitary sewer pipes, the manhole replacements or rehabilitation cannot be ignored. An old, deteriorated brick manhole is a main source of inflow and infiltration of storm and ground water into the collection system. Several technologies are used to rehabilitate defective manholes. Some of the most common technologies include spraying the inside surface of a defective manhole using urethane resin, epoxy, cementitious materials, cured-in-place epoxy resin liner, and a fiber glass insert (Kung'u 1999).

The materials used to rehabilitate manholes are designed to withstand external hydrostatic pressure and resist corrosive gases. The materials will cure immediately eliminating the need for bypass pumping and minimizing the disruption in services.

9.5 Video Inspection

Knowing the condition of the pipe to be rehabilitated is essential for determining the proper rehabilitation technique. New technologies are used to televise the inside of the pipe so that the designer can make an educated decision for the pipe rehabilitation. Infrared cameras available on the market today can provide the design engineer with critical information such as thickness and roundness of the existing pipe. Sonar technologies can determine the depth and amount of settled debris on the bottom of the pipe.

9.6 Summary

The existing pipe materials, ground conditions, and project location will determine which method of rehabilitation will be most effective. Since rehabilitation cost is high and available funding is limited, it is the responsibility of the design engineer to choose the most efficient rehabilitation technique.

10 Construction Management

10.1 Introduction

The main goal of construction management is to ensure a high quality final product that will exceed its life expectancy which is also dictated by the high cost of construction. At a construction cost of six to eight dollars per gallon, a wastewater treatment plant must be constructed to last a minimum of 50 years with room for potential growth. Construction Management is a professional service that is applied to construction projects and programs through the planning, design, construction, and post construction phases for the purpose of achieving project objectives including the management of quality, cost, time, and scope (Gannett Fleming 2008).

Construction management, starting with the preliminary design phase and ending at the completion of construction, is necessary to build long lasting projects. Aspects of construction management such as quality assurance, work and materials specifications, quality control, value engineering, and construction planning guarantees the completion of projects on schedule and ensures high quality final products. Construction management is regulated by government codes that specify items such as different types of construction contracts, types of construction cost estimates, types of construction management fees, and safety and security measures.

Wastewater projects in recent years, general public and private sector projects have become increasingly difficult. They are complicated by stricter regulatory requirements, increasing costs, and aging infrastructure (Gannett Fleming 2008). Therefore, the need for specialized inspections by specialized construction managers is critical for a final functioning product. Contractors have a responsibility to construct the project in accordance with the plans and specifications, and to satisfy the customer's cost, quality, and time expectations. The construction project team is organized for the purpose of accomplishing those objectives (Knutson, Kraig, Fiori, Schexnayder and Mayo 2008). The Construction management team has the task of ensuring that the construction team accomplish their objectives.

10.2 Construction Management

Project owners should use the size and complexity of the project to determine the need for a project management team to ensure the successful completion of the project. For example, projects including electrical construction must have electrical specialists to inspect the installation. The major objectives of construction management are to complete the project within the allotted time and without exceeding the budget; not to deviate from the scope of work; minimize change orders; and utilize experts to optimize the design and improve construction quality.

Construction management, when used, will bring to the design and specifications as well as to the construction phase field experiences that will enhance the cost estimating, systems analysis, value engineering, constructability, procurement, and construction coordination and supervision. Construction managers should be involved with the project at the beginning of the planning phase through the construction of the project. The early involvement of construction managers with a project will allow for early start and completion of the project. The most traditional, and some would say "purest" form of construction management is that where the Construction Manager (C.M.) acts as the owner's agent as a consultant, providing estimating, cost control and scheduling services and undertaking administrative responsibilities during construction (Gannett Fleming 2008).

Construction management will incur an additional cost to the project. Construction managers and field inspectors will impose an additional fee to the owner. However, using value engineering and ensuring the construction of a high quality product that exceeds its life expectancy will, in the long run, offset the construction management cost.

10.2.1 Construction Management Services

The type of project and its scope of work will determine the extent of the required project management to ensure an excellent final product. For a project to be constructed as per plans, the construction management services should start during the preliminary design phase. Once the design is complete, a construction manager can conduct value engineering to get the best product for the money to be spent. Prior to initiating construction, a construction manager should be involved in public hearings to educate the public of the upcoming construction. During construction, a construction manager will conduct all phases of inspection, coordinate with all utility owners, supervise all material testing, ensure the projects stays within the CPM, and ensure the final product is built as per design drawings and standard specifications. The construction manager coordinates all the progress meetings as needed, acts as a liaison between the owner and contractor, and approves all pay requests prior to submitting them to the owner. Finally, the construction manager documents all changes and deviations from the original design and provides the engineer with the information to prepare final as built drawings.

10.3 Quality Assurance and Quality Control

The perfect design can become the owner's nightmare if not constructed as per drawings and standard details. It is the responsibility of the construction manager to provide quality assurance in order to construct a product using the specified materials that will perform its intended function throughout its life expectancy. In 1987, the Building research establishment surveyed the quality problems on Britain's construction sites. They found that half of the faults were design related, and 40% of the problems arose from faulty construction. Ten percent were product failing (Gannett Fleming 2008).

Including construction management in the design phase of the project will minimize design problems such as drawing projects that cannot be constructed safely. A construction manager involved in the construction phase is in charge of quality control and will ensure that the contractor is using materials specified in the contract documents the way it is specified in the design drawings, and skilled laborers are performing the construction with superior workmanship. An effective quality control program will minimize the use of defective products or the construction of projects that do not meet the minimum requirements of the specifications. The best known formal certification for quality improvement is the International Organization for Standardization's ISO 9000 standard. ISO 9000 emphasizes good documentation, quality goals and a series of cycles of planning, implementation, and review (Hendrickson 2008). Quality control may also include detailed procedures for construction.

10.4 Specifications for Materials and Workmanship

The contract documents should include specifications to cover every aspect of the project. The contract documents should have specifications for simple materials such as stabilized sand as well as those for complicated equipment. Every item that will be used in the project and every component that will be constructed or installed should have a specification on what it is made of as well as how to install it or construct it. The quality of the final product is highly dependent on the written specifications of items that have been used and tested.

General construction specifications are established by organizations such as the American Society for Testing and Materials (ASTM) and the American National Standards Institute (ANSI) and are available for use by the engineers and owners. It is up to the design engineer to choose the specification that will meet the requirements of the project and modify it if needed. Materials testing before and during construction is usually part of the specifications.

The design engineer can use two different types of specifications. One type will provide information on the chemical and physical characteristics of the material to be used. The second type of specification concentrates on the ability of the material to perform a certain task under specified conditions. The type of project usually determines the specification type to be used.

10.5 Legal Responsibilities

The owner of the project is responsible for hiring the design engineer and awarding the project to the lowest most responsible bidder. The ability to determine who will design a project and who will construct it provides the owner the flexibility needed to shift all liabilities to the engineer and/or contractor. In general, design flaws are the responsibility of the engineer, while materials defects and construction mistakes are the responsibility of the manufacturer and contractor respectively. Although the owner does not want to assume any responsibilities of mistakes committed by the engineer or contractor, the owner does not want to lose control over who and how such mistakes will be corrected. On the engineering side, the owner should make sure that the engineer is carrying adequate insurance coverage. As for the contractor, he should provide appropriate liability insurance and sufficient bonding capacity that can be directed by the owner and contract documents in case the contractor defaults on the project. The owner has the power to force the engineer and contractor to pay for any errors through their insurance and bond dictated by the contract documents.

10.6 State and Federal Regulation

Public safety and public health related projects are regulated by different state and federal organizations. In general, construction projects that can jeopardize public health and safety such as sanitary sewer, street, and drainage projects must be performed under the direct supervision of a registered professional engineer. The EPA and the TCEQ regulate all aspects of the wastewater industry including construction management especially for projects funded by state and federal monies. Owners must be aware of the impacts of these regulations on the costs and durations of various types of construction projects as well as possibilities of litigation because of various contentions (Hendrickson 2008).

10.7 Value Engineering

Although value engineering can be performed during the planning and design phase, it is usually implemented if the construction cost of the project exceeds the projected budget amount. The engineer will research alternatives for items such as equipment, materials, and construction methods specified in the original bid documents to reduce the cost without jeopardizing quality, performance, and life expectancy. Effective value engineering usually requires thinking outside the box and using new products that may not have been used before. The contractor may be part of the value engineering process during design or after being awarded the project by proposing innovative construction methods and construction techniques that will save time and money.

10.8 Construction Planning

The construction of any project includes the integration of several components together. It involves the choice of technology, the definition of work tasks, the estimation of the required resources and durations for individual tasks, and the identification of any interactions among the different work tasks. Developing the construction plan is a critical task in the management of construction, even if the plan is not written or otherwise formally recorded (Hendrickson 2008).

For example, the rehabilitation of a sanitary sewer interceptor includes flow monitoring, cleaning, and televising the existing pipe, installing new pipe, replacing manholes, and reconnecting service laterals. Construction planning will include the start and finish time of every task to minimize the construction time and eliminate non productive periods. Different contractors will provide different construction plans for the same project based on their experiences. However, each one of the proposed plans may experience construction problems that were not anticipated delaying the project completion time and increasing its cost. Construction planning is usually performed by the contractor during the bidding phase. The construction plan has a large effect on the final project estimated cost. Contractors may win or lose bids and profit or lose money based on the efficiency, safe constructability, and delivery of their construction plan. Once the contractor is awarded the bid, the project manager will evaluate, approve and/or modify the proposed contractor construction plan and monitor its implementation.

10.9 Cost Estimates and Construction Management

While designing a project, the design engineer should consider the construction cost as well as the operational cost. The owner requires the engineer to provide a cost estimate for the project for budgetary purposes. The initial design estimate provided by the engineer may not be accurate. However, as the design progresses, a more detailed estimate will be available with the final engineer's estimate provided when the plans and specifications are completed. The contractor is only concerned with the construction cost of the project and the margin of profit. The contractor may also affect cost by proposing alternative products and construction methods that can save the owner money. Contractors take into account the cost of subcontractor, cost of materials and labor, construction procedures, overhead and profit when preparing their bids. The construction manager's job is to make sure the project is constructed within the budget limits and allotted time. In addition, construction managers will make sure the lowest bidder is within the current market value.

10.10 Types of Construction Contracts

Several types of construction contracts are available for owners to use. The owner is in control in deciding which type of contract to use based on the design, available funds, potential change orders, and allocated risk.

10.10.1 Lump Sum Contract

In a lump sum contract, the owner has essentially assigned all the risk to the contractor, who in turn can be expected to ask for a higher markup in order to take care of unforeseen contingencies. Beside the fixed lump sum price, other commitments are often made by the contractor in the form of submittals such as a specific schedule, the management reporting system or a quality control program. If the actual cost of the project is underestimated, the underestimated cost will reduce the contractor's profit by that amount. An overestimate has an opposite effect, but may reduce the chance of being a low bidder for the project (Civil Engineering Link 2010).

10.10.2 Unit Price Contract

In a unit price contract, the risk of inaccurate estimation of uncertain quantities for some key tasks has been removed from the contractor. However, some contractors may submit an "unbalanced bid" when it discovers large discrepancies between its estimates and the owner's estimates of these quantities. Depending on the confidence of the contractor on its own estimates and its propensity on risk, a contractor can slightly raise the unit prices on the underestimated tasks while lowering the unit prices on other tasks. If the contractor is correct in its assessment, it can increase its profit substantially since the payment is made on the actual quantities of tasks; and if the reverse is true, it can lose on this basis. Furthermore, the owner may disqualify a contractor if the bid appears to be heavily unbalanced. To the extent that an underestimate or overestimate is caused by changes in the quantities of work, neither error will affect the contractor's profit beyond the markup in the unit prices (Civil Engineering Link 2010).

10.10.3 Cost Plus Fixed Percentage Contract

For certain types of construction involving new technology or extremely pressing needs, the owner is sometimes forced to assume all risks of cost overruns. The contractor will receive the actual direct job cost plus a fixed percentage and have little incentive to reduce job cost. Furthermore, if there are pressing needs to complete the project, overtime payments to workers are common and will further increase the job cost. Unless there are compelling reasons, such as the urgency in the construction of military installations, the owner should not use this type of contract (Civil Engineering Link 2010).

10.10.4 Cost Plus Fixed Fee Contract

Under this type of contract, the contractor will receive the actual direct job cost plus a fixed fee, and will have some incentive to complete the job quickly since its fee is fixed regardless of the duration of the project. However, the owner still assumes the risks of direct job cost overrun while the contractor may risk the erosion of its profits if the project is dragged on beyond the expected time (Civil Engineering Link 2010).

10.10.5 Cost Plus Variable Percentage Contract

For this type of contract, the contractor agrees to a penalty if the actual cost exceeds the estimated job cost, or a reward if the actual cost is below the estimated job cost. In return for taking the risk on its own estimate, the contractor is allowed a variable percentage of the direct job-cost for its fee. Furthermore, the project duration is usually specified and the contractor must abide by the deadline for completion. This type of contract allocates considerable risk for cost overruns to the owner, but also provides incentives to contractors to reduce costs as much as possible (Civil Engineering Link 2010).

10.10.6 Target Estimate Contract

This is another form of contract which specifies a penalty or reward to a contractor, depending on whether the actual cost is greater than or less than the contractor's estimated direct job cost. Usually, the percentages of savings or overrun to be shared by the owner and the contractor are predetermined and the project duration is specified in the contract. Bonuses or penalties may be stipulated for different project completion dates (Civil Engineering Link 2010).

10.10.7 Guaranteed Maximum Cost Contract

When the project scope is well defined, an owner may choose to ask the contractor to take all the risks, both in terms of actual project cost and project time. Any work change orders from the owner must be extremely minor if at all, since performance specifications are provided to the owner at the outset of construction. The owner and the contractor agree to a project cost guaranteed by the contractor as maximum. There may be or may not be additional provisions to share any savings if any in the contract. This type of contract is particularly suitable for turnkey operation (Civil Engineering Link 2010).

10.11 Schedule and Budget Updates

A schedule for a project is established at the beginning of construction and is updated on a monthly basis. The schedule changes may cause budgetary changes that must be updated by the contractor with the schedule submitted to the construction manager for review and approval.

Construction problems and lack of materials availability may be overcome through schedule changes that can keep the project on track. Poor scheduling can increase the contract time and cost the owner and contractor money.

On "fast track" projects, initial construction activities are begun even before the facility design is finalized. In this case, special attention must be placed on the coordinated scheduling of design and construction activities. Even in projects for which the design is finalized before construction begins, change orders representing changes in the "final" design are often issued to incorporate changes desired by the owner (Hendrickson 2008).

10.12 Summary

Construction management, especially of complex projects, is necessary to ensure the project is built in accordance with design plans, specifications, and contract documents. The best designed projects will not meet budget and design life if not constructed properly using specified materials and equipment.

11 Security

11.1 Introduction

September 11, 2001, was the beginning of a new security era in the United States. Previous attacks on vital infrastructure such as the "intentional release of naphtha, a cleaning solvent, and alcohol into a sewer in Akron, Ohio by vandals at a rubber manufacturing plant that caused explosions 3.5 miles away from the plant, damaging about 5,400 feet of sewer line and resulting in more than $10 million in damage" (U.S. Government Accountability Office 2005) did not initiate the awareness we have today. The modern terrorists consider attacks in the United States on any infrastructure a defeat to the United States Government and its military.

Following September 11, 2001, the US government directed attention to improving the security of the nation's water infrastructure, meaning both its drinking water and its wastewater systems to protect against future terrorist threats. In December 2003, the President issued Homeland Security Presidential Directive-7, which established the Environmental Protection Agency (EPA) as the lead federal agency to oversee the security of the water sector, both drinking water and wastewater. The EPA and its industry partner, the Association of Metropolitan Water Agencies (AMWA) created the Water Information Sharing and Analysis Center (Water ISAC), which serves more than 1,000 users by providing real-time alerts of possible terrorist activity and access to a library of information and contaminant databases to water utilities throughout the nation (U.S. Government Accountability Office 2005). In addition, the EPA has funded nonprofit technical support and trade organizations including the Association of Metropolitan Sewerage Agencies (AMSA) and the Water Environment Federation to develop tools and training on conducting vulnerability assessments to reduce utility vulnerabilities and on planning for and practicing response to emergencies and incidents (U.S. Government Accountability Office 2005).

The infrastructure related to collecting and treating domestic and industrial wastewater is an essential component for the existence of cities and the growth of their economies. In addition, a major failure in any of the components in a wastewater system can expose the public to fatal health hazards. Wastewater systems include collection systems and treatment facilities. Collection systems are, generally, widely dispersed geographically and have multiple access points including manholes, most of which are not monitored. The underground network of sewers includes wastewater collection lines that may range from 4 inches to greater than 20 feet in diameter. According to the U.S. Government Accountability Office (GAO) report, some of the nation's older cities continue to have combined sanitary and storm water lines. Sewers are connected to all building and streets within typical communities through indoor plumbing and curb drains (U.S. Government Accountability Office 2005).

A typical wastewater treatment plant uses a series of physical, biological, and chemical processes to treat wastewater. "Primary treatment includes the removal of larger objects, such as rags, cans, or driftwood, through a screening device or a grit removal system, and solids are removed through sedimentation. Secondary treatment includes a biological process that consumes pollutants, as well as final sedimentation. Some facilities also use tertiary treatment to remove nutrients and other matter even further. Following secondary or tertiary treatment, the wastewater is disinfected to destroy harmful bacteria and viruses. Disinfection is often accomplished with chlorine gas, which is stored on-site at the wastewater treatment plant" (U.S. Government Accountability

Office 2005). Wastewater systems have become increasingly computerized and rely on the use of automated controls to monitor and operate them, which, in turn, require electricity.

The collection system piping network, sanitary sewer pump stations, the different treatment components of a wastewater treatment plant, treatment chemicals, operating control systems, and the interdependency of a wastewater system on its own components as well as other infrastructure such as transportation, provides a terrorist with too many vital assets to effectively attack a wastewater system.

It is the responsibility of the manager of a wastewater system to enhance the security performance of the system. When developing security standards and guidelines for an effective physical protection for wastewater systems, utility managers must consider deterrence, detection, delay, response, crime prevention, and target hardening measures in their design. These security measures must be considered for new and existing facilities. Prior to design of security systems, the physical and human assets that are critical to a utility's mission must be identified and the capabilities and motivation of the likely adversary or malevolent threat must be determined so that the design is focused on successfully protecting these assets (Gabel, Hasit, and Thompson 2008). Vulnerability assessment studies must be conducted for wastewater systems the same way they are conducted for water systems. The vulnerability assessment studies mandated by the federal government for water systems concluded that it is difficult to deter a determined attacker. However, different layers of protection may make him/her look for easier targets. Nationwide, more than 16,000 publicly-owned wastewater treatment plants, approximately 600,000 miles of sanitary sewers, 200,000 miles of storm sewers, and

100,000 major pumping stations serve more than 200 million people, or about 70 percent of the U.S. population. The remainder of the population is served by privately-owned utilities or by on-site systems, such as septic tanks. About 500 large public wastewater systems provide service to 62 percent of the sewered population, according to data in a recent GAO report titled "Wastewater Security." A vulnerability assessment study of a wastewater system will determine if changes such as the use of treatment chemicals with lower impacts on public health and better collaboration between local, state, and federal agencies will improve the security system and deter attackers.

11.2 Vulnerable Assets of Wastewater Facilities

The diversity of the components of a wastewater system and their distribution over a large geographical area magnifies the security problems that can be faced by the system managers. GAO conducted a survey of fifty wastewater experts who identified the most important vulnerabilities and the most important activities required to improve wastewater facilities' security. The eight most important wastewater system vulnerabilities according to the fifty solicited experts are: collection systems' network of sewers, treatment chemicals, key components of a wastewater treatment plant, control systems, pumping stations, lack of security culture, interdependencies among all major wastewater assets, and interdependencies between wastewater systems and other critical infrastructure (U.S. Government Accountability Office 2005).

11.2.1 Collection Systems' Network of Sewers

Based on the population served, type of economy, and the size of pipes in the collection systems' network, an attacker can choose the type of attack and related damage that can be caused. A city with sanitary sewer pipes larger than six feet in diameter can provide physical access to an attacker to place explosives in areas with large populations causing the failure of infrastructure above ground and hence a large number of casualties. In a rural small community served by a package plant or a wetlands system, an attacker can pour chemicals in the sanitary sewer collection system causing the bacteria at the treatment facility to die, disrupting the treatment process and causing the discharge of wastewater into the waterways. In addition, the sanitary sewer collection system can be infiltrated from a manhole in a secluded area or a cleanout in a residences' backyard making the detection of the attack nearly impossible.

Eighty-four percent of the respondents to the GAO survey ranked the collection systems' networks of sewers as the greatest vulnerability to wastewater systems and sewered populations. "Several [experts] noted that sewers make underground travel from a point of entry to a potential target almost undetectable. Many also suggested that adversaries could use the collection system as an underground transport system without ever physically entering the system for explosive or toxic agents. For example, several experts explained, an adversary could pour a highly toxic chemical into the sewer that could destroy the biological agents vital to the treatment process" (U.S. Government Accountability Office 2005).

11.2.2 Treatment Chemicals

Prior to discharging the treated wastewater into the waterways, it must be disinfected. Regardless of the advancement of new technologies such as onsite chlorine generation systems, chlorine gas remains the most economical and widely used chemical in the last phase of the treatment process in a wastewater treatment plant. However, the use of chlorine gas is accompanied by the dangers of potential explosions and spills during transportation as well as at the wastewater treatment facilities.

The GAO survey found that the second greatest vulnerability of wastewater systems (32/50 or 62% respondents) is treatment chemicals, specifically, chlorine gas, which is extremely volatile and lethal when inhaled, and requires precautions for its safe transport, storage, and use. For example, railroad cars are designed to withstand a bullet from a normal handgun or rifle, but not explosives that are within the skill set of a terrorist (U.S. Government Accountability Office 2005).

11.2.3 Key Components of a Wastewater Treatment Plant

The treatment of wastewater is a complex operation that is composed of physical, biological, and chemical processes that depend on each other to produce a final product that meets state and federal discharge regulations. A disruption at the head of the plant with the pumps or the screens can cause the backup of wastewater in the collection system, and therefore, overflows throughout the city. The destruction of the primary or secondary clarifiers or the poisoning of the waste eating bacteria can stop the biological process and cause the discharge of untreated wastewater into the waterways. Similarly, damage to the chlorine treatment facilities can lead to the pollution of the waterways.

The GAO survey found that the third greatest vulnerability of wastewater systems (29/50 respondents) is damage to components of the wastewater treatment facility system, which would result in inadequately treated wastewater and contaminated drinking water sources, harming the environment, and causing untold economic damage. Experts noted that of all the facility components, the "headworks," where wastewater carried through the collection system first enters the plant, is particularly vulnerable to attack (U.S. Government Accountability Office 2005).

11.2.4 Control Systems

The enhancement of new technologies provides the wastewater system managers with continuous control over the operations of the wastewater facilities. Remotely, via Supervisory Control and Data Acquisition (SCADA) systems, a manager can be notified of any power or pump failures and make operational changes to convert to generator power or turn on another pump with very short time disruptions to operations. However, this ease with operations is accompanied by vulnerabilities from attackers that can hack into the SCADA and enforce operational changes that will inhibit the wastewater treatment facility from performing its physical, biological or chemical functions. In addition, the SCADA can malfunction causing undesired operational failures.

The GAO survey found that the fourth greatest vulnerability (18/50 respondents) is the automated Supervisory Control and Data Acquisition (SCADA) systems, which control vital system operations, among other functions. "These systems can be vulnerable because of loose security in the control rooms at some plants, and remote access to SCADA through the internet, among other reasons. One expert described a breach of cyber security in Australia which caused the release of thousands of gallons of raw sewage" (U.S. Government Accountability Office 2005).

11.2.5 Pumping Stations

In flat areas, the use of a gravity wastewater collection system will generate the need for very deep pipes making maintenance and future rehabilitation very difficult. Therefore, sanitary sewer lift stations are used to collect sanitary sewer from different areas and pump it into another gravity system. Sanitary sewer lift stations can be small enough to serve one residence or large enough to serve thousands of people. Sanitary sewer lift stations are usually located away from homes because of the noise and smell factors. A terrorist attack on a sanitary sewer lift station can be minor through damaging the electrical source or major by destroying all the pumps and wet wells. Regardless of the magnitude of the attack, the attack will cause the backup of sanitary sewer into peoples' homes as well as the discharge of wastewater on the streets and ditches and hence waterways.

The GOA survey found that the fifth greatest vulnerability (16/50) is pumping stations, which are often used to move sewage to the treatment plant when gravity alone is not sufficient. "As one expert explained, destroying or disabling a pumping station could cause the collection system to overflow raw sewage into the streets, and into surface waters, and back up sewage into homes and businesses...The remoteness and geographic distribution of pumping stations, and their lack of continuous surveillance, make them particularly vulnerable" (U.S. Government Accountability Office 2005).

11.2.6 Lack of Security Culture

Prior to September 11, 2001, security of wastewater systems was not a necessity. In general, managers of wastewater systems do not invest a lot of time and money on security measures. However, an attack on a wastewater system can have a negative economical impact and expose the citizens to health hazards. Security should be a part of the daily activities at wastewater facilities. A relaxed security attitude by the wastewater systems' managers will provide an attacker an easy target.

Some of the GAO survey respondents pointed out that "wastewater utilities generally do not have a security culture because they are often more focused on operational efficiency and may, therefore, be reluctant to add security procedures and access control elements to their operations. For example, one expert noted the ease with which many types of individuals (employees, contractors, and visitors) and vehicles typically enter wastewater treatment facilities. As this expert pointed out, some facilities do not check to ensure that individuals entering the property have legitimate reasons for being there" (U.S. Government Accountability Office 2005). Another potential security issue is lack of inspection of incoming truckloads at some wastewater treatment plants, which could result in delivering contaminants or explosives to destroy the treatment process of the entire facility. Also, there may be little background screening of utility employees (U.S. Government Accountability Office 2005).

11.2.7 Interdependencies Among All Major Wastewater Assets

The disruption of any component in a wastewater treatment facility will prevent the complete treatment of the wastewater. The wastewater treatment process must follow a certain cycle prior to discharging the final product into the waterways. Based on the location of the different treatment units in the wastewater treatment plant, an attacker will find an easy access point and interrupt the entire process. Usually the head works at a wastewater treatment plant are located close to the entrance and can be damaged easier than the chlorine treatment facilities which are usually located at the back of the plant. Regardless of which component gets attacked, untreated wastewater will be discharged into the waterways.

A few of the GAO survey respondents pointed out that interdependence among the components of the wastewater treatment system means that the system accomplishes its purpose only when all of its components are in proper working order. One expert explained that, "because treatment plants are less able to recover from an attack, they may have a higher level of security than other assets, such as the collection system. However, because collection and treatment are part of one integrated system, securing one asset does not ensure that the system as a whole is more protected. For example, gates and fences around the main treatment plant may stop an adversary from coming onto the physical property, but it will not prevent a harmful agent from entering the facility through the collection system—an event that could destroy the facility's entire secondary treatment process" (U.S. Government Accountability Office 2005).

11.2.8 Interdependencies Between Wastewater Systems and Other Critical Infrastructure

The operation of the wastewater facilities is also dependent on a power source, chemical production plant and suppliers, external contractors, communication providers, equipment manufacturers, and state and federal support during emergencies. A wastewater facility should have an emergency management plan in place to provide a step by step procedure to overcome interruptions in any of these critical components for its operations. An attacker is most likely to target a facility that cannot recover in a timely manner to maximize the damage.

Experts in the GAO survey noted that interdependencies between wastewater systems and other critical infrastructures is a final major vulnerability. "Disruptions in electric power, cyber systems, and transportation of treatment chemicals can result in a failure of wastewater treatment systems. One expert cautioned that the interruption of the power grid could render the wastewater plant useless, noting 'Several hours without power would cause the biological treatment process to halt and wastewater would back up in the collection system.' Such an event occurred in 2003, when a major power failure caused treatment plants in Cleveland, Ohio, to release at least 60 million gallons of raw untreated wastewater into...Lake Erie or the Cuyahoga River and other tributaries" (U.S. Government Accountability Office 2005).

11.3 Specific Activities to Improve Wastewater Security

The three most important activities to improve wastewater security are: replacing gaseous chemicals used in wastewater treatment with less hazardous alternatives, improving local, state and regional collaboration efforts, and completing vulnerability assessments for individual wastewater systems.

11.3.1 Replacing Gaseous Chemicals Used in Wastewater Treatment with Less Hazardous Alternatives

The use of chlorine gas as a disinfectant at wastewater treatment facilities increases the possibilities of an attack at different levels. Starting at the manufacturers location, passing through cities during transportation, and finally, at the wastewater treatment facilities. The replacement of chlorine gas with chlorine generating systems on site will eliminate the dangers associated with manufacturing and transportation. In addition, the chlorine generating systems will reduce the volume of required onsite storage decreasing the probability of leaks and magnitude of explosions.

In the GAO survey, 29/50 respondents rate replacement of gaseous chemicals at wastewater treatment facilities with less hazardous alternatives as warranting highest priority for federal funding. The availability of chlorine gas makes wastewater treatment facilities an attractive target for terrorist attack. Conversion to sodium hypochlorite and ultraviolet disinfection is expensive, but an increasing number of plants are doing just that. One expert suggested that conversion of individual facilities is a good candidate for federal funding. Another expert suggested reducing the size of containers (from 90-ton railroad tanker car size to 1-ton canisters) used to transport and store gaseous chemicals to deter terrorist acts (U.S. Government Accountability Office 2005).

11.3.2 Improving Local, State, and Regional Collaboration Efforts

A determined attacker will exhaust all efforts to destroy his target. In case of a successful attack, an effective response will minimize the impact of the attack. A wastewater systems' manager with only general employees, do not have the resources required to put a wastewater system back in operation in a reasonable time. The coordination, planning, and collaboration with other private, state, and federal agencies will result in an expeditious restoration of the damaged components of the wastewater system. Knowledge of state and federal requirements is essential for a municipality to recover its cost imposed by an emergency. In the case of service interruptions, utility providers should have a prioritized list of the wastewater system facilities so that they will know which facilities they should restore the services to first.

In the GAO survey, 23/50 experts highly rated efforts to improve collaboration between utilities, local and state law enforcement agencies, fire departments, and other first response agencies through periodic field and tabletop exercises in advance of an emergency situation. One expert lamented that wastewater facilities remain largely disconnected from these entities, and wastewater facilities' efforts for emergency response planning are, therefore, often undertaken independently. "This lack of collaboration perpetuates the community's idea that 'sewers lead to [a] magical place where [materials] simply go away without consequence. The expert added that this misperception is demonstrated by a failure of some in the medical response community to adequately plan for proper disposal of waste resulting from decontamination efforts of a chemical, biological, or radiological event. Directly discharging such material to the wastewater influent stream could significantly damage or destroy the wastewater treatment process" (U.S. Government Accountability Office 2005).

11.3.3 Completing Vulnerability Assessments for Individual Wastewater Systems

The TCEQ and EPA rules and regulations require water systems to have backup power. This is not a requirement for wastewater systems. The hurricanes that the Gulf Coast experienced since 2005 made the wastewater system managers realize that powered water treatment plants will cause illegal sewer discharges into the environment if the sanitary sewer lift stations and wastewater treatment plants are down from power outages. Similarly, after September 11, 2001, the federal government required water systems to conduct a vulnerability assessment study, whereas, the security of a wastewater system remained unnoticed. All wastewater systems should conduct a vulnerability assessment study to identify and prioritize their weaknesses in order to make the necessary changes to protect their assets. Security and layers of defense at the wastewater systems should be done prior to an attack with the intentions to deter one.

In the GAO survey, 20/50 respondents rated vulnerability assessment completion highest. The Bioterrorism Act of 2002 required vulnerability assessments for drinking water utilities serving more than 3,300 people, but did not include a comparable requirement for wastewater utilities. Software titled "Vulnerability Self Assessment Tool (VSAT), developed and released by the AMSA, provides an interactive framework for conducting vulnerability assessment (U.S. Government Accountability Office 2005).

Utilities serving critical infrastructure, including government, commercial, industrial, and medical centers and hospitals, should receive highest priority for federal funding. In decreasing order of priority after serving critical infrastructure are facilities using large quantities of gaseous chemicals, serving areas with large populations, where a security breach would adversely impact environmental resources (e.g., receiving waters), having completed vulnerability assessments, serving areas with medium or small populations, and serving buildings, monuments, parks, tourist attractions, or other entities that have symbolic value (U.S. Government Accountability Office 2005).

11.4 Governmental Mandates Related to the Security of Wastewater Systems

State and federal agencies have enacted several laws and enforced many regulations to ensure the security of wastewater systems and the safety of the public. The most effective regulation is listed in the "Wastewater Treatment Works Security Act of 2009 (TITLE III OF H.R. 2868). The following are the main items addressed by this act (U.S. Environmental Protection Agency October 2009).

11.4.1 Role of Wastewater Systems

Title III authorizes significant federal resources to enhance the security of public sewage treatment facilities. Title III requires each sewage treatment facility that treats at least 2.5 million gallons per day (estimated by EPA to be a facility that serves a population of 25,000 or greater), or in the discretion of the Administrator, presents a security risk, to: (1) conduct a vulnerability assessment; (2) develop and implement a site security plan; and (3) develop an emergency response plan for the facility. Vulnerability assessments and site security plans developed under this title are required to be submitted to the EPA Administrator for review and approval, and to be updated on a periodic basis (U.S. Environmental Protection Agency October 2009).

11.4.2 Role of EPA

Title III requires the EPA Administrator, in consultation with the Department of Homeland Security, to categorize the nation's sewage treatment facilities into one of four risk-based tiers, with tier 1 representing a facility with the highest degree of security risk. Owners and operators of sewage treatment facilities would be required to implement appropriate site security and emergency response plans based on the perceived degree of risk to critical infrastructure, public health or safety, or the environment from an intentional incident at the facility (U.S. Environmental Protection Agency October 2009).

11.4.3 Regulates the Use of Chemical Substances of Concern

Title III authorizes the EPA Administrator, in consultation with the Department of Homeland Security, to designate a chemical substance as a substance of concern, based on likelihood that a release of the substance could result in death, injury, or serious adverse impact to human health or the environment (U.S. Environmental Protection Agency October 2009).

11.4.4 Requires the Assessment and Implementation of Methods to Reduce the Consequence of a Chemical Release from an Intentional Act (Inherently Safer Technologies)

Title III requires all sewage treatment facilities that possess a substance of concern to undertake an assessment of methods to reduce the consequence of a chemical release from an intentional act, more commonly referred to as inherently safer technologies (IST). For high-risk sewage treatment facilities, title III authorizes States with approved programs under the National Pollutant Discharge Elimination System (section 402 of the Clean Water Act) or EPA (in the case of states without an approved program) to require implementation of inherently safer technologies where implementation: (1) would significantly reduce the risk of death, injury, or serious adverse effects to human health; (2) would not increase the onsite storage of chemicals; (3) would ensure that the facility could continue to meet its existing Clean Water Act obligations to protect water quality; and (4) is feasible. Individual states, and the EPA Administrator, are provided discretion to take enforcement action against a facility to ensure compliance with the inherently safer technology provisions of this title (U.S. Environmental Protection Agency October 2009).

11.4.5 Ensures Security-Related Audits and Inspections, and Provides for Whistleblower Protections

Title III requires the EPA Administrator to audit and inspect individual sewage treatment facilities to ensure compliance with the security-related provisions of this Title, and provides whistleblower protections for employees with information on the failure to implement required security measures (U.S. Environmental Protection Agency October 2009).

11.4.6 Ensures the Protection of Security-Related Information

Title III provides for appropriate access to security-related information among federal, state, and local governments, tribal representatives, and sewage treatment employees, as well as law enforcement and first responder personnel (U.S. Environmental Protection Agency October 2009).

11.4.7 Allows State and Localities to Implement More Stringent Security Standards

Title III explicitly authorizes states and localities to enact more stringent wastewater treatment security standards if they determine that such measures are necessary (U.S. Environmental Protection Agency October 2009).

11.5 Summary

The interruption in services from a terrorist attack on any component of a wastewater system can affect a large number of customers. Therefore, security measures must be implemented with the methodology of attempting to deter or prevent an attack while planning a response if it is imminent.

12 Funding

12.1 Introduction

The new construction and rehabilitation cost of wastewater systems infrastructure imposes the need for funding sources to minimize the immediate financial impact on the customers. Wastewater system managers usually understand the needs of their infrastructure and know the measures required to protect the environment and provide uninterrupted service. However, rehabilitating an eight inch sanitary sewer pipe for approximately $32 per linear foot, building one million gallons a day lift station for approximately $700,000 and refurbishing trickling filters for a 47 MGD plant for an approximate cost of $1.2 million (City Of Beaumont Bidding Documents) are a few examples of infrastructure rehabilitation costs. Previously, knowing the magnitude of the potential expenditures and the necessary rate increases to accomplish it, the wastewater system manager's methodology was to spot repair deteriorated infrastructure instead of complete replacement or rehabilitation. Regularly changing, stringent state and federal regulations, failures in infrastructure causing major sanitary sewer overflows, and wastewater system managers' new approach of renewing infrastructure to last a minimum of 30 years have initiated a new interest in wastewater funding from state, federal and local sources.

Since 1972, Congress has directly invested more than $77 billion in the construction of publicly owned treatment works and their related facilities. State and local governments have spent billions more over the years. The total non-federal spending on sewer and water between 1991 and 2005 was $841 billion. Nevertheless, the physical condition of many of the nation's 16,000 wastewater treatment systems is poor because of a lack of investment in plants, equipment, and other capital improvements over the years (American Society of Civil Engineers 2010).

In 2008, the U.S. Environmental Protection Agency (EPA) reported that the total investment needs of America's publicly owned treatment works as of January 1, 2004, were $202.5 billion (American Society of Civil Engineers 2010).

For the second time, America's infrastructure rates a cumulative grade of D. Aging systems discharge billions of gallons of untreated wastewater into the U.S. surface waters each year. The Environmental Protection Agency estimates that the nation must invest $390 billion over the next twenty years to update or replace existing systems and build new ones to meet increasing demand (American Society of Civil Engineers 2010).

12.2 Wastewater Infrastructure Funding Sources

Knowing the need to rehabilitate, upsize and renew small diameter collection system pipes, large diameter interceptors, sanitary sewer lift stations, force mains, and wastewater treatment facilities, wastewater system managers are searching for and acquiring federal, state and local funds. There is an immediate need to significantly reinvest in repairing and replacing America's traditional water and wastewater infrastructure or risk having water quality regress to mid-1970s pollution levels (U.S. Environmental Protection Agency October 2003).

12.2.1 Federal Funding

The state and federal government implements rules and regulations to protect the environment and public health. However, the state and federal government also understand the cost associated with the construction required to abide by the rules. Therefore, funding programs such as loans and grants are designed to minimize the financial impact on the customers and encourage the wastewater system managers to proceed with needed improvements to restore the structural integrity and operational efficiency of the system. In general, the federal government allocates funding to wastewater systems that is funneled through state agencies that monitor the project's progress and expenditure. The State Revolving Fund (SRF) regularly distributes federal money to the states, who then lend the money at below-market level rates to local governments to repair or upgrade wastewater infrastructure (a parallel program exists for drinking water). In more than twenty years since its inception in 1987, the Clean Water SRF has provided $68 billion to over 20,000 projects, serving almost 95 million people. The money from the program is flexible – in addition to fixing pipes, SRF funding can be used for water efficiency, green infrastructure, and nonpoint source pollution reduction (U.S. Environmental Protection Agency October 2003).

One of the major wastewater funding programs is the Clean Water State Revolving Fund (CWSRF) which is used for planning, design, and construction of publicly-owned wastewater treatment projects. The program also funds a variety of publicly- or privately-owned nonpoint source and estuary management projects. Clean Water State Revolving Fund (CWSRF) programs provided more than $5 billion annually in recent years to fund water quality protection projects for wastewater treatment, nonpoint source pollution control, and watershed and estuary management. CWSRFs have funded over $68 billion, providing over 22,700 low-interest loans to date. The CWSRFs offer low interest rates with flexible terms, significant funding for nonpoint source pollution control and estuary protection, assistance to a variety of borrowers, and partnerships with other funding sources (U.S. Environmental Protection Agency October 2003).

The most recent effort by the federal government to stimulate the economy was the enactment of the American Recovery and Reinvestment Act (ARRA). The ARRA provides free funding or funding with very low interest rates for projects that can bid immediately and go to construction in order to create jobs. The American Recovery and Reinvestment Act (ARRA) of 2009 provided the CWSRF programs with $4 billion to fund high priority wastewater infrastructure projects (U.S. Environmental Protection Agency July 2010b).

Following the American Recovery and Reinvestment Act of 2009 requirement that 20% of Clean Water SRF funds should be permanently set-aside for green infrastructure projects and 20% of the Drinking Water SRF should be set aside for water efficiency and reuse; we believe that these set-asides should be included in the SRF. Such set-asides are critical in the near-term to move communities towards more sustainable water infrastructure. While the SRF already allows the use of funds for green infrastructure and other innovative practices, currently, only 4% of funds nationwide are being used to reduce nonpoint source pollution (U.S. Environmental Protection Agency October 2003).

12.2.2 State Funding

The federal government allocates the responsibilities of administering the funding programs to the states. States have flexibility in how they structure their SRF programs and in deciding which projects can be funded. Some states have innovative programs that fund both traditional and non-structural or green approaches to clean water (U.S. Environmental Protection Agency October 2003).

The states allocate the responsibilities of spending the funding to different state agencies. In the State of Texas, most water and wastewater projects are funded by the Texas Water Development Board (TWDB). The legislature created the Texas Water Development Board (TWDB) in 1957 in response to the drought of the 1950s to plan for and to provide financing for the State's future water needs. The mission of the TWDB is to provide leadership, planning, and financial assistance for the state's water and wastewater infrastructure through a variety of loan and grant programs.

Some of the state funded programs are (Texas Water Development Board 2008):

- Development Fund (DFund);
- Funding of planning, design, and construction of water and wastewater projects;
- Rural Water Assistance Fund (RWAF);
- State Participation;
- Economically Distressed Programs (EDAP); and
- Funding of planning, acquisition, design (PAD), and construction of water and wastewater projects (Texas Water Development Board 2008).

12.2.3 Local Funding

Although grants may be available for certain wastewater projects, the majority of the rehabilitation and renewal efforts will have to be paid for using the water and wastewater revenues. Therefore, a wastewater system must generate enough revenue to operate, maintain, and borrow funds to finance capital improvement projects. The most economical approach with the lowest interest rate is the sale of bonds that is dependent on the excess revenue available and the dollar amount available in the water fund.

Financing for capital program projects is provided by the "cash flow" approach, whereby debt is issued to generate enough cash to pay the expenditure anticipated during the year for both existing and new projects. This approach provides the most efficient use of citizen's dollars by allowing multi-year projects to be initiated without issuing debt for the full cost of the projects at the time of project commencement. All available funding sources are considered including Certificate of Obligation, Community Development Block Grant funds, and available cash. Although funding for water and sewer projects is determined using the cash flow approach, Water Revenue Bonds are issued rather than tax supported Certificates of Obligation. This type of bond is serviced utilizing revenues from the water and sewer customers. Planning, design, and construction costs all factor into the decision of when and how much debt to issue (City of Beaumont 2010).

Wastewater systems can generate revenue from the sale of water and wastewater services, and impact fee. Impact Fee was originally developed in 1988. It is a charge or assessment imposed by a political subdivision against new development to generate revenue for funding or to recoup the costs of capital improvements for facility expansions necessitated by and attributable to new development, Texas Local Government Code 395.001(4) (State of Texas 2001).

Approximately 85 % of the cities within the urbanized growth areas of the Dallas Fort Worth Metroplex utilize Wastewater Impact Fees (Freese and Nichols 2010).

In most cities, current water and wastewater rates are a small fraction of the daily cost of living. Compared to other utilities, such as gas and electricity, water and wastewater services are at affordable rates. Therefore, rate increases to accommodate needed improvements should not generate public discontent.

12.3 Summary

The high cost of constructing, replacing, and rehabilitating wastewater system infrastructure makes the operators seek funding from local, state, and federal sources. However, most of the projects are funded through bond sales that are financed by water and wastewater rate increases.

13 Summary

Sanitary sewer collection systems consisting of a network of gravity and pressure pipes and lift stations appear to be a simple infrastructure that operate efficiently with minimal attention. However, having most of the sanitary sewer collection system underground and not visible to the operators, keeps its condition unknown. In addition, the daily deterioration to the components of a wastewater collection system from hydrogen sulfide gases reduces its structural integrity and reduces its capacity and efficiency with minimal surface indications prior to failure. Since the inception of wastewater collection systems, operators started learning about the system's reduced reliability and capacity with time, the impact of FOG on overflows and public health and safety, and the increased flows from inflow and infiltration during wet weather events. The conditions of existing wastewater collection systems in combination with the experiences of the operators, forced the initiation of a planning process that includes system evaluation and hydraulic modeling for better planning the rehabilitation projects, public awareness and education to improve the quality of wastewater customers discharge into the collection system, pipe renewal and lift station rehabilitation to reduce the inflow and infiltration and overflows, and a scheduled maintenance program to increase the capacity and prolong the life of the system.

Identifying the problems in the wastewater collection system and planning to efficiently resolve them requires knowledge of the assets to be able to better manage the system and flows. In addition, design criteria to meet current and future demands must be specified for the design engineer so that today's wastewater collection systems will have a minimum life expectancy of fifty years with minimal maintenance.

With the increased demand for city utility services, it is important for a city to review its sanitary sewer collection system to determine system needs and capacity and related Capital Improvement Program needs.

This dissertation performed a comprehensive evaluation of an entire wastewater collection system describing its deficiencies, needs, and setting standards for prioritizing a rehabilitation plan. The efficient operation of wet and dry well sanitary sewer lift stations is based on a design that meets EPA and TCEQ requirements with pump capacity, type, and configuration that accommodates the influent raw sewage while maximizing performance, provide reliable and uninterruptible power supply, accommodate future capacity for expansion, reduce odor discharges, minimize economic and environmental impacts on adjacent properties, and avoid overflows. The operation of a sanitary sewer lift station should be paralleled by a well planned maintenance program designed through the use of an asset management program. It is the wastewater system's operators' knowledge of the collection systems infrastructure, experience during normal and emergency situations, and dedication to protecting public health and safety that optimizes the operation of sanitary sewer systems.

A wastewater treatment plant, conventional including primary and secondary treatment or advanced with tertiary treatment, is a major asset to the wastewater system. The treated wastewater discharged into the waterways should improve the quality of the water and the sludge removed during the treatment process should be disposed of properly. The design criteria provided by the EPA and TCEQ should be used as a minimum standard and potential impacts by inflow and infiltration must be considered during the design process. Innovative technologies that can produce better effluent must be implemented. A wastewater treatment plant's operators should expand every effort to stay within the permit limits and never have intentional illegal discharges unless it is an act of God. Regardless of the type of treatment used, the technologies implemented or the quality of effluent, a CMOM program is needed to provide consistency in treatment, minimum service interruption, extended life expectancy of the equipment and facilities, and economical and efficient operations.

Wastewater should be treated properly prior to discharging it into the waterways in order to protect the public's health and environment. Meeting this objective requires a joint effort between the state and federal governments permitting procedures and inspection programs, the wastewater system operators and the public. All involved parties have to fulfill their responsibilities in order to successfully complete the wastewater collection and treatment process. The wastewater operators must gather accurate data, perform testing as per standard procedures, and perform maintenance required to prevent service interruption. The state and federal government should act as monitors to the wastewater system operations and educators to the operators, commending high performers and penalizing those who refuse to abide by the rules and regulations. To maximize the efficiency of the treatment process and save money, the public, industry, and developers must perform their duties to the treatment process such as keeping grease out of the sink and disposed of as solid waste, drain yards into the storm sewer instead of the sanitary sewer collection system, and construct sewer systems per plumbing codes.

Inflow and infiltration is a problem faced by most wastewater system operators. The quantity, quality, and source of storm and ground water vary depending on the age of infrastructure, drainage system condition, type of soil, and nature of the terrain. Until a rehabilitation program becomes effective enough to reduce the storm and ground water entering into the collection system, managing the inflow and infiltration is essential to reducing the number of overflows. While the inflow and infiltration management program is implemented and the rehabilitation efforts are exhorted, an effective maintenance program will assist in providing uninterrupted service to the customers.

The SSOI is a comprehensive approach by the EPA and the TCEQ to encourage wastewater systems to plan and implement rehabilitation programs that will reduce SSOs and protect the public health and environment. The SSOI is available to all wastewater systems including but not limited to municipalities, municipal utility districts, and private systems. The EPA and TCEQ provide rules and guidance to those who chose to participate in the SSOI. The plan should identify areas and provide quantities of the infrastructure that will be rehabilitated within a certain time frame as well as measuring tools for the effectiveness of the plan. In the State of Texas, the SSOI started in 2004 in the City of Houston. Since then, several cities adopted the SSOI and its effectiveness has been proven. For example, the City of Beaumont reduced its inflow and infiltration volumes by 34 percent for a one inch rain within two years of implementation of the SSOI. This translated into a 40 percent reduction in SSOs (City of Beaumont SSOI Annual Report). The success of the SSOI is dependent on the wastewater system's understanding of the collection system and their ability to prioritize the areas that need rehabilitation.

Effective management of a wastewater system requires comprehensive knowledge of the system's history and assets, daily monitoring of operations and flows, strategically planned maintenance programs, and detailed standard operating procedures and hydraulic modeling. This information, once available, can be used to determine the appropriate management measures needed to minimize SSOs. The flow management can be as simple as pumping the collection system down prior to a rain event to increase the storage capacity, or as sophisticated as building a wet weather pump station and a force main to divert flows from a basin with deteriorated pipes to one that has limited inflow and infiltration sources. However, SSOs can be reduced through a combination of efforts, including but not limited to, rehabilitation of deteriorated pipes and flow management. If all measures to eliminate overflows fail, an emergency response plan should be in place to respond immediately and minimize the effect of the illegal discharge on the environment.

Most cities in the United States are behind schedule on sanitary sewer pipe replacement due to poor planning and limited funding availability. As a result, deteriorated pipes cause interruption in services and sanitary sewer overflows jeopardizing the public's health and negatively impacting the environment. Efficient pipe replacement techniques are essential for accelerated rehabilitation programs. The soil conditions, structural integrity, depth, size and material type of the existing pipe, and the need for additional capacity will dictate the rehabilitation technique to be utilized. Although sliplinning, chemical grouting, cured in place pipe, fold and form, pipe jacking, tunneling, microtunneling, and shotcrete have their specialized applications to satisfy certain conditions, pipe bursting remains the most flexible and economical technique used.

Pipe bursting is the perfect solution for a municipality looking to increase the capacity of its sewer pipes or to replace deteriorated and leaking pipes. All of this is possible without extensive excavation and all the associated costs of surface restoration.

Because it is trenchless, pipe bursting is the preferred method for replacing old pipes in urban areas where disruption to surrounding utilities, local residences, businesses, and the environment are a consideration (Mocon Corporation 2010).

Construction management is an integral part of the successful construction of a project. Construction management services are diverse and should start during the preliminary phase of design. Quality assurance and quality control of items such as materials specifications and high quality workmanship are used to ensure the integrity of a construction management program. However, any project related to public health and safety is regulated by state and federal agencies in addition to associated legal responsibilities. Once a project is bid, value engineering is usually conducted to reduce cost without effecting quality and performance. Once construction starts, in addition to regular schedule updating, construction planning is an essential tool used to keep the project on schedule and within budget. Different types of construction contracts are available for the owner to choose from basically to shift associated risk to the contractor.

Construction management services offer the owner the potential for speed, quality, and reduced cost for delivering a project (Mocon Corporation 2010). The successful completion of a project requires a coordinated effort between the design engineer, construction manager, contractor, and owner. The construction manager's primary concern is strict adherence to schedule and budget, with the designer focusing on quality. During the design phase, the construction manager addresses such issues as constructability, cost, schedules, and work packaging (York and Potts 1995). A project with a defined scope and detailed set of contract documents, planning, open communications between owner, design engineer and contractor, and a high quality construction management team and program will be completed on time, within budget and operate beyond its life expectancy.

The vast size of a wastewater system and the number of components required to effectively transport and treat sanitary sewer creates a security challenge to the managers and operators. Whether an attack takes place in the collection system, at the pump stations, at any component of the wastewater treatment facilities, or the chemical treatment aspects of manufacturing, transporting or storing, a disruption of the entire treatment process will occur. The interruption can be minor causing few sanitary sewer overflows or major discharging untreated wastewater into the waterways and polluting the potable water sources. Therefore, the managers of wastewater systems should utilize tools provided by the federal government such as Wastewater Treatment Work Security Act of 2009, Title III of H.R. 2868, to fund a vulnerability assessment study that will identify the security weaknesses of the system and suggest methods to prevent an attack. However, if preparedness and prevention techniques do not prevent a persistent attacker, a contingency plan must be in place to minimize the interruption to services. Security of wastewater systems should become a way of life to the managers and operators in order to prevent and/or deter a disaster.

The United States wastewater infrastructure is deteriorating from age and lack of required maintenance that is essential to extending the life expectancy of the system. Ignoring the immediate rehabilitation and renewal demands will create a crisis in the near future that will jeopardize the public health and the nation's economy. Therefore, sources of funding whether at the federal, state, or local levels must be made available through water and wastewater revenues. The water and wastewater rates should provide for operations, maintenance and capital improvement projects. However, water and wastewater rate increases should be planned over a period of years so that no sudden rate increase will be necessary to address emergency failures.

On February 1st, 2010, President Obama revealed his $3.8 trillion budget for fiscal year 2011. The budget provides a total of $3.3 billion for the Clean Water and Drinking Water State Revolving Funds. Clean Water SRF funding would fall from $2.1 billion this year to $2 billion in 2011 and Drinking Water SRF investment would fall from $1.387 in FY 2010 to $1.287 in FY 2011 (National Utility Contractors Association 2010). The recent reduction in available funding by the federal government is proof that wastewater systems should be self sufficient funding necessary projects through bond sales.

14 Conclusion

The invention of wastewater systems including collection piping networks, lift stations, and different treatment methods played an important role in advancing humanity and protecting the public health and environment. As populations increase, generating approximately 100 gallons per capita per day of wastewater, a city the size of Houston is collecting, transporting, and treating on average 267,000,000 gallons of wastewater a day (City of Houston 2009). If this wastewater volume is discharged in the waterways it will cause an environmental disaster that would take years to clean up. Prior to 1970, wastewater system infrastructures were built and forgotten since they are underground and not visible. The lack of preventative and routine maintenance in conjunction with the harsh environment forced the infrastructure to deteriorate causing inflow and infiltration of storm and ground water into the collection system which in turn causes illegal sanitary sewer discharges. New environmental regulations and more public awareness are requiring the implementation of maintenance, rehabilitation, and flow management programs. Structured and organized maintenance program will extend the life of the equipment and pipe, increase capacity, enhance reliability and save money. Rehabilitation of wastewater infrastructure should be the main solution for inflow and infiltration problems. Expanding wastewater treatment facilities may absorb the volumes during wet weather events. However, additional real estate will be needed that may not be available. During dry weather, the expansion will include equipment that will be sitting idle and deteriorating. The larger the facilities the more manpower will be needed to operate and maintain the treatment facility. The potential risk of violations and fines increases as the number of equipment increases. A wastewater system is designed to last fifty years. However, initially it is designed for a specific treatment volume of certain wastewater characteristics. Therefore, after certain periods of time optimizing the wastewater system will require a reevaluation based on flow changes and new wastewater characteristics. The addition of new technologies must be implemented if needed. The wastewater industry must step outside of the normal procedures and processes and implement ideas such as reuse of treated wastewater, capture sewer gases and use it to generate power, recycle the solids into items such as fertilizers, and use manmade and natural wetlands as a final polishing phase of the treatment process. Finally, the efficiency of a wastewater system is highly dependent on the knowledge, experience and dedication of its operators.

The greatest need of a modern city is its water supply. Without it, city life would be impossible. The next most important need is the removal of waste matters, particularly wastes containing human excreta or the germs of disease. To exist without street lights, pavements, street cars, telephones, and the many other attribute of modern city life might be possible, although uncomfortable. To exist in a large city without either water or sewerage would be impossible (Babbitt 1922).

References

3 Rivers Wet Weather. 2010. *Understanding the Sewer Collection System.* http://www.3riverswetweather.org/d_weather/d_inflow.stm (accessed August 2010).

AJP Engineering. 2007. AJP Engineering Photo Gallery. http://ajp-engineering.com/pics/1/Cured%20In%20Place%20Pipe%20-%20Small%20CIPP%20-%20Over%20The%20Hole/slides/Cured-in-Place-Pipe%20Lining.html (accessed September 2010).

American Society of Civil Engineers. 2010. Report Card - American's Infrastructure. http://www.infrastructurereportcard.org/fact-sheet/wastewater (accessed September 2010).

APWA, ASCE, NACWA, Water Environment Federation. 2010. Core Attributes of Effectively Managed Wastewater Collection Systems. http://www.google.com/search?hl=en&rlz=1T4ADBF_enUS284US284&q=core+attributes+of+effectivelt+managed+wastewater+collection+systems&aq=f&aqi=m1&aql=&oq=&gs_rfai= (accessed October 2010).

Babbitt, Harold E. 1922. *Sewerage and sewage treatment.* New York: John Wiley & Sons, Inc.

Bentley. 2010. *Wastewater Collection System Modeling and Design.* http://www.bentley.com/en-US/Training/Products/Resources/Books/WCSM.htm (accessed July 17, 2010).

Bureau of Engineering. 1992. Sewer Design. *Bureau of Engineering Manual - Part F.* http://eng.lacity.org/techdocs/sewer-ma/f800.pdf (accessed October 2010).

Caldwell, John T. 2007. Wastewater Collection System Rehabilitation and Replacement (R&R) Program Prioritization. http://cedb.asce.org/cgi/WWWdisplay.cgi?159273 (accessed September 2010).

Carterton District Council. 2007. Wastewater - Asset Mangement Plan. http://cartertondc.co.nz/pdfs/AMPWasteWaterExecSum%20(3).pdf (accessed September 2010).

Chicago Metropolitan Agency for Planning. 2010. *Go 10 20/40 Imagine That.* http://www.cmap.illinois.gov/ (accessed September 2010).

City of Beaumont. 2010. *City of Beaumont Annual Budget Report.* Budget Report. Beaumont: City of Beaumont Finance Department.

City of Houston. 2004. Wastewater Collection System Sanitary Sewer Overflow Plan and Schedule.

—. 2009. Capital Improvement Plan. http://www.houstontx.gov/cip/09cipadopt/execsummary/es-waste.pdf (accessed October 2010).

—. 2010. Public Works and Engineering, Wastewater FAQ's. http://www.publicworks.houstontx.gov/utilities/faq.html (accessed October 2010).

Civil Engineering Link. 2010. Types of Construction Contracts. *Civil Engineering Link - Civil Engineering Jobs & Construction Projects Management.* http://civilengineerlink.com/types-construction-contracts/ (accessed September 2010).

Dent, Shawn and Len Wright. 2007. Defining Collection System Performance Criteria to Meet Level of Service Goals. *World Environmental and Water Resources*

Congress. pp 1-17. Washington, D.C.
http://cedb.asce.org/cgi/WWWdisplay.cgi?159401 (accessed September 2010).

Echochem. 2008. *EC-220B Bio-Cube, Lift Station Maintenance - Grease Control.* http://www.ecochem.com/t_220_cube.html (accessed October 2010).

Environmental Leverage, Inc. 2003. Wastewater Lift Stations. http://www.environmentalleverage.com/Wastewater%20Lift%20Stations.htm (accessed September 2010).

Favre, Tracy. 2002. *Water & Wastes Digest.* http://www.wwdmag.com/Pipes-Choosing-the-Right-Rehabilitation-Method-article3260 (accessed September 2010).

Freese and Nichols. 2010. *Funding options for water infrastructure programs in Texas.* Financial Assistance Programs. Beaumont: Freese and Nichols.

Gabel, Dale, Yakir Hasit, and Ken Thompson. 2008. Design Considerations in Water, Wastewater, and Stormwater Utility Security. *World Environmental and Water Resources Congress.* pp 1 - 10.

Gannett Fleming. 2008. Construction Management. http://www.gannettfleming.com/cm/cm-waterwastewater.aspx (accessed September 2010).

Global Water Instrumentation, Inc. 2010. *Inflow and Infiltraton.* http://www.globalw.com/support/inflow.html (accessed October 2010).

Gokhale, S. and M. Hastak. 2003. Automated assessment technologies for sanitary sewer evaluation. *New pipeline technologies, security and safety.* Baltimore: American Society of Civil Engineers.

Governmental Accounting Standards Board, *GASB.* July 2010. http://www.gasb.org/

(accessed September 2010).

Government of Japan. March 2005. Japan International Cooperation Agency and Baghad Mayoralty. *4.2.2 Stormwater Drains/Combined Sewers.* http://www.jica.go.jp/iraq/english/activities/pdf/training07_07.pdf (accessed October 2010).

Grundfos Commercial Building Services. 2002. http://cbs.grundfos.com/india/lexica/WW_Pumping_station.html (accessed September 2010).

Hendrickson, Chris. 2008. Quality Control and Safety During Construction. Project Management for Construction. http://pmbook.ce.cmu.edu/13_Quality_Control_and_Safety_During_Construction.html (accessed September 2010).

Insituform Technologies, Inc. 2010. Insituform Technologies: Municipal Sewers, Industrial Pipes, Water Mains, Trenchless Technology, Tunneling, Boring. http://www.idswater.com/water/us/Insituform/Municipal_Sewers/120_0/g_supplier.html (accessed September 2010).

Kaliappan, S. 2009. Treatment Process Flow Sheets. http://www.scribd.com/doc/7019099/Treatment-Process-Flow-Sheets (accessed September 2010).

Karaa, Fadi A. 1989. Infrastructure maintenance management systems development. *Journal of Professional Issues in Engineering.* 115(4): 422 - 432.

Kembla Watertech PTY LTD. 2005. Kemseal Chemical Grouting. http://www.kemblawatertech.com.au/default.asp?area=products&menuitem=9

(accessed October 2010).

Kiest Jr., L. and S.M. Flanery. 2003. Criteria for an effective lateral renewal project utilizing trenchless technology. *New Pipeline Technologies, Security and Safety.* Baltimore: American Society of Civil Engineers.

Knutson, Kraig, Christine Fiori, Clifford Schexnayder, and Richard Mayo. 2008. *Construction management fundamentals.* Tempe, AZ: McGraw-Hill Science Engineering.

Kung'u, Francis T. October 4, 1999. Sanitary sewer system rehabilitation techniques vary. *Water Online.* http://www.wateronline.com/article.mvc/Sanitary-sewer-system-rehabilitation-techniqu-0002?VNETCOOKIE=NO (accessed 2010).

Majdalani, Joseph, Bill Golloby and Sherman Irish. 2007. Corral the Grease. http://www.tawwa.org/TW07Proceedings/070411p/WWWPublicInfo/Corral%20the%20Grease_2007-04-11_130pm.pdf (accessed September 2010).

Malone II, John G. 2008. Keeping Sewage off the Streets - Insuring Lift Station Capacity for Now and the Future. http://cedb.asce.org/cgi/WWWdisplay.cgi?165926 (accessed September 2010).

Mocon Corporation. 2010. *Mocon Pipe Bursting.* http://mocontrenchless.com/id1.html (accessed September 2010).

National Pollutant Discharge Elimination System (NPDES) Permits Program. February 3, 2010. http://www.epa.gov/region6/water/npdes/index.htm (accessed September 2010).

National Utility Contractors Association. 2010. http://www.nuca.com/i4a/pages/index.cfm?pageID=1434 (accessed September

2010).

Pierce County Public Works and Utilities. 1996 - 2010. Strategic Planning and Asset Management. http://www.co.pierce.wa.us/pc/abtus/ourorg/pwu/sewer/spam.htm# (accessed October 2010).

Probe International. n.d. EPA Regulations and Oil. http://www.probeinternational.org/epareg%5B1%5D.htm (accessed September 2010).

Qasim, Syed R. 1994. *Wastewater treatment plants - planning, design, and operation.* Arlington: Technomic Publishing Company, Inc.

Rabbi, Fazle. 2007. Public Works Department. Houston: City of Houston.

Sample, David, Rob Bocarro, and Monique Latalladi. 2005. Development of an SSO Mitigation Plan: Lessons Learned from the Field. http://scitation.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=ASCECP0001730407920001760000001&idtype=cvips&gifs=yes&ref=no (accessed September 2010).

Sever, V. Firat and Barton Bradshaw. 2009. Adding value to sanitary sewers - An important asset of municipalities. http://cedb.asce.org/cgi/WWWdisplay.cgi?0906558 (accessed October 2010).

State of Texas. 2001. *Local Government Code Chapter 395.* http://www.statutes.legis.state.tx.us/SOTWDocs/LG/htm/LG.395.htm (accessed September 2010).

Sterling, Raymont L. 2001. *Guidelines for Pipe Bursting.* TTC Technical Report # 2001.02. Jadranka Simicevic.

Texas Commission on Environmental Quality. July 2006. Domestic Wastewater Permit Application: Sewage Sludge Technical Reports. http://www.tceq.state.tx.us/assets/public/permitting/waterquality/forms/10056ins.pdf (accessed September 2010).

—. April 2010. Sanitary Sewer Overflow (SSO) Initiative: Information for Prospective Participants. http://www.tceq.state.tx.us/comm_exec/forms_pubs/pubs/gi/gi-389.html (accessed September 2010).

—. August 2010. Domestic Wastewater Permit. http://www.tceq.state.tx.us/permitting/water_quality/wastewater/municipal/WQ_Domestic_Wastewater_Permits.html (accessed September 2010).

Texas Secretary of State. 2008. *Texas Administrative Code.* http://www.sos.state.tx.us/tac/index.shtml (accessed September 2010).

Texas Water Development Board. 2008. Managing the State's Water Resources Through Planning and Financing. *Financial Assistance Programs.* www.ntaep.org/NTAEP_Presentation_20080116.ppt (accessed October 2010).

Tohme, Hani. 2009. *Sanitary Sewer Overflow Initiative Annual Report.* Annual Report of the Sanitary Sewer Initiative. Beaumont, TX.

TT Technologies, Inc. 2002. http://www.tttechnologies.com/jstories/gcrack/BRENNAN/index.html (accessed September 2010).

U.S. Environmental Protection Agency. July 2002. *Complaince Inspection Manual.* http://www.epa.gov/compliance/resources/publications/monitoring/cwa/inspections/npdesinspect/npdesinspect1.pdf (accessed October 2010).

—. October 2007. Computer Tools for Sanitary Sewer System Capacity Analysis and Planning. http://www.epa.gov/ORD/NRMRL/pubs/600r07111/600r07111.pdf (accessed October 2010).

—. April 8, 2010. Eliminating Sanitary Sewer Overflows in New England. http://www.epa.gov/ne/sso/index.html (accessed October 2010).

—. February 2008. Emerging Technologies for Wastewater Treatment and In-Plant Weather Management. http://water.epa.gov/scitech/wastetech/upload/2008_03_13_mtb_emerging_technologies.pdf (accessed September 2010).

—. 1991. *EPA NPDES Permit Writers' Manual - 87.* http://www.epa.gov/npdes/pubs/chapt_06.pdf (accessed September 2010).

—. April 2002. Fact Sheet: Asset Management for Sewer Collection Systems. http://yosemite.epa.gov/water/owrccatalog.nsf/1ffc8769fdecb48085256ad3006f39fa/8e6f88d7b69d21b885256c4100538c02!OpenDocument (accessed September 2010).

—. June 1, 2010. Federal Register. http://www.epa.gov/npdes/regulations/frn_sso.pdf (accessed September 2010).

—. April 2007. Guidance for Preparing Standard Operating Procedures (SOPs). http://www.epa.gov/quality/qs-docs/g6-final.pdf (accessed October 2010).

—. January 2005. Guide for Evaluating Capacity, Management, Operation, and Maintenance (CMOM) Programs at Sanitary Sewer Collection Systems. http://www.cmom.net/cmom_guide_for_collection_systems.pdf (accessed October 2010).

—. 2003. *Handbook on Coordinating Funding for Water and Wastewater Infrastructure.* http://www.epa.gov/safewater/dwsrf/pdfs/guide_dwsrf_funding_infrastructure.pdf (accessed October 2010).

—. 1998. *National Center for Environmental Economics.* http://yosemite.epa.gov/ee/epa/ria.nsf/EIO/5009B7788ACF962E852568C60050BCD3 (accessed October 2010).

—. October 2008. National Pollutant Discharge Elimination System (NPDES). http://cfpub.epa.gov/npdes/npdesreg.cfm?program_id=45 (accessed September 2010).

—. September 2000. National Service Center for Environmental Publication (NSCEP). Collection Systems Technology Fact Sheet, Sewers, Lift Station. http://nepis.epa.gov/Exe/ZyNET.exe?Client=EPA&Index=2000+Thru+2005&Docs=&Query=%28efficiency+reflects+the+pump%29+OR+FNAME%3D%22901U0X00.txt%22+AND+FNAME%3D%22901U0X00.txt%22&FuzzyDegree=0&ZyAction=ZyActionD&User=ANONYMOUS&Password=anonymous&SortMethod=h% (accessed October 2010).

—. July 2010a. *Office of Water.* http://water.epa.gov/ (accessed September 2010).

—. July 2010b. *Office of Water.* http://www.epa.gov/owm/cwfinance/cwsrf/index.htm (accessed September 2010).

—. August 2010. Report on Condition Assessment of Wastewater Collection Systems. http://www.epa.gov/nrmrl/pubs/600r10101/600r10101.pdf (accessed October 2010).

—. October 2009. *Wastewater Treatment Works Security Act of 2009.*

http://transportation.house.gov/Media/file/water/HR%202868%20Title%20III%20Summary%20and%20SectionXSection.pdf (accessed September 2010).

—. 2009. *White Paper on Condition Assessment of Wastewater Collection Systems.* Final Report. Washington, DC: Office of Research and Development.

U.S. Government Accountability Office, *GAO.* January 2005. http://www.gao.gov/docsearch/locate?searched=1&o=0&order_by=date&search_type=publications&keyword=GAO-05-165&Submit=Search (accessed September 2010).

Vallabhaneni, Srinivas, Carl C. Chan, and Edward H. Burgess. October 2007. *Computer Tools for Sanitary Sewer System Capacity Analysis and Planning* . http://www.epa.gov/nrmrl/pubs/600r07111/600r07111.pdf (accessed 2010).

Viessman, Warren Jr., and Mark J. Hammer. 1998. *Water supply and pollution control,* 6th ed. Menlo Park, CA: Addison-Wesley.

Wikipedia. 2010a. *Pumping station.* http://en.wikipedia.org/wiki/Pumping_station (accessed September 2010).

—. 2010b. *Standard Operating Procedure.* http://en.wikipedia.org/wiki/Standard_Operating_Procedures (accessed October 2010).

York, David and Elsa Potts. 1995. Construction management. *Domestic Wastewater Treatment Plants in Florida.* http://www.fwrj.com/articles/9501.pdf (accessed September 2010).