CHAPTER 7
OPERATION, MAINTENANCE, AND REHABILITATION TECHNIQUES

A systematic operation, maintenance, and rehabilitation program is an essential element in the management of a wastewater collection system. Effective inspection, cleaning, and rehabilitation are key processes for optimizing the proper functioning of a collection system.

Information for this chapter was primarily obtained from the following sources: U.S. EPA's *Guide for Evaluating Capacity, Management, Operation, and Maintenance Programs for Sanitary Sewer Collection Systems* (DRAFT) and *Collection Systems O&M Fact Sheet Trenchless Sewer Rehabilitation,* California State University's *Collection Systems: Method for Evaluating and Improving Performance and Operation and Maintenance of Wastewater Collection Systems (Volumes I & II).*

7.1 Methods and Equipment

The following information outlines the methods and equipment frequently utilized to inspect and clean gravity collection systems and pumping stations. Frequent inspection and cleaning is essential for normal functioning and problem identification. Information is also presented regarding spare parts and equipment necessary for effective operation.

7.1.1 Gravity Collection Systems

Physical Inspection

A physical inspection is vital to an O&M program. Without it, a maintenance program cannot be implemented in a systematic way since system problems cannot be quantified. Elements of a physical inspection program include visual and equipment-based techniques that use established industry methods of system evaluation. Physical inspections should be performed on a regularly scheduled basis as a part of the preventive maintenance program.

The purpose of conducting inspections is to:

- Identify what is in the system (inventory).
- Identify the location of the system's components.
- Determine the condition of the components (assessment).
- Prevent problems from developing.

Before acceptance of a newly constructed collection system, O&M personnel should conduct a physical inspection to verify the accuracy and completeness of the record drawings. Inspection before acceptance will also ensure that the new components are clear of construction debris and rocks.

Physical inspections are performed to accomplish the following goals:

- Identify defects in the system that can contribute to or cause backups, overflows, and bypasses.
- Identify chronic problem areas so maintenance can be planned and scheduled.
- Identify defects that if not fixed will result in a future failure.
- Determine the system needs for long-term replacement and rehabilitation.
- Develop a baseline for future comparison to determine rates of deterioration.
- Assist in setting and justifying realistic user charges.

Inspection provides a detailed inventory of the system that includes size, material, condition, line sags, joint types, elevations, slopes, location of manholes and pump stations, location of building lateral connections and other system attributes that are necessary for managing the entire O&M program.

Inspection data provide location information that allows more efficient O&M planning and scheduling and emergency response. During stoppages that involve overflows and/or backups, valuable time is lost if location information is not available, increasing the risk of regulatory violations, property and environmental damage, and threats to public health and safety.

Inspection provides the data necessary for managers to make informed decisions on all maintenance, repair, and rehabilitation actions. This results in an O&M program that is effective and efficient.

The primary methods of inspection and testing include the following:

- Air testing
- Vacuum testing
- Mandrel testing
- Smoke testing
- Dye water testing
- Closed-circuit television (CCTV)
- Visual (including lamping)
- Tape measurements
- Sonic Testing

Air testing and vacuum testing can test the integrity of the sewer main line, service laterals, and manholes. Mandrel testing will indicate whether the pipe has the proper flushing and vertical and horizontal tolerances and is normally done in new pipe before placing it in service. Smoke Testing indicates sources of inflow and sometimes infiltration. Dye water testing is used to determine sources of both I/I and permitted flow where dye is introduced into the potential source and downstream manholes are observed to determine if and where it enters the system. Closed circuit television inspection will indicate pipe conditions including breaks and leaks, leaking and protruding laterals, root intrusions and other blockages including the exact locations of all features and problems. The tapes provide a visual history of the sewer for future reference and can be put on CDs for integration into a GIS system. Visual testing using manhole access both from above and below ground, sometimes with the use of mirrors, gives an inexpensive indication of blockages, pipe size, materials, and condition.

IF MANHOLES ARE ENTERED, PROPER TRAINING IN CONFINED SPACE ENTRY AND PROPER SAFETY HARNESS, TRIPOD, CALIBRATED GAS DETECTION DEVICES, AND VENTILATION EQUIPMENT ARE A MUST.

Visual and CCTV inspections will provide verification that manholes and cleanouts are on proper grade and accessible for future use. Accurate tie information and tape measurements also are used to physically locate manholes and cleanouts in case they are paved over or are otherwise concealed. Inspection records should be updated regularly to include the exact locations of service taps and property lines so that they can be located when maintenance is required in the future. Sonar-based (sonic) equipment can be used to measure the internal cross-sectional profile of sewer systems. Sonar technology is also very useful for inspecting depressed sewers (inverted siphons), where the pipe is continually full of water under pressure.

Uniform coding of the system is a requirement to track all future inspection results and compare current data to the baseline data. Each segment of sewer and each maintenance structure should have its own unique identification. Numerous computer maintenance management systems (CMMSs) are available that can manage the vast amount of sewer system data generated from inspection programs, but they all rely on unique identification of structures, main line segments, and laterals.

Routine scheduled inspection of the entire wastewater collection system is required to verify the condition of the system so that blockages and overflows can be prevented. Some agencies plan an inspection of the entire system over a period of time: for example, 20 percent of the entire system is scheduled for CCTV inspection each year. In the north, this is usually scheduled during early spring runoff and high groundwater conditions to look for sources of I/I. Priorities may be established based on age of pipe, pipe material, or other factors, which maximize the agency's resources by identifying areas with a higher probability of problems. Once the system has been completely inspected and the condition quantified, scheduled inspections are prioritized based on need and availability of resources rather than simply re-inspecting the entire system using CCTV.

Any components of the system located along streams are particularly vulnerable to the effects of rainstorms. Each sewer crossing of a stream should be inspected to be sure the sewer is not in danger of being broken. Also, the manholes on each side of the stream should be checked to see that no excess flow is taking place, which would indicate a leaking sewer under the stream. Since these sewers are often in remote locations, they are susceptible to vandalism and can overflow for long periods of time without detection.

Locking covers with adequate lid sealing is appropriate in these instances. Stream stabilization and sewer relocation can require long-range planning, design, permitting, and construction periods so it is important to identify problems as early as possible.

Cleaning

Stoppages in gravity sewers usually are caused either by structural defects or by an accumulation of material in the pipe. Accumulated material can include fats, oil, grease, sediment, or other materials. Certain structural defects, such as protruding taps, may catch debris, which then causes a further buildup of solids that will eventually block the sewer. Root intrusion through structural defects is a major contributor to blockages. Repair or elimination of any defects that contribute to a buildup of material in the pipe should be evaluated as part of a rehabilitation program since the defects will always be a maintenance problem.

Mechanical and hydraulic cleaning of sewers is a cost-effective method of removing material that interferes with the proper operation of the sewer. The objective is to remove all material clinging to the interior surface of the pipe so that the sewer pipe can carry full pipe flow without any restrictions that might result in blockages due to reduced pipe capacity.

Sewer cleaning should be scheduled on a regular cycle: for example, 100 percent of the pipes are cleaned every 1, 3, or 5 years. However, unless the cleaning schedule is adjusted to take into account the actual conditions in various parts of the collection system pipelines, routine cleaning can result in over-maintenance of the system. In most collection systems, some sections do not require frequent cleaning while other sections may require cleaning on a more frequent basis, such as monthly, if they are susceptible to blockages. Information from the inspection program should be used to help identify chronic problem areas in the gravity sewer system and related structures in the wastewater collection system, quantify defects and problem areas, and develop a preventive maintenance sewer cleaning program based on actual conditions in a particular wastewater collection system.

Cleaning is either scheduled or unscheduled. Scheduled cleaning is proactive in that cleaning is done on a preventive basis to remove material prior to a stoppage occurring. Preventive cleaning activities can be supplemented by additional cleaning on an as-needed basis in cases where predictive information such as previous history, inspection data, pipe age and material, slope, or other information indicates a need for more frequent cleaning.

Scheduled cleaning is usually coordinated with planned CCTV since televising requires a clean pipe for access and visually provides a much better picture of conditions.

Unscheduled cleaning is usually the result of a reported stoppage and is therefore reactive. When reactive maintenance is the primary form of maintenance (that is, waiting until a failure occurs before performing maintenance), it will always result in poor system performance, especially as the system ages. Normally, this type of cleaning is done on an emergency basis to clear a stoppage, restore pipe capacity to full flow, and relieve a surcharging situation in the sewer that has caused a backup into homes and/or an overflow.

Various hydraulic and mechanical methods are available for main line sewer cleaning. Hydraulic cleaning methods include equipment that uses water and water velocity to clean the invert and walls of the sewer pipe. Mechanical cleaning methods use equipment to physically remove the material from the walls and invert of the sewer pipe.

A. Hydraulic Cleaning

High-Velocity Cleaners

High-velocity cleaners are very efficient machines that provide the most flexibility with the least personnel required. A high-pressure stream of water is aimed at the surface to be cleaned.

High-velocity cleaners can either be truck mounted or trailer mounted; in either case, they are designed as self-contained units for maximum efficiency.

All tools required to route traffic, remove manhole covers, and for safety of the job site are carried on the truck, as are the various nozzles and hoses required for proper operation.

The removal of debris from the sewer usually requires two operators on the normal high-velocity machine, but some agencies operate with a one-person crew in certain situations. Under these circumstances, additional crewmembers should be available nearby if needed.

An enhancement to the high-velocity machine is the addition of a vacuum unit for removal of debris from the manhole. When sand, silt, and other material are brought back to the manhole, it can be removed easily with the vacuum unit instead of manually removing it. When a vacuum unit is combined with a high-velocity cleaner on the same vehicle, it is frequently referred to as a combination machine.

Another advantage of larger high-velocity cleaners is the availability of root cutters. This device is basically a flat blade that attaches to the end of the nozzle. Pressure from the high-velocity stream of water spins the cutting blade causing it to cut through roots as it passes through the sewer. With the addition of root cutters, high-velocity cleaners are capable of cleaning every type of debris from a sewer main. High-velocity cleaners are the most frequently used equipment for sewer maintenance.

It is important to remove sand and gravel at the nearest downstream manhole as flushing progresses. If it is washed downstream, it can create even greater problems at pumping stations and treatment plants.

There are other devices (balls, kites, bags, parachutes, scooters, etc.) that can be used to improve performance of hydraulic cleaners, particularly in large gravity sewers where high-velocity cleaners are not as effective. These devices use water pressure behind the tool to develop hydraulic water pressure and scour the pipe as the tool moves through the pipe.

Most small to medium size systems and many larger systems subcontract cleaning and televising to specialists who have the proper tools and training to not only clean and televise, but seal and grout leaks and cut off protruding service connections.

B. Mechanical Cleaning

Rodders

Mechanical cleaning means the use of some type of physical device that scrapes, cuts, or pulls material from the main line gravity sewer. The original method, called hand rodding, is the oldest and most labor-intensive method of mechanical cleaning. Small engine-powered rodding machines are now available. These machines are very inexpensive and provide a very effective method of cleaning in smaller systems and also in remote easements or right-of-way areas where large equipment cannot gain access.

Larger mechanical power rodders are equipped with a reel to carry the steel rods and an engine to provide the force to rotate, push, and pull the steel rods. Power rodders are available in both truck-mounted and trailer-mounted models and a variety of different engine sizes are available for each type of unit.

Truck-mounted rodders can travel more quickly than trailer-mounted rodders, which must be towed to the work location. Also, truck-mounted units have the advantage of offering power takeoff capability. Some disadvantages of truck-mounted units are their limited maneuverability and the fact that if the rodder breaks down, the truck cannot be used for any other purpose while repairs are made. With a trailer-mounted unit, the truck can be used for other purposes when the power rodder is not in use. Also, the trailer-mounted unit costs less.

Power rodders can clear most obstructions in a sewer main. The rodder is effective in cleaning roots and grease as well as cleaning or opening stoppages in the main line. The power rodder is not as effective when working with deposits of solids such as sand or gravel because the tools do not have the ability to move the material. The tools are designed to cut or scrape materials from the pipe walls and are most effective on hardened grease and roots.

Power rodders are usually less expensive than high-velocity or combination machines. However, power rodders do involve more setup time than high-velocity cleaners. Power rodders normally must have drivable surfaces to operate efficiently; in extreme cases, a trailer-mounted unit can be hauled into off-road situations by using a backhoe to pull it along. Both the power rodder and the high-velocity cleaner must have well-trained operators. Either machine can seriously injure operators or damage the sewer main if it is not operated properly.

Bucket Machine

Power bucket machines are another type of mechanical cleaning device; they are used to remove debris, roots, grease, or sediments from main line sewers. A bucket machine is equipped with a set of specialized winches that pull a special bucket through a pipe to collect debris. The captured materials are then physically removed from the pipe.

These machines are very powerful and offer the best cleaning product with the least opportunity for operator error that could affect the results. Since a full-size cutter and brush can be pulled through the line, each cleaning should be thorough and no residual debris should be left in the sewer main. Operating bucket machines is a very labor-intensive process; therefore, power buckets are normally used only for specific cleaning purposes, especially removing large amounts of debris from larger sewers.

Cable Machines

Cable machines are extremely effective in larger diameter sewers where the other equipment is less effective. They operate similar to bucket machines except a winch is usually truck-mounted. The normal procedure is to pull a cable through the main line sewer from one manhole to the next, attach a cutter, brush, or bucket to the cable, and pull it back through the sewer to clear any grease, roots, sludge, sand, or gravel from the sewer.

There are two types of cable machines. Double-drum machines allow you to operate from one manhole but require a cable to be laid over the ground surface, which can cause safety concerns. Single-drum machines require setup at both manholes but all activity takes place below the surface. Cable drag operations are labor intensive and involve the longest setup time to complete the work. However, there are still specialized conditions that make this cleaning operation the best for a particular situation.

With any mechanical cleaning equipment, the operator must know where plastic pipe has been installed in the wastewater collection system. High-velocity cleaning machines are least likely to damage a plastic pipe system. Power rodders can be used carefully to remove obstructions, but there is always the possibility of damaging the pipe wall if the cutter is suddenly deflected off the blockage and into the pipe wall. Mechanical cleaning tools such as cutters and brushes should not be used in plastic pipe since they can score the pipe and reduce the flow characteristics by increasing the pipe wall roughness. A suitable pipe identification system should be in place to warn the operator where plastic pipe has been installed. Generally speaking, high velocity flushing is the method of choice for most sewer cleaning programs.

C. Chemical Cleaning

Several chemicals and application methods are available to kill and retard the regrowth of roots in the wastewater collection system. Methods of application include foaming, dusting and liquid application. Special equipment is required for all three application methods. If the problem is roots alone, chemical treatment is a very cost-effective method of cleaning

Grease can also be cleaned from sewers by the addition of chemicals or by bioaugmentation (addition of bacteria to speed up the breakdown of grease). Various chemicals are available, such as enzymes, hydroxides, caustics, biocides, and neutralizers, for removing and/or controlling grease buildups. The effectiveness of a particular chemical depends largely on the exact nature of the problem and site-specific circumstances. In most cases, these compounds tend to be an expensive method of treatment if they are applied routinely on an ongoing basis. If the grease is not removed at the source, it can create additional problems downstream at the pumping stations and treatment plants. An effective grease control ordinance is an important part of any service program.

> Specialized training must be provided for personnel who are at any time involved in the handling and application of chemicals. In addition, proper care must be taken to protect the public and the environment from any adverse effects. Chemical reactions frequently produce gases as a product of the reaction. Proper ventilating and control of these potentially hazardous gases must be planned. Because of the extreme safety requirements and cost of the chemicals, traditional hydraulic and mechanical cleaning methods are more cost-effective for most situations. When applying chemicals for any reason, you should always notify the receiving wastewater treatment facility of the type of chemical, quantity used, and time of application.

7.1.2 Pump Stations and Force Mains

Operation, maintenance and repair of pump stations require special electrical, hydraulic and mechanical knowledge. Proper design, construction and operator training are also important. All pump stations (with the exception of those continuously staffed and very small pump stations) should be equipped with secondary power and at least the most basic telemetry system, one which transmits a high and low water level alarm to a central location. Even very small pump stations should be equipped with an audible/visual high water alarm.

A pump station maintenance program should be based on two factors. The first is the equipment manufacturers' recommendations for such activities as lubrication of bearings, oil changes, and parts replacement. The manufacturers' recommendations should be followed closely during the warranty period to avoid invalidating the warranty. In general, they should be followed closely thereafter as well. The collection system authority should be able to readily produce the manufacturers' recommended maintenance schedules in the original manuals.

The second factor is the specific requirements of the individual pump station. These are items developed by the operators and their supervisors that are based on observations of the pump station and also include knowledge gained by experience of local conditions. Extremes of heat or cold may require the use of lubricants different than those in more temperate climates.

Pump stations should be subject to inspection and preventative maintenance on a regular schedule. The frequency of inspection may vary from once per week for a reliable pump station equipped with a telemetry system to a continuously staffed large pump station. A checklist should be established to ensure that proper inspection and maintenance procedures are routinely followed. The basic inspection should include verification that alarm systems are operating properly, wet well levels are properly set, all indicator lights and voltage readings are within acceptable limits, suction and discharge pressures are within normal limits, and that the pumps are running without excessive heat or vibration and have the required amount of lubrication. Less frequent inspections may include such items as vibration analysis, infrared photography, and internal inspection of pump components. Occasionally a supervisor should perform an unscheduled inspection to confirm that tasks have been performed as expected.

A typical weekly pump station inspection should include observations of the following:

- The components comprising the alarm system, i.e., the wet well controller and electrical system. Note how the pumps are sequenced.
- The pumps: bearings, packing, seals, suction and discharge gauge pressures.
- The pump motors: temperature, amperage and voltage, coupling and alignment, vibration and noise.
- Valves: check and pressure relief.
- Oil levels and lubrication.
- Belt wear and tightness.
- Emergency generator (exercise under load—if present).

Many pumping stations are considered confined spaces and should be entered by only trained authorized personnel using the required safety equipment. The station's ventilation system and gas detection equipment need to be checked and calibrated regularly.

Force Mains

Force mains are pipelines that convey wastewater under pressure from the discharge side of a pump or pneumatic ejector to a discharge point. Pumps or compressors located in a lift station provide the energy for wastewater conveyance in force mains. Force mains are very reliable when they are properly designed and maintained. In general, force main reliability and useful life are comparable to that of gravity sewer lines, but pipeline reliability may be compromised by excessive pressure surges, corrosion, or lack of routine maintenance.

Pressure surges are abrupt increases in operating pressure in force mains, which typically occur during pump start-up and shut-off. Pressure surges may have negative effects on force main integrity but can be reduced by proper pump station and pipeline design. Pressure surge control devices can be installed to reduce pipeline pressure below a safe operating pressure during lift station start-up and shut-off.

Force mains are constructed from various materials and come in a wide range of diameters. Wastewater characteristics govern the selection of the most suitable pipe material. Operating pressure and corrosion resistance also impact the choice. Ductile iron and polyvinyl chloride (PVC) are the most frequently used materials for wastewater force mains. Corrosion-resistant plastic lined piping systems are used for certain waste carrying applications. Polyethylene-lined ductile iron pipe and fittings known as "poly-bond-lined" pipe are widely used for force mains conveying highly corrosive industrial or municipal wastewater.

The types of thermoplastic pipe materials used for force main service are PVC, acrylonitrile-butadiene-styrene (ABS), and polyethylene (PE). The use of composite material pipes, such as fiberglass reinforced mortar pipe ("truss pipe"), is increasing in the construction of force mains. A truss pipe is constructed of concentric ABS cylinders with annular space filled with cement. Pipe fabricated of fiberglass reinforced epoxy resin is almost as strong as steel, as well as corrosion and abrasion resistant.

The dissolved oxygen content of the wastewater is often depleted in the wet-well of the lift station, and its subsequent passage through the force main results in the discharge of septic wastewater, which not only lacks oxygen but often contains sulfides. Frequent cleaning and maintenance of force mains is required to remove solids and grease buildup and minimize corrosion due to the high concentration of sulfides.

The operation of force main-lift station systems is usually automated and does not require continuous on-site operator presence. However, annual force main route inspections are recommended to ensure normal functioning and to identify potential problems.

Special attention should be given to the integrity of the force main surface and pipeline connections, unusual noise, vibration, pipe and pipe joint leakage and displacement, valve arrangement and leakage, lift station operation and performance, discharge pump rates and pump speed, and pump suction and discharge pressures.

One common method of determining the condition of the force main is by routine pump station calibration. If this is done on an annual basis, any changes in capacity and discharge head in the pump station can be identified. Because these changes could also be attributed to pump wear, it is essential to verify that the pumps are in good working order before determining that the force main needs cleaning.

The most common method of cleaning force mains is by use of polyurethane swabs, which are better known as “poly pigs.” Poly pigs are available in various densities and surface coatings. To use this method, poly pigs are inserted into the pipeline, which is then pressurized behind the pig. As the device travels through the force main it scours the inside of the pipe.

Normally, the use of poly pigs requires that the pump station be temporarily shut down. Provisions must be made for handling incoming wastewater, either through bypass pumping or by providing adequate short-term storage.

A launching point must be available for insertion of the pig and access at the discharge end of the force main must be available for removing the pig. Insertion facilities can be located within the pump station. Several launching and retrieval stations are usually provided in long force mains to facilitate cleaning the pipeline.

The following factors should be considered when using poly pigs to clean force mains:

- Provisions must be made for bypassing the pump station or providing alternative wastewater storage while the force main is being cleaned.
- A launching station must be provided, either in the pump station or at the beginning of the force main.
- External pumps and a water supply are needed to propel the pig through the force main.

- The force main must be drained any time it is worked on.
- Provisions must be made to track the pig through the force main in case it gets hung up and can not be removed except by digging up the pipeline.
- The debris removed by the cleaning operation must be collected and taken to an appropriate disposal site.

7.1.3 Siphons

Sewage siphons, which are designed to convey wastewater under low areas (such as the bed of a stream or river) without the use of pumps, are critical components in some collection systems. Siphons are relatively simple devices that are made up of an inlet and outlet chamber connected by closed pipes or conduits through which wastewater flows under pressure. The driving force causing wastewater to flow is the hydraulic head in the inlet chamber. The individual pressurized pipes or conduits are normally smaller in diameter than the gravity system they are serving, causing the wastewater to flow at higher velocities. The higher velocity serves to keep heavier solids normally found in wastewater in suspension, avoiding (in theory) the deposition of solids that could otherwise accumulate in the pressurized pipes and interfere with the free flow of the wastewater.

Siphons are typically constructed with multiple pipes or conduits so that the number in active use can be matched to the range of wastewater flow being conveyed. This also provides redundancy in the event of a blockage in one of the pipes. Typically, there is a need for frequent siphon monitoring and maintenance due to the probability of solids deposition. In some collection systems siphons can be a “known problem area” requiring elevated levels of monitoring and maintenance in order to prevent chronic overflows.

7.1.4 Alternative Collection Systems

Alternative wastewater collection systems are often implemented in situations where conventional wastewater collection systems are not feasible. Alternative collection systems include vacuum systems, small diameter gravity sewers, and pressure systems, which include septic tank effluent pump (STEP) systems and grinder pump (GP) systems.

A common need of all alternative collection systems is proper administration and management. Since the needs of these technologies are different from conventional collection systems, operation and maintenance staff members must be properly trained in the particular needs of the type of system employed.

Vacuum Systems use differential air pressure to move wastewater. This requires a central source of power to run vacuum pumps, which maintain vacuum within a system of collection mains. Pipe sizes generally range from 6 inches to 10 inches in diameter, with 4-inch lines used only for short runs on branch lines. Line profiles are carefully controlled, with the majority of the pipeline having a positive (downhill) slope. Uphill transport is achieved by using a saw-tooth profile.

The system requires a normally closed vacuum/gravity interface valve at each entry point to seal the lines so that vacuum is maintained. These valves, located in a pit, open when a predetermined amount of wastewater accumulates in a collection sump. The resulting differential pressure becomes the driving force that propels the wastewater towards the vacuum station.

Vacuum mains are typically installed at shallow depths (4 to 6 feet deep) in public streets. Isolation valves should be strategically located throughout the vacuum system in order to isolate sections of the system for maintenance. When there is an operational problem in the system, including cracks or breaks in the piping system, a drop in vacuum pressure is indicated at the vacuum station. Isolation valves are then used to systematically locate the area that is causing the pressure loss. Repairs to damaged piping can then be completed while the system is still under vacuum, maintaining service while the repairs are made.

Aside from the gravity service connection, the system is a closed system, minimizing infiltration. There are no manholes in a vacuum system and flushing connections are typically not needed since high velocities in vacuum mains (15-20 feet per second) prevent the accumulation of debris.

Small Diameter Gravity Sewers (SDGS) convey effluent by gravity from an interceptor tank (or septic tank) to a centralized treatment location or pump station for transfer to another collection system or treatment facility. These systems generally use smaller diameter pipes with a slight slope or follow the surface contour of the land, reducing the amount of excavation and construction costs.

Most suspended solids are removed from the wastestream by septic tanks, reducing the potential for clogging to occur and allowing for smaller diameter piping both downstream of the septic tank in the lateral and in the sewer main. Cleanouts are used to provide access for flushing; manholes are rarely used. Air release risers are required at or slightly downstream of summits in the sewer profile. Odor control is important at all access points since the SDGS carries odorous septic tank effluent.

Because of the small diameters and flexible slope and alignment of the SDGS, excavation depths and volumes are typically much smaller than with conventional sewers. Minimum pipe diameters can be three inches. Plastic pipe is typically used because it is economical in small sizes and resists corrosion.

The operation and maintenance requirements for SDGS systems are usually low, especially if there are no lift stations. Periodic flushing of low-velocity segments of the collector mains may be required. The septic tanks must be pumped periodically to prevent solids from entering the collector mains. Disposing of collected septage from septic tanks is probably the most complex aspect of the SDGS system and should be carried out by local authorities. However, many tanks are installed on private property requiring easement agreements for local authorities to gain access. Contracting to carry out these functions is an option, as long as the local authorities retain enforceable power to ensure compliance with maintenance requirements.

Where lift stations are used, such as in low lying areas where wastewater is collected from multiple sources, they should be checked on a daily or weekly basis. A daily log should be kept of all operational inspections, maintenance performed, and service calls. Regular flow monitoring is useful to evaluate whether inflow and infiltration problems are developing. The municipality or sewer utility should be responsible for operation and maintenance of all of the SDGS system components to ensure a high degree of system reliability.

Pressure Systems are particularly adaptable for rural or semi-rural communities where public contact with effluent from failing drain fields presents a substantial health concern. Since the mains for pressure systems are, by design, watertight, the pipe connections ensure minimal leakage of wastewater. This can be an important consideration in areas subject to groundwater contamination. Two major types of pressure systems are the STEP system and the GP system.

In STEP systems, wastewater flows into a conventional septic tank to capture solids. The liquid effluent flows to a holding tank containing a pump and control devices. The effluent is then pumped and transferred for treatment.

In a GP system, sewage flows to a vault where a grinder pump grinds the solids and discharges the sewage into a pressurized pipe system. GP systems do not require a septic tank but may require more horsepower than STEP systems because of the grinding action.

Annual preventive maintenance calls are usually scheduled for GP components of pressure sewers. STEP systems also require pump-out of septic tanks at two to three year intervals. Public education is necessary so the user knows how to deal with emergencies and how to avoid blockages or other maintenance problems.

Odors and corrosion are potential problems because the wastewater in the collection sewers is usually septic. Proper ventilation and odor control must be provided in the design and non-corrosive components should be used. Air release valves are often vented to soil beds to minimize odor problems and special discharge and treatment designs are required to avoid terminal discharge problems. The inherent septic nature of wastewater in pressure sewers requires that system personnel take appropriate safety precautions when performing maintenance to minimize exposure to toxic gases, such as hydrogen sulfide, which may be present in the sewer lines, pump vaults, or septic tanks.

Most system maintenance activities involve responding to homeowner service calls, usually for electrical control problems or pump blockages. Generally, it is in the best interest of the municipality and the homeowners to have the municipality or sewer utility assume responsibility for maintaining all system components. General easement agreements are needed to permit access to on-site components, such as septic tanks, STEP units, or GP units on private property.

7.1.5 Spare Parts and Equipment

The collection system authority must maintain an adequate inventory of spare parts, equipment, and supplies. Without such an inventory, the collection system may experience long down times or periods of inefficient operation in the event of a breakdown or malfunction. The inventory should contain information from the equipment manufacturer's recommendations, supplemented by historical experience with maintenance and equipment problems.

A review of the equipment and manufacturer's manuals will aid in determining what spare parts should be maintained. The authority should then consider the frequency of usage of the part, how critical the part is, and finally how difficult the part is to obtain when determining how many to have on hand. Spare parts should be kept in a clean, well-protected stock room. The authority should have a procedure for determining which spare parts are critical. *Critical parts* are those that are essential to the operation of the collection system. Like equipment and tools management, a tracking system should be in place, including procedures on logging out materials when maintenance personnel must use them.

7.2 Rehabilitation Options

The objective of sewer rehabilitation is to maintain the overall viability of a conveyance system. This is done in four ways: (1) by ensuring its structural integrity, (2) limiting the loss of conveyance and wastewater treatment capacity through reducing infiltration and inflow, (3) limiting the potential for groundwater contamination through controlling exfiltration from the wastewater collection system, and (4) limiting the potential for sewer backups and overflows by maintaining pipeline integrity.

There are many rehabilitation methods. The choice of methods will depend on pipe size, type, location, dimensional changes, sewer flow, material deposition, surface conditions, severity of I/I and other physical factors. Non-structural repairs typically involve the sealing of leaking joints in otherwise sound pipe and manholes. Pull-through packer systems are used to test (using air pressure), inject a variety of chemical grouts into leaking joints, and then retest sealed joints, all without excavation. Elastomer sealing rings may also be placed (typically in larger pipes) to seal joints. Specialized equipment is also used to seal leaking joints in service laterals and at the point of connection of those laterals to the sewer main as well as in manhole joints and around covers and frames.

Structural repairs involve either the replacement of all or a portion of a sewer line, or the lining of the sewer. These repairs can be carried out by excavating (common for repairs limited to one or two pipe segments; these are known as point repairs) or by trenchless technologies (in which repair is carried out via existing manholes or a limited number of access excavations). These include *slip lining* (in which a smooth plastic liner is pulled through the pipe), cured-in-place-pipe (CIPP) technologies (in which a resin-soaked felt liner is "inverted" into the pipe and cured in place), and *fold-and-form technologies* (in which a heated plastic liner is folded, pulled into place, and then expanded and allowed to harden). A variation of slip lining is *pipe bursting,* in which a bursting head is pulled through the existing pipe, bursting it, and at the same time pulling a continuous replacement pipe through the resulting "hole in the ground." A benefit of pipe bursting is that it can be used to increase the diameter of the new pipe. These technologies all create a smooth, continuous, and generally leak-free "pipe-within-a-pipe."

7.2.1 Choosing the Best Option

Trenchless sewer rehabilitation methods are now routinely applied to wastewater collection system improvement projects in the United States and many other countries. While trenchless techniques may be applied to rehabilitate existing pipelines in a variety of conditions, they are particularly valuable in urban environments where construction impacts are disruptive to businesses, homeowners, and automotive and pedestrian traffic. Other underground utilities and existing infrastructure are an obstacle in the traditional dig-and-replace method, and trenchless techniques are widely applied where these are present. Most trenchless techniques are applicable to both gravity and pressure pipelines. Many trenchless methods are capable of performing spot repairs as well as manhole-to-manhole lining.

For most applications, trenchless sewer rehabilitation techniques require less installation time and therefore less pump-around time than traditional dig-and-replace methods. Installation time can be critical in deciding between trenchless sewer rehabilitation methods and dig-and-replace methods. Trenchless sewer rehabilitation, with the potential to reduce surface disturbance over traditional dig-and-replace methods, can reduce the number of traffic and pedestrian detours, minimize tree removal, decrease construction noise, and reduce air pollution from construction equipment. In addition to these benefits, reducing the amount of underground construction labor and surface construction zone area confines work zones to a limited number of access points, reducing the area where safety concerns must be identified and secured. On the downside there is less control of line and grade for gravity sewers and additional opportunity for extra expenses due to utility interferences and breaks and soil problems including rocks, ledge and clay.

Trenchless sewer rehabilitation can be performed to increase the hydraulic capacity of the collection system. While pipe bursting typically yields the largest increase in hydraulic capacity, rehabilitation by other trenchless methods may also increase hydraulic capacity by reducing friction. A hydraulic analysis of the pre- and post-rehabilitation conditions can be performed to evaluate the impact on collection system capacity.

The sliplining, deform-and-reform methods, and CIPP methods will reduce the pipe diameter, tending to decrease the hydraulic capacity of the sewer. The rehabilitated pipeline, however, may be less rough than the original. The roughness coefficient depends on the liner material. New high performance plastic materials tend to reduce pipe roughness compared to aged concrete materials.

In any sewer rehabilitation program, the hydraulic capacity may be modified as groundwater intrusion is inadvertently redirected to unlined side sewers and house services.

7.2.2 Cost Considerations

Sewer rehabilitation by both trenchless and traditional dig-and-replace methods can reduce treatment and O&M costs at the receiving treatment plant. In addition to treatment cost savings, energy costs for transporting flows to the treatment plant could also be reduced due to the reduced flow volume.

A cost comparison of trenchless and traditional sewer rehabilitation methods must consider the condition and site characteristics of the existing pipeline. Factors influencing the cost of a trenchless sewer rehabilitation project include:

- The diameter of the pipe.
- The amount of pipe to be rehabilitated.
- Specific defects in the pipe, such as offset joints, root intrusions, severe cracking or other defects.
- The depth of the pipe to be replaced and changes in grade over the pipe length.
- The locations of access manholes.
- The number of additional access points that need to be excavated.
- The location of other utilities and structures that have to be avoided during construction.
- Provisions for flow by-pass.
- The number of service connections that need to be reinstated.
- The number of directional changes at access manholes.
- The soil's characteristics.

In general, the greater the amount of excavation required for a rehabilitation operation, the more cost-effective trenchless sewer rehabilitation becomes as compared with the traditional dig-and-replace method.

7.3 Hydrogen Sulfide Issues

Hydrogen sulfide is generated by anaerobic bacteria in slow moving wastewater such as that which sits in a long force main or a pump station wet well or conditions such as low pH or high temperature. The hydrogen sulfide is released when the wastewater undergoes turbulence or aeration. The hydrogen sulfide is converted to sulfuric acid by other bacteria on the pipe wall and corrosion of the pipe wall begins to take place. Hydrogen sulfide is a major source of odors and corrosion in collection systems. Hydrogen sulfide corrosion may cause structural failure of the affected component. Hydrogen sulfide smells like rotten eggs but quickly numbs the sense of smell so that it can no longer be detected.

HYDROGEN SULFIDE IS AN ACUTELY TOXIC MATERIAL THAT IS DANGEROUS TO HUMAN HEALTH AND HAS BEEN RESPONSIBLE FOR THE DEATHS OF A NUMBER OF COLLECTION SYSTEM WORKERS.

Hydrogen sulfide is heavier than air and therefore can be found in the lower portion of manholes. This deadly gas, whose toxicity has been ranked with hydrogen cyanide, is colorless and has a characteristic rotten egg smell at low concentrations. As the level of hydrogen sulfide increases, workers are generally unaware of its presence. A person’s ability to sense dangerous concentrations by smell is quickly lost. If the concentration is high enough, unconsciousness will come suddenly, followed by death if there is not a prompt rescue. It is essential that a collection system utility’s safety program contain procedures and training for monitoring for hydrogen sulfide and confined space entry.

The collection system utility should have a program under which it monitors areas of the collection system which may be vulnerable to the adverse effects of hydrogen sulfide. It may be possible to perform visual inspections of these areas. The records should note such items as the condition of metal components, the presence of exposed rebar (metal reinforcement in concrete), copper sulfate coating on copper pipes and electrical components, and loss of concrete from the pipe crown or walls.

Coupons may be installed in structures or pipelines believed to be potentially subject to corrosion. Coupons are small pieces of steel inserted into the area and measured periodically to determine whether corrosion is occurring. The collection system utility should be aware that a system in which infiltration and inflow has successfully been reduced may actually face an increased risk of corrosion since the reduction of flow through the pipes allows un-submerged conditions to occur and acid to be deposited.

Collection systems vary widely in their vulnerability to hydrogen sulfide corrosion. Vitrified clay and plastic pipes are very resistant to hydrogen sulfide corrosion. Concrete, steel and iron pipes are susceptible to hydrogen sulfide corrosion. The physical aspects of the collection system are also important. A terrain that encourages the wastewater to move at a higher velocity will be freer of hydrogen sulfide than one where the wastewater may experience longer detention times in the pipes. Therefore, some systems may need a more comprehensive corrosion control program while some might limit observations to vulnerable points.

7.4 Pumps, Motors, and Efficiency

According to the U.S. Department of Energy, pump systems account for nearly 20 percent of the world's electrical energy demand and range from 20-50 percent of the energy usage in certain plant operations.

Although pumps are typically purchased as individual components, they provide a service only when operating as part of a system. The energy and materials used by a system depend on the design of the pump, the design of the installation, and the way the system is operated. These factors are interdependent. What's more, they must be carefully matched to each other, and remain so throughout their working lives to ensure the lowest energy and maintenance costs, the longest equipment life, and other benefits. The initial purchase price is a small part of the life cycle for higher usage pumps. While operating requirements may sometimes override energy cost considerations, an optimum solution is still possible.

Conservative engineering practices often result in the specification, purchase, and installation of pumps that exceed requirements of the system. Engineers often include a margin of safety in sizing pumps to compensate for uncertainties in the design process. Anticipated system capacity expansions and potential fouling effects add to the tendency to source pumps that are "one size up" from those that meet the system requirements.

Unfortunately, over-sizing pumps adds to system operation costs both in terms of energy and maintenance requirements—costs that are often overlooked during the system specification process. Since many of these operating and maintenance costs are avoidable, correcting an oversized pump can be a cost-effective system improvement.

Most pumps are driven by electric motors. Although some pumps are driven by direct current (DC) motors, the low cost and high reliability of alternating current (AC) motors make them the most common type of pump prime mover. In recent years, largely due to efforts of the Department of Energy, the efficiencies of many types of AC motors have improved. In high run time applications, improved motor efficiencies can significantly reduce operating costs. However, a more important aspect to minimizing operating costs is a "systems approach" that uses proper component sizing and effective maintenance practices to avoid unnecessary energy consumption.

Pump speed adjustments provide the most efficient means of controlling pump flow. Adjustable speed drives—specifically, variable frequency drives (VFDs)—allow pump speed adjustments over a continuous range. VFDs adjust the electrical frequency of the power supplied to a motor to change the motors rotational speed. For many systems, VFDs offer a means to improve pump operating efficiency despite changes in operating conditions. This efficiency response provides an essential cost advantage; by keeping the operating efficiency as high as possible across variations in the system's flow demands, the energy and maintenance costs of the pump can be significantly reduced. VFDs can also decrease energy losses by lowering overall system flow or head. By slowing the pump and lessening the amount of fluid energy imparted to the system when it is not needed, VFDs offer substantial savings with respect to the cost per gallon of liquid pumped.

A greater understanding of all the components that make up the total cost of ownership will provide an opportunity to dramatically reduce energy, operational, and maintenance costs. Reducing energy consumption and waste also has important environmental benefits.

7.5 More Information

Additional information concerning odor and corrosion from hydrogen sulfide is available in the following EPA guidance document: *Design Manual: Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants.* EPA No. 625-1-85-018, October 1985.

Additional information pertaining to motor and pump energy efficiency can be obtained from the U.S. Department of Energy's Office of Industrial Technologies website: *www.oit.doe.gov.*

Two helpful, free software packages are available. *MotorMaster + 4.0* is used to identify inefficient or oversized facility motors and compute the energy and demand savings associated with selection of a replacement energy-efficient model. *Pumping System Assessment Tool* (PSAT) helps users assess the efficiency of pumping system operations. Both can be downloaded from *www.oit.doe.gov/bestpractices/software_tools.shtm.*

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