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ALTERNATIVE CONVEYANCE SYSTEMS

SMALL DIAMETER GRAVITY SEWERS

Prepared for
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August 1990

CHAPTER 1

OVERVIEW OF ALTERNATIVE CONVEYANCE SYSTEMS

INTRODUCTION

Small Diameter Gravity Sewers

Description

Small diameter gravity sewers (SDGS) are rapidly gaining popularity in unsewered areas because of their low construction costs. Unlike conventional sewers, primary treatment is provided at each connection and only the settled wastewater is collected. Grit, grease and other troublesome solids which might cause obstructions in the collector mains are separated from the waste flow and retained in interceptor tanks installed upstream of each connection (Figure 1.1). With the solids removed, the collector mains need not be designed to carry solids as conventional sewers must be. Large diameter pipes designed with straight alignment and uniform gradients to maintain self-cleansing velocities are not necessary. Instead, the collector mains may be smaller in diameter, laid with variable or inflective gradients and have fewer manholes. Construction costs are reduced because SDGS may be laid to follow the topography more closely than conventional sewers and routed around most obstacles within their path without installing manholes. The interceptor tanks are an integral part of the system. They are typically located on private property, but usually owned by the utility districts so that regular pumping to remove the accumulated solids for safe disposal is ensured.

Small diameter gravity sewers (SDGS) were first constructed in Australia in the 1960's. They were used to provide a more cost effective solution than conventional gravity sewers to correct problems with failing septic tank systems in densely developed urban fringe areas. The SDGS were designed to collect the effluent from existing septic tanks. Since the tanks would remove the suspended solids that might settle or otherwise cause obstructions in the mains, smaller collector mains 100 mm (4 in) in diameter, laid on a uniform gradient sufficient to maintain only a 0.45 m/s (1.5 ft/s) flow velocity were permitted. This alternative proved to reduce construction costs by 30 to 65%. Routine maintenance also proved to be low in cost. As a result, by 1986 over 80 systems had been constructed with up to 4,000 connections per scheme (Laver, 1975; South Australia Health Commission, 1986; Tucker, 1989).

In the United States, small diameter gravity sewers were not introduced until the mid-1970's (Otis, 1986). The first systems, located in Mt. Andrew, Alabama and Westboro, Wisconsin, were small demonstration systems with 13 and 90 connections respectively. The Mt. Andrew system was constructed as a variable grade system with sections of sewer depressed below the static hydraulic grade line (Simmons,et al.,1982). The Westboro system was designed with uniform gradients using the more conservative Australian guidelines (Otis, 1978). The Westboro system proved to be 30% less costly than conventional sewers.

As knowledge of the success of these systems spread, SDGS began to gain acceptance and by the mid-1980's, over 100 systems had been constructed (US EPA, 1986). The designs of most of the systems constructed prior to

1990 followed the Australian guidelines, but as experience has been gained, engineers are finding that the guidelines can be relaxed without sacrificing performance or increasing maintenance costs. Variable grade systems in which the sewers are allowed to operate in a surcharged condition are becoming more common. Minimum flow velocities are no longer considered as a design criterion. Instead, the design is based on the system's capacity to carry the expected peak flows without raising the hydraulic grade line above the interceptor outlet inverts for extended periods of time. Inflective gradients are allowed such that sections of the mains are depressed below the static hydraulic grade line. Despite these significant changes from the Australian guidelines, operation and maintenance costs have not increased.

Small diameter gravity sewer systems consist of: a) house connections; b) interceptor tanks; c) service laterals; d) collector mains; e) cleanouts, manholes and vents; and f) lift stations.

a) **House Connections** are made at the inlet to the interceptor tank. All household wastewaters enter the system at this point.

b) **Interceptor Tanks** are buried, vented, watertight tanks with baffled inlets and outlets. They are designed to remove both floating and settleable solids from the waste stream through quiescent settling over a period of 12 to 24 hours. Ample volume is also provided for storage of the solids which must be periodically removed through an access port. Typically, a single-chamber septic tank, which is vented through the house plumbing stack vent, is used as an interceptor tank.

c) **Service Laterals** connect the interceptor tank with the collector main. Typically, they are 75-100 mm (3-4 in) in diameter, but should be no larger than the collector main to which they are connected, They may include a check valve or other backflow prevention device near the connection to the main.

c) **Collector Mains** are small diameter plastic pipes with typical minimum diameters of 75 to 100 mm (3-4 in), although 30 mm (1.25 in) pipe has been used successfully. The mains are trenched into the ground at a depth sufficient to collect the settled wastewater from most connections by gravity. Unlike conventional gravity sewers, small diameter gravity sewers are not necessarily laid on an uniform gradient with straight alignment between cleanouts or manholes. In places, the mains may be depressed below the hydraulic grade line. Also, the alignment may be curvilinear between manholes and cleanouts to avoid obstacles in the path of the sewers.

d) **Cleanouts, Manholes and Vents** provide access to the collector mains for inspection and maintenance. In most circumstances, cleanouts are preferable to manholes because they are less costly and can be more tightly sealed to eliminate most infiltration and grit which commonly enter through manholes. Vents are necessary to maintain free-flowing conditions in the mains. Vents in the household plumbing are sufficient except where depressed sewer sections exist. In such cases, air release valves or ventilated cleanouts are necessary at the high points of the main.

e) **Lift Stations** are necessary where elevation differences do not permit gravity flow. Either STEP units (See Pressure Sewer Systems) or mainline lift stations may be used. STEP units are small lift stations installed to pump wastewater from one or a small cluster of connections to the collector main, while a mainline lift station is used to service all connections in a larger drainage basin.

Although the term "small diameter gravity sewers" has become commonly accepted, it is not an accurate description of the system, since the mains need not be small in diameter (the size is determined by hydraulic considerations) nor are they "sewers" in the sense that they carry sewage solids. The most significant feature of small diameter sewers is that primary pretreatment is provided in interceptor tanks upstream of each connection. With the settleable solids removed, it is not necessary to design the collector mains to maintain minimum self-cleansing velocities. Without the requirement for minimum velocities, the pipe gradients may be reduced and, as a result, the depths of excavation. The need for manholes at all junctions, changes in grade and alignment, and at regular intervals is eliminated. The interceptor tank also attenuates the wastewater flow rate from each connection which reduces the peak to average flow ratio allowing reductions in the sewer diameter. Yet, except for the need to evacuate the accumulated solids in the interceptor tanks periodically, SDGS operate similarly to conventional sewers.

Application

Small diameter gravity sewers have potential for wide application. They are a viable alternative to conventional sewers in many situations, but are particularly well-suited for low-density residential and commercial developments such as small communities and residential fringe developments of larger urban areas. Because of their smaller size, reduced gradients and fewer manholes, they can have a distinct cost advantage over conventional gravity sewers where adverse soil or rock conditions create excavation problems or where restoration costs in developed areas can be excessive. In new developments, construction of the sewers can be deferred until the number of homes built warrant their installation. In the interim, septic tank systems or holding tanks can be used. When the sewers are constructed, the tanks can be converted for use as interceptor tanks. However, SDGS usually are not well suited in high density developments because of the cost of installing and maintaining the interceptor tanks.

Extent of Use in the U.S.

The use of small diameter gravity sewers has been rapidly increasing in the U.S. They have been referred to by different names including variable grade sewers (VGS), small bore sewers (SBS), septic tank effluent drains (STED) and common effluent drains (CED). They are all similar in design except that CED typically are designed to have uniform gradients with a minimum flow velocity of 0.3 m/s (1 fps). The others do not require uniform gradients, but will allow inflective gradients where sections of the sewer are depressed below the hydraulic grade line. Minimum flow velocities may not be required.

The use of small diameter gravity sewers has been largely limited to existing rural communities. The first SDGS system was installed in 1977 and by the early 1990's over 200 systems were operating. Increasingly, they are been used for residential fringe developments and new subdivision and resort developments where the topography is favorable. Frequently, the systems built are hybrid gravity and pressure systems.

Experience with the sewers has been excellent. The sewers have proved to be trouble-free with low maintenance requirements. As a result, confidence with the systems has grown and the designs have become less conservative.

Myths Versus Reality

Deterrents to the use of small diameter gravity sewers have come from both the engineering/regulatory community and the potential users themselves. Engineers and regulatory agencies have been reluctant to promote SDGS because of the concern over long-term performance. The concern has been over whether the sewers could handle the flows without backups or obstructions occurring. This concern is fading as experience shows the sewers to be relatively trouble-free.

Potential users have discouraged their use because of the conception that SDGS are a "second-rate" system. Typical concerns are for odors and whether the system can be expanded to accommodate growth. However, where SDGS have been installed, users have found them to perform no differently than conventional sewers. With proper planning, expansion can be accommodated and with proper design, odors problems are avoided.

Construction of SDGS may not be the lower in cost than conventional sewers in all unsewered developments. The cost of installing interceptor tanks is a significant cost. Usually existing septic tanks cannot be used as interceptor tanks because they are not watertight and cannot be inspected and repaired cost effectively. As in any project, all reasonable alternatives should be evaluated before design commences.

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CHAPTER 3:

SMALL DIAMETER GRAVITY SEWERS

INTRODUCTION

Small diameter gravity sewers are a system of interceptor tanks and small diameter collection mains. The interceptor tanks, located upstream of each connection and usually on the property served, remove grease and settleable solids from the raw wastewater. The settled wastewater is discharged from each tank via gravity or by pump (STEP unit) into the gravity collector mains usually located in the public right-of-way. The mains transport the tank effluents to the treatment facility.

Because the interceptor tanks remove the troublesome solids from the waste stream, the collector mains need not be designed to carry solids. This reduces the gradients needed and, as a result, the depths of excavation. The need for manholes at all junctions, changes in grade and alignment, and at regular intervals is eliminated resulting in further potential cost savings. The sewer diameter can also be reduced because the interceptor tank attenuates the wastewater flow to reduce the peak to average flow ratio. Yet, except for the need to evacuate the accumulated solids from the interceptor tanks periodically, SDGS operate similarly to conventional sewers.

The compatibility of septic tank effluent pumping (STEP) systems with SDGS allows an efficient low-cost hybrid collection alternative in many unsewered developments. A hybrid design can often eliminate or minimize the need for lift stations to reduce both capital, operation and maintenance costs. It is cautioned that grinder pump (GP) systems are not compatible with SDGS because the waste solids and grease are not removed from the waste stream before discharge to the collector main.

DESCRIPTION OF SYSTEM COMPONENTS

Typical small diameter gravity sewer systems consist of: building sewers, interceptor tanks, service laterals, collector mains, cleanouts, manholes and vents, and lift stations (See Figure 3.1). Other appurtenaces may be added as necessary

Building Sewers

All wastewaters enter the small diameter gravity sewer system through the building sewer. It conveys the raw wastewaters from the building to the inlet of the interceptor tank. Typically it is a 100-150 mm (4-6 in) diameter pipe laid at a prescribed slope, usually no less than 1%, made of cast iron, vitrified clay, acrylonitrile butadiene styrene (ABS) or polyvinyl chloride (PVC).

Interceptor Tanks

Interceptor tanks perform three important functions: 1) removal of settleable and floatable solids from the raw wastewater, 2) storage of the removed solids and, 3) flow attenuation. The tanks are designed for hydraulic retention times of 12 to 24 hours when two-thirds full of solids to permit liquid-solid separation via sedimentation and flotation. Outlet baffles on the tanks prevent floating solids from leaving the tank. The tank has sufficient volume to store the solids until which time they can removed, typically on 1 to 10 year cycles for residential connections and semi-annually or annually for commercial connections with food service. Anaerobic digestion does take place within the tank which reduces the volume of accumulated sludge and prolongs the storage time. The interceptor tanks also provide some surge storage which can attenuate peak flows entering the interceptor tank by more than 60% (Baumann, et al., 1978; Otis, 1986).

Septic tanks are typically used as interceptor tanks (Figure 3.2). Pre-cast reinforced concrete and coated steel tanks are usually available locally in a variety of sizes. Fiberglass (fiber reinforced plastic, FRP) and high density polyethylene tanks (HDPE) are also available regionally. Pre-cast concrete tanks are most commonly used in SDGS systems, but polyethylene and fiberglass tanks are gaining in popularity because they are more watertight and lighter in weight for easier installation. However, FRP and HDPE tanks require more care in proper bedding and anti-flotation devices where high ground water occurs.

Service Laterals

Service laterals connect the interceptor tank to the collection main. The laterals are usually plastic pipe no larger in diameter than the collector main. They are not necessarily laid on a uniform grade nor with a straight alignment (Figure 3.3).

Optional lateral appurtenances include check valves, "p"-traps or "running" traps and corporation stops. Most existing SDGS systems do not include these options, but check valves are being used more frequently to prevent backups into low-lying connections during peak flows. "P"-traps have been retro-fitted on connections where odors issuing from the house plumbing vent stack have been a problem. Corporation stops are used primarily on "stub outs" reserved for future connections.

Collector Mains

Collector mains convey the settled wastewater to either a lift station, manhole of a conventional gravity sewer system or directly to a treatment plant. Plastic pipe, with solvent weld or rubber gasket joints is used almost exclusively. Flexible, high density polyethylene pipe with heat fused joints has also been used successfully.

Manholes and Cleanouts

Manholes and cleanouts provide access to the collector main for maintenance. Since hydraulic flushing is sufficient to clean the mains, the use of manholes is usually limited. Common practice is to use manholes only at major junctions because they can be a significant source of infiltration, inflow and sediment. Cleanouts are typically used at upstream termini, minor main junctions, changes in pipe size or alignment, high points, and at intervals of 120 to 300 m (400-1000 ft).

Air Release Valves and Vents

Vents are necessary to maintain free-flowing conditions in the mains. In SDGS systems installed with continuously negative gradients, the individual house connections will provide adequate venting if the sewer lateral is not trapped. In systems where inflective gradients are allowed, the high points in the mains must be vented. Air release or a combination of air release/vacuum valves are commonly used in combination with a cleanout (Figure 3.4). Individual connections located at a summit can also serve as a vent if the service is not trapped or has a check valve.

Lift Stations

Lift stations may be used at individual connections which are too low in elevation to drain by gravity into the collector. They are also used on the collector mains to lift the wastewater from one drainage basin to another. Individual or STEP lift stations are usually simple reinforced concrete or fiberglass wet wells following the interceptor tank with low head, low capacity submersible pumps operated by mercury float switches (Figure 3.5). In a few systems where the static lift is great, high head, high capacity turbine pumps have been used successfully. This is only possible if the wastewater affluent is screened prior to pumping to eliminate any solids that might clog the turbines. Mainline lift stations are similar in design to the "residential" lift stations, but because of corrosion problems which commonly occur in the wet well, the construction of dry wells is becoming more common to reduce corrosion problems and to facilitate maintenance.

SYSTEM DESIGN CONSIDERATIONS

Hydraulic Design

A small diameter gravity sewer system conveys settled wastewater to the selected outlet by utilizing the difference in elevation between its upstream connections and its downstream terminus. It must be set deep enough to receive flows from the majority of the service connections and have sufficient capacity to carry the expected peak flows. Therefore, design decisions regarding its location, depth, size and gradient must be carefully made to hold the hydraulic losses within the limits of available energy. Where the differences in elevation are insufficient to permit gravity flow from an individual connection, energy must be added to the system by a lift pump (See Pressure Sewer Section). The number and location of individual lift stations or STEP units generally is determined from the comparisons of their costs of construction, operation and maintenance with the cost of construction and maintenance of deeper and/or larger diameter (smaller headloss) sewers. The hybridization of SDGS with STEP is quite common.

Design Flow Estimates

The hydraulic design of sewer mains is based on the estimated flows which the sewer must carry. Since wastewater flows vary throughout the day, the sewer main must be designed to carry the expected prolonged peak flows, typically the peak hour flow. Conventional sewer design assumes 380 L/d (100 g/d) per capita times a typical peaking factor of 4 for collector mains. This estimate includes allowances for commercial flows and infiltration. However, experience with SDGS has shown that these design flow estimates exceed actual flows because most SDGS serve residential areas where daily per capita flows are less than 380L/d (100 g/d) per capita the peak to average flow ratio is also less than 4 because the interceptor tanks attenuate peak flows markedly.

Measured average daily wastewater flow per capita is approximately 170 L/d (45 g/d) (Anderson and Watson, 1967; Bennett and Linstedt, 1975; Siegrist, et al., 1976). However, in small communities and residential developments where little commercial or industrial activity exists, average per capita wastewater flows in sewers may be as much as 25% less (Otis, 1978). Household wastewater flow can vary considerably between homes but it is usually less than 227 L/d (60 g/d) and seldom exceeds 284 L/d (75 g/d) U.S. EPA, 1980). Typically, 190 L/d (50 g/d) is assumed for per capita wastewater flows in residential areas. Commercial and industrial flows are estimated individually using established criteria (U.S. EPA, 1980).

The collector mains are sized to carry the daily peak flows rather than the average flows. In residential dwellings, the rate of wastewater discharged from the building depends on the water use appliances and fixtures used. Instantaneous peak flows are typically 0.3 to 0.6 L/s (5 -10 g/m) (U.S. EPA, 1980). Maximum hourly flows of 380 L/h (100 g/h) may occur (Watson, et al., 1967; Jones, 1974). However, the interceptor tank in SDGS systems attenuates these peaks dramatically. Monitoring of individual interceptor tanks showed that outlet flows seldom exceeded 0.06 L/s (1 g/m) and most peaks ranged between 0.03 and 0.06 L/s (0.5-0.9 g/m) over 30 to 60 minutes periods. There were long periods of zero flow (Otis, 1986). The degree of attenuation depends on the design of the interceptor tank and /or its outlet (see below).

In addition to wastewater flows, allowance must be made for potential clear water infiltration/inflow. A common source of infiltration in SDGS systems is the building sewer and interceptor tank. In SDGS systems in which the existing septic tanks were used as interceptor tanks, wet weather flows have been significantly higher than dry weather flows. Leaking building sewers, cracked tanks and poorly fitting tank covers are the most common sources of infiltration. Where all new tanks were installed and the building sewers tested or replaced, the ratio of wet weather to dry weather flows have been much lower (Otis, 1986). In all systems, foundation drains and roof leaders may be significant sources of inflow and SDGS projects should attempt to eliminate them during construction.

Experience with SDGS systems has shown that the criteria used to estimate design flows have been conservatively high. Design flows have generally ranged from 190 to 380 L/d (50-100 g/d) per capita with peaking factors ranging from 1 to 4. More recent designs have been based on flows per connection of 0.006 to 0.02 L/s (0.1-0.3 g/m). These design flow estimates have been successful because the interceptor tanks have storage available above the normal water level to store household flows for short peak flow periods.

Flow Velocities

Conventional sewer design is based on achieving "self-cleansing" velocities during normal daily peak flow periods to transport any grit which may enter the sewer, scour grease and resuspend solids that have settled in the sewer during low flow periods. However, in SDGS systems, the primary treatment provided in the interceptor tanks upstream of each connection remove grit, and most grease and settleable solids. Studies have shown that the remaining solids which enter the collectors and any slime growths which develop within the sewer are easily carried when flow velocities of 0.15 m/s (0.5 ft/s) are achieved (Otis, 1986). Experience with SDGS has shown that the normal flows which occur within the systems are able to keep the mains free-flowing. Thus, SDGS need not be designed to maintain minimum flow velocities during peak flows although many state agencies require that minimum velocities of 0.3 to 0.45 m/s (1.0-1.5 ft/s) during daily peak flow periods be maintain.

Maximum velocities should not exceed 4-5 m/s (13-16 f/s). At flow velocities above this limit, air can be entrained in the wastewater that may gather in air pockets to reduce the hydraulic capacity of the collector. Drop cleanouts or manholes should be employed where the pipe gradient results in excessive velocities.

Hydraulic Equations

Hydraulic equations used for design of the sewer mains are the same as those used in conventional gravity sewers. However, unlike conventional gravity sewers, sections of SDGS systems are allowed to be depressed below the hydraulic grade line such that flows may alternate between open channel and pressure flow. Therefore, separate analyses must be made for each section of sewer in which the type of flow does not change.

Both Manning's and Hazen-Williams pipe flow formulas are used. Roughness coefficients used range from 0.009 to 0.015 for Manning's "n" and 100 to 150 for Hazen-Williams "C". Typical values used are 0.013 and 140 respectively (Otis, 1986). Nomographs and hydraulic elements graphs may be found elsewhere (WPCF, 1982).

Design depths of flow allowed in the sewer mains have been either half-full or full. Most older systems designed with uniform gradients have used half-full conditions to dictate changes in pipe size. However, systems with variable gradients allow the collector main to be surcharged at capacity. In these systems, pipe size changes are dictated by the relative elevation of the hydraulic grade line to any service connection elevation.

Design procedures follow conventional sewer design except in sections where pressure flow occurs. In these sections, the elevation of the hydraulic grade during daily peak flow conditions must be determined to check that it is lower than any interceptor tank outlet invert. If not, free-flowing conditions will not be maintained at every connection. Where the hydraulic grade line is above a tank invert, the depth of the sewer can be increased to lower the hydraulic grate line, or the diameter of the main can be increased to reduce the frictional headloss or a STEP unit can be installed at the affected connection to lift the wastewater into the collector. If short term surcharging above any interceptor tank outlet inverts is expected, check values on the individual service lateral may suffice to prevent backflow.

Collector Mains

Layout

The layout of SDGS is a dendriform or branched system similar to that of conventional sewers except that the mains are usually not laid down the street center line so that expensive pavement restoration is avoided. In most cases, SDGS are located along side of the pavement in the street right-of-way. If there are numerous services on both sides of the street, collectors may be provided on both sides to eliminate pavement crossings.

Another alternative is to locate the collectors down the back property lines to serve a whole block with one collector. The backlot alternative may be the most accessible to homeowners since most septic tank systems are located in the backyard. Therefore, homeowners are not required to reroute the building sewer to the front of the lot, but access for interceptor maintenance may be limited. Since new interceptor tanks are usually installed, SDGS are installed most often in the front of the lots. If necessary, the building drains are reversed to direct the flow to the front.

Alignment and Grade

The horizontal alignment of SDGS need not be straight. Obvious obstacles such as various utilities, large trees, rock outcrops, etc. should be avoided with careful planning, but unforeseen obstacles can often be routed around by bending the pipe. The radius of the bend should not exceed that recommended by the manufacturer.

The gradient of SDGS must provide an overall fall sufficient to carry the estimated daily hourly peak flows, but the vertical alignment need not be uniform. Inflective gradients, where sections of the main are depressed below the static hydraulic grade line, are permissible if the invert elevation is controlled where the flow in the pipe changes from pressure to open channel flow. The elevation of these summits must be established such that the hydraulic grade line does not rise above any upstream interceptor tank outlet invert during peak flow conditions. Adequate venting must also be provided at the summit. Between these critical summits, the profile of the sewer should be reasonably uniform so unvented air pockets do not form which could create unanticipated headlosses in the conduit and excessive upstream surcharging.

<u>Pipe Diameter</u>

The pipe diameter is determined through hydraulic analysis. It varies according the to the number of connections and the available slope. The minimum diameter used is typically 100 mm (4 in), but 50 mm (2 in) pipe has been used successfully in recent projects (Meza, 1989). Where the smaller pipe is used, the interceptor outlets have flow control devices to control peak flows to a maximum rate and check valves at each service connection to prevent flooding of services during peak flow periods.

<u>Depth</u>

The depth of burial for the collector mains is determined by the elevation of the interceptor tank outlet invert elevations, frost depth or anticipated trench loadings. Either condition may control. In most cases, it is not attempted to set the depth such that all connections can drain by gravity. Where gravity drainage is not possible STEP lift stations are used at the affected connections. An optimum depth is selected to minimize the costs between excavation and the installation of STEP units. However, the depth must not be less than that sufficient to prevent damage from anticipated loadings. Where the pipe is not buried below pavement or subject to traffic loadings, the minimum depth is typically 0.75 m (30 in). Pipe manufacturer should be consulted to determine the minimum depth recommended. In cold climate areas, the frost depth may determine the minimum depth of burial unless insulated pipe is used.

Pipe Materials

Polyvinyl chloride (PVC) plastic pipe is the most commonly used pipe material in SDGS systems. Standard dimension ratio (SDR) 35 is used in most applications, but SDR 26 may be specified for road crossings or where water lines are within 3 m (10 ft). For deep burial, SDR 21 may be necessary. Where the use of STEP units is anticipated, only SDR 26 or 21 should be used for the collector mains because of the compatibility of pipe fittings. Typically, elastomeric (rubber ring) joints are used, however, for pipe smaller than 75 mm (3 in), only solvent weld joints may be available.

Flexible, high density polyethylene (HDPE) has been used infrequently, but successfully. Pipe joining is by heat fusion.

Service Laterals

Typical service laterals are 100 mm (4 in) PVC pipe, although laterals as small as 30 mm (1-1/4 in) have been used. The service lateral should be no larger than the diameter of the collector main to which it is connected. The connection is typically made with a wye or tee fitting. Where STEP units are used, wye fittings are preferred.

Occasionally, check valves are used upstream of the connection to the main to prevent flooding of the service connection during peak flows. If used, it is important that the valve be located at the collector main connection. Air binding of the service lateral can occur if the valve is located near the interceptor tank outlet (Bowne, 1989).

Interceptor Tanks

Location

The interceptor tanks should be located where they are easily accessible for periodic removal of accumulated solids. Typically, they are located near the house between the house and the collector main adjacent to or in place of the existing septic tank. If the collector main is located on the opposite side of the building, reversal of the building drainage may be desirable, but not necessary. Access for maintenance is the critical factor in location. In some projects, the tank has been located in the public right-of-way to eliminate the need for the utility district to enter private property to pump the tank (Figure 3.6).

Design

Prefabricated, single-compartment septic tanks are typically used for interceptor tanks in SDGS systems. Most projects standardize the use of 3785 L (1000 gal) tanks for all residential connections. For commercial establishments, local septic tank codes are commonly used to determine the necessary volume. For a given volume, several tank designs may be available locally. Shallow tanks, or tanks with the greater water surface area for a given volume are preferred designs because of the greater flow attenuation that they provide.

Inlet and outlet baffles are provided in conventional septic tanks to retain solids within the tank. These baffles are adequate for SDGS applications. The inlet baffle must be open at the top to allow venting of the interceptor tank through the building plumbing stack vent. On the outlet, various "gas deflection" baffles or outlet screens may be used to capture low density or neutral buoyancy solids that might otherwise pass through the tank (Figure 3.7). These devices are not necessary, however, since these solids have not caused problems in SDGS systems.

Flow control devices may also be used on interceptor outlets to limit peak flow rates to a predetermined maximum. Surge chambers were added to interceptor tanks in early projects (Simmons, et al., 1982). The surge chamber contained a standpipe with a small orifice drilled near the bottom (Figure 3.8). During peak flow periods, the chamber provides storage for the wastewater while the orifice controls the rate of flow from the tank. These chambers are no longer used because the orifices plug readily so the chambers are not effective in flow attenuation (Ref: Markle, R., 1989). They also require about 0.3-0.4 (1.0-1.5 ft) of headloss which may require deeper burial of the collectors and, as a result, higher construction costs. Where flow control is desirable, it has been incorporated into outlet screening devices made from plastic such as polypropylene in such a manner that the typical freeboard provided in the tank is sufficient for the necessary storage volume (Figure 3.9).

Water tightness is a critical criterion in selection of an interceptor tank. For that reason, existing septic tanks are seldom converted to interceptor tanks. Earlier systems attempted to use the existing septic tank at each home to reduce construction costs. It was found that septic tanks are difficult to inspect and repair properly. SDGS systems with significant numbers of old tanks all have high ratios of wet weather to dry weather flows (Otis, 1986). Common practice now is to replace all tanks. This practice has the added advantage of requiring the property owner to replace the building sewer to ensure greater watertightness. Some projects incorporate the replacement of the building sewer to allow inspection of the building plumbing to eliminate roof leaders, foundation drains and other unwanted connections that contribute clear water inflow.

Access to the tank for periodic inspections and solids removal is required. A sufficiently large opening over the tank inlet or outlet to allow inspection and effective sludge removal should be provided. However, because of the septic wastes, personnel must not enter the tank. The opening should be a minimum of 45 cm (18 in) square or in diameter. A watertight riser terminating 15 cm (6 in) above grade with a bolted or locking air tight cover is preferred to a buried access.

Material

Prefabricated septic tanks are typically used for interceptor tanks. They are available in reinforced concrete, coated steel, fiberglass and high density polyethylene. Unfortunately, the quality of manufacture varies from locality to locality. Therefore, it is necessary to carefully inspect and test random tanks for structural soundness for the intended application and for watertightness. Coated steel tanks are not recommended because the coating is easily damaged leading to severe corrosion and short tank life.

All tank joints must be designed to be watertight. The joints include tank covers, manhole risers and covers and inlet and outlet connections.

Rubber gasket joints for inlet and outlet connections are preferred to provide some flexibility in case of tank settlement.

Manholes and Cleanouts

In most SDGS systems, cleanouts have replaced manholes except at major junctions at mains. Since hydraulic flushing is all that is necessary to maintain the mains in a free-flowing condition, cleanouts provide sufficient access to the mains. Cleanouts are less costly to install than manholes and are not a source of infiltration, inflow or grit. Since the SDGS system is not designed to carry grit, elimination of manholes is strongly recommended. They also eliminate what was a common source of odors in SDGS systems.

Cleanouts are typically located at upstream termini of mains, junctions of mains, changes in main diameter and at intervals of 120 to 300 m (400 - 1000 ft) (Figures 3.10). Cleanouts may also be used in place of drop manholes (Figure 3.11). The cleanouts are typically extended to ground surface within valve boxes.

Manholes, if used, are located only at major junctions. The interiors should be coated with epoxy or other chemical resistant coating to prevent corrosion of the concrete. The covers used are typically gas-tight covers to limit the egress of odors and inflow of clear water.

Where depressed sections occur, the sewer must be well vented. Cleanouts may be combined with air relief valves at high points in the mains (Figure 3.4) or an open vent cleanout installed (Figure 3.12).

Valves

Air release, combination air release/vacuum and check valves may be used in SDGS systems. Air release and combination air release/vacuum valves are used for air venting at summits in mains that have inflective gradients in lieu of other methods of venting. These valves must be designed for sewage applications with working mechanisms made of type 316 stainless steel or of a plastic proven to be suitable (Bowne, 1989). The valves are installed within meter or valve boxes set flush to grade and covered with a water tight lid (Figure 3.4). If odors are detected from the valve boxes, the boxes may be vented into a small buried gravel trench beside the boxes.

Check valves are sometimes used on the service connections at the point of connection to the main to prevent backflow during surcharged conditions. They have been used primarily in systems with 50 mm (2 in) mains. Many types of check valves are manufactured, but those with large, unobstructed passageways resilient seats have performed best. Wye pattern swing check valves are preferred over tee pattern valves when installed horizontally (Bowne, 1989). Although the systems with 100 mm (4 in) mains have operated well without check valves, they can provide an inexpensive factor of safety. An alternative method used to prevent pumping backups in some projects has been to provide an interceptor tank overflow pipe to the drain field of the abandoned septic tank system. In Australia, a "bounder trap" is included at every connection which provides an overflow to the groomed surface if backups occur (Figure 3.13)

Odors and Corrosion

Odors are a commonly reported problem with SDGS systems. The settled wastewater collected by SDGS is septic and therefore contains dissolved hydrogen sulfide and other malodorous gases. These gases tend to be released to the atmosphere in quantity where turbulent conditions occur such as in lift stations, drop cleanouts or hydraulic jumps which occur at rapid and large changes of grade or direction in the collector main. The odors escape primarily from the house plumbing stack vents, manholes or wet well covers of lift stations.

The odors have been easily controlled by either minimizing turbulence or sealing air outlets. Drop inlets have been effective in eliminating most odors at lift stations (Figure 3.14). Gas tight lift station covers should be installed if odors are persistent and odor control provided for the fresh air vent. An effective odor control measure is to terminate the vent in a buried gravel trench (Figure 3.15). Carbon filters have been used successfully, but require regular maintenance. Manholes should be replaced with cleanouts, but if used, gas tight covers can be used. Odors from house plumbing vents can be controlled most easily by sealing the vent on top of the interceptor tank outlet baffle or by installing water traps in the service lateral.

The atmosphere created by the released gases is very corrosive. Corrosion is a common problem in lift stations. Corrosion resistant materials must be used (See Pressure Sewer Systems). More recent SDGS systems have used wet well/dry well design for lift stations to reduce the exposure of components to the corrosive atmosphere.

OPERATION AND MAINTENANCE CONSIDERATIONS

Administration

Utility or special purpose districts are commonly formed to administer, operate and maintain SDGS systems located outside municipal boundaries. These districts vary in structure and powers from state to state, but they typically have most of the powers of municipal government except for methods of generating revenues.

The sewer utility should be responsible for maintenance of the entire system. This includes all interceptor tanks and any appurtenances such as STEP units located on private property. Typically, the utility district assumes responsibility for all SDGS components downstream from the interceptor tank inlet. In some projects, the responsibility for maintenance of the components located on private property have been left to individual property owner. This practice is favored by some districts to avoid the need to enter private property. However, since the interceptor tank is critical to the proper performance of the SDGS system, responsibility for maintenance should be retained by the district. It is strongly recommended that the district assume ownership of the interceptor tank and the components downstream of the tank to ensure access and timely appropriate maintenance.

To obtain access to the SDGS components located on private property, perpetual general easements are typically secured from the owner. The easements can take several forms, but general easements or easements by exhibit are recommended over metes and bounds easements because of the time and expense of writing metes and bounds. In most cases, the easements are obtained without compensation to the owner. Where it is necessary to cross private property with the collector mains, metes and bounds easements are usually used.

An example of a general easement appears below:

KNOW ALL MEN BY THESE PRESENTS:
That, in consideration of One Dollar and other good and valuable consideration paid to the undersigned respectively, hereinafter referred to as GRANTORS by the utility district, hereinafter referred to as GRANTEE, the receipt whereof is hereby acknowledged, the GRANTORS each, for their respective heirs, distributees, personal representatives, successors and assigns, do hereby grant, bargain, sell, transfer, convey, release, quit claim and remise unto the GRANTEE, its successors and assigns, a PERPETUAL EASEMENT to erect, construct, install, lay, use, operate, maintain, inspect, alter, clean, remove and replace sewer pipes, pumps, interceptor tanks and all appurtenances necessary and incident to the purposes of the easement, and, in connection with the same, temporarily to place machinery and materials which may be necessary to effect the purposes of the easement upon lands of the respective GRANTORS situate in the name of county and state TOGETHER WITH the right of ingress and egress over adjacent lands of GRANTORS, their respective heirs, distributees, personal representatives, successors and assigns, as the same may be required in order to effect the purposes of the easement. The location of the easement on the lands of each GRANTOR is respectively shown on Sheet No. __ of Contract No. __ for the contract drawings of the local entity, dated _____.

The GRANTEE expressly agrees that any and all disturbance to the surface of the lands of the GRANTOR will be promptly repaired and to the extent possible restored to their pre-existing condition, whether such disturbance takes place during the initial installation or at any time thereafter as may be occasioned by subsequent repairs or maintenance to the said sewer line and interceptor tank with the easement area.

Executed at the local entity on the respective dates as follows:

Date	Signature	Street Address	Tax Acct.
_______	_____________	___________________	_________
_______	_____________	___________________	_________

Operation and Maintenance Manual

An operation and maintenance manual is essential to every project. Although most maintenance tasks are relatively simple and usually do not involve mechanical equipment, the manual does provide a valuable reference for location of components and services and typical drawings detailing the design and construction of each component. In addition, the manual should contain a comprehensive maintenance log to document all maintenance performed and any performance problems and the corrective actions taken.

A good manual should contain, at a minimum, the following:

1. Description of the system

   A description of the botu system and each of its components should be provided. The component descriptions should include the function of each, their relation to adjacent components and typical performance characteristics. Specific design data, shop drawings, as-built plans and profiles of the collector mains and detailed plan drawings of each service connection are essential.

2. Description of the system operation

   Normal operation, emergency operation situations and procedures and failsafe features should be described.

3. System testing, inspection, and monitoring

The purpose and methods of all recommended testing, inspections and monitoring should be described. Sample recording forms should also be included.

4. Preventive maintenance procedures and schedules

A clear description of all preventive maintenance procedures is needed with specific schedules for their performance.

5. Troubleshooting

A description of common operating problems, how they may be diagnosed and procedures to correct them is helpful.

6. Safety

Safety practices and precautions should be described to alert personnel to the potential hazards and methods to avoid or mitigate them. The dangers of working with septic wastes which generate dangerous hydrogen sulfide and methane gases must be emphasized.

7. Recordkeeping Logs and Forms

Sample recordkeeping forms and logs should be provided.

8. Equipment Shop Drawings and Manuals

   Shop drawings and installation and maintenance manuals of all major equipment should be included. Manufacturers and their suppliers should be listed with contact names, addresses and telephone numbers.

9. Utilities List

   A list of all utilities in the project area, location maps and contact names, addresses and phone numbers should be provided.

10. System Drawings

    Complete as-built drawings of the system are necessary. Detailed drawings of the service connections showing the precise location of all components with maintenance logs for each should be included.

Staff and Equipment Requirements

Operation and maintenance requirements of SDGS systems are generally simple in nature requiring no special qualifications for maintenance staff other than familiarity with the system operation. The operator's responsibilities will be limited largely to service calls, new service connection inspections and administrative duties. In most systems, interceptor tank pumping is usually performed by an outside contractor under the direction of the utility district.

ent is also limited. A truck mounted centrifugal suction to /ide most emergency operation equipment needs. hould be purchased to reach between cleanouts. Other ovided by outside contractors as needed.

ing for SDGS maintenance personnel is not necessary. lls, however, are desirable. If a significant number of ns include STEP units, an understanding of pumps and s is also helpful. (For a small number of such units, it utility district to retain local plumbing and electrical available for any necessary repairs.) The staff should ngers of exposure to sewer gases and to avoid entry into less nroperly protected. Since a significant portion of ted private property, it is important that the staff ation skills and a willingness to work with people.

ory

ems have few mechanical parts, the need to maintain a ory is limited. However, if individual STEP units are ystem requiring that spare pumps and controls must be gency repairs. A minimum of two spare pumps and the itches and controls should be maintained. Pipe and pipe kept on hand to repair any pipeline breaks that may eptor lids and riser rings should also be kept.

As-Built Drawings

As -built drawings of the entire SDGS system including all on-lot facilities is essential to maintenance of the system. Curvilinear alignments and few manholes or cleanouts make locating the collector main routes difficult unless accurate drawings tying the location of the line to permanent structures are developed. As-built drawings of each individual service connection should also be made. These drawings are necessary when repairs are needed or when the components must be located to avoid damage due to other construction activities.

Maintenance

Normal

Normal maintenance is generally limited to call-outs by users. The call-outs are usually due to plumbing backups or to odors. In nearly every case reported, the plumbing backups were due to obstructions in the building sewer. Although the building sewer is the property owner's responsibility, most utilities have assisted the owner in clearing the obstruction. Odor complaints are common. As with the plumbing backups, faulty venting in the building plumbing is usually the cause. If improved venting fails to eliminate the odor complaints, the interceptor inlet vent can be sealed or running traps placed in the service lateral to prevent the sewer main from venting through the service connection.

Preventive

Preventive maintenance includes inspection and pumping of the interceptor tanks, inspection and cleaning of the collection mains and inspection and servicing of any STEP units or lift stations.

Interceptor Tanks: The interceptor tanks must be evacuated of solids periodically to prevent solids from entering the collector mains. Prescribed pumping frequencies are typically 3 to 5 years, but operating experience indicates that a longer time between pumpings, of 7 to 10 years, is adequate. Restaurants and other high use facilities, such as taverns, require more frequent pumping. Common practice is to pump tanks serving these facilities every 6 to 12 months. Tank inspection is usually performed immediately after the tank has been evacuated to check for cracks, leaks, baffle integrity and general condition of the tank. If effluent screens are used on the tank outlet, they must be pulled and cleaned by flushing with water. Annual flushing of the screens is recommended if they are to be effective.

Most utilities do not perform the pumping themselves. Private pumpers are usually hired through annual contracts to pump a designated number of tanks each year and to be on call for emergency pumping. The septage removed is usually land spread or discharged into a regional treatment plant. During the pumping operations, utility district personnel should be present to record the depth of sludge and thickness of any scum in each tank so that the schedule can be altered according to need.

Collector Mains: Periodic inspection and cleaning of the collector mains is usually recommended maintenance functions. Hydraulic flushing is most often recommended for cleaning. Pressure hoses to push pigs through the mains has also been suggested as a cleaning method, but is not recommended if the collector mains are SDR 35 pipe. Reported performance of systems has been good and, therefore, inspection and flushing has not been deemed necessary by most utilities and has seldom been performed. In systems where the mains have been inspected, no noticeable solids accumulations have been noted. The experience with SDGS in Australia is similar. Many large systems there have been operating over 30 years without main cleaning. However, regular flushing is still recommended for long flat sections in which daily peak flow velocities are less than 0.15 m/s (0.5 ft/s).

Lift Stations: Mainline lift stations should be inspected on a daily or weekly basis. Pump operation, alarms and switch function should be checked and running times of the pumps recorded. The discharge rate of each pump should be calibrated annually.

Emergency Operation

Mainline or service lateral obstructions and lift station failures require that emergency actions be taken to limit the time the systems is out of service to prevent environmental or property damage that might occur. It requires that the utilities have defined emergency operation procedures.

Obstructions: If an obstruction occurs, the utility must be able to respond quickly such that backups do not occur at upstream service connections. Usually the obstruction will be caused by construction debris which cannot be removed by simple flushing. It may require that the main be excavated to remove the obstruction. While the obstruction is cleared, the utility must be prepared to pump from the cleanout, manhole or interceptor tank immediately above the obstruction to a cleanout or manhole below. A contractor's centrifugal suction pump or truck mounted pump works well for this.

Fortunately, obstructions have been rare. All reported obstructions have occurred soon after construction or after a service connection has made. Construction debris has been the cause. Obstructions from other causes have not been reported.

Lift Stations: Lift stations may fail due to loss of power or a mechanical failure. Standby emergency generators can be provided for power during prolonged outages, but the generators can be costly and require regular maintenance. Because of the costs, many small communities have provided added storage at the lift station (Figure 3.16) and/or truck mounted pumps that can pump from the wet well to a downstream hose connection on the forcemain (Figure 3.17). This latter method also works well for mechanical failures.

Record Keeping

Good record keeping of all operation and maintenance duties performed is essential for preventive maintenance and trouble shooting when problems occur. A daily log should be kept and maintenance reports on all equipment filed. Flows at the mainline lift stations should be estimated daily by recording the pump running times. This is helpful in evaluating whether infiltration or inflow problems are developing. A record of each service call and corrective action taken should be filed by service connection identification number. This record should include tank inspection and pumping reports. These records are particularly useful if reviewed prior to a service call out.

Troubleshooting

Odors

Odors are the most frequently reported problem with SDGS systems. Odors typically occur at lift stations and from house plumbing stack vents, particularly at homes located at higher elevations or ends of lines. Odors are most pronounced where turbulence occurs. The turbulence releases the obnoxious gases dissolved in the wastewater.

Odors at lift stations have been successfully eliminated by installing drop inlets that extend below the pump shut off level. This eliminates most of the turbulence. Other successful corrective measures include soil odor filters (Figure 3.15), air tight wet well covers and vents that extend 3 to 5 m (10-15 ft) above grade.

Odors at individual connections originate from the collection main. If a sanitary tee or similar baffle device is used at the interceptor tank inlet or outlet, the top of the tee can be sealed or capped to prevent the gases escaping into the building sewer. P-traps or running traps on the service lateral have also been used (Figure 3.13). In some cases, extension of the main further upslope to where it can be terminated in a vented subsurface gravel trench has been employed successfully. The trench filters the odors before venting the gas to the atmosphere.

Corrosion

Corrosion is a problem that is largely limited to lift stations and manholes. Nonferrous hardware must be used in lift station wet wells. Concrete manholes and wet wells must be coated with corrosion resistant materials. Alternatively, corrosion problems can be reduced in lift stations by using wet well/dry well construction with a well vented wet well.

Infiltration/Inflow

Clear water infiltration/inflow was a common problem with earlier SDGS systems that used a high percentage of existing septic tanks for interceptor tanks. Leaking tanks or building sewers were the primary entry points of clear water. Systems that have installed all new interceptor tanks and pressure test building sewers and tanks have few infiltration/inflow problems.

SYSTEM COSTS

Construction

SDGS systems have resulted in reported savings of 0 to 50% in comparison to conventional gravity sewers. The unavoidable costly component of SDGS is the installation of the interceptor tanks which in some instances, have caused the construction costs of SDGS to exceed the estimated costs of conventional sewer construction. However, the pretreatment provided by SDGS eliminates the need for primary treatment which may reduce the cost of the treatment facility.

Construction costs are affected directly by site factors and system design. Site factors include topography, depth to bedrock, depth to ground water, soil type and other factors that can affect the cost of pipeline installation. Some of these factors can be mitigated through thoughtful design. The design itself can also reduce construction costs independent of site factors.

In a study of 10 systems, construction costs of individual components were ranked from most costly to least costly as follows (Otis, 1986):

1. Collector mains
2. Interceptor tanks (including service lateral)
3. Mainline lift stations
4. Pavement restoration
5. Crossings (road, stream, utility)
6. STEP lift stations
7. Manholes
8. Site restoration
9. Force main
10. Cleanouts

This ranking suggests in which areas efforts should be made in system design and construction methods to reduce the total costs.

Costs of installing the collector mains and the inteceptor tanks typically accounts for over 50% of the total costs of construction. Pipe installation costs are affected most by the depth of excavation. Where frost does not control the depth at which the sewers must be installed, shallow placement can reduce the total costs significantly. Consideration should be given to eliminating gravity drainage for basement drains. Greater use of individual STEP units can also reduce the required depth of the collectors. Several projects have shown that hybrid systems using pressure connections into gravity collectors can be cost effective in areas of undulating topography. Reducing the depth may also eliminate the need for some mainline lift stations. Shallow placement will allow the use of continuous trenching equipment as well.

The cost of installation of the interceptor tanks and service laterals includes the cost of evacuation and abandonment of the existing septic tank. Installation costs should be reduced by combining more than one connection on one tank. However, this is seldom done.

Often times the cost of the service connection is affected by the attitude of the contractor towards working on private property. Many contractors dislike working on private property because of the insistence of the property owner for complete restoration of their property. Several methods have been used to mitigate this problem to control the cost. Video taping of each site prior to construction helps to resolve complaints concerning appropriate restoration. Letting a separate contract for the service connections to allow a smaller contractor who is typically more accustomed to working with property owners to perform the work has been effective. Placement of the interceptor tanks in the public right-of-way eliminates the need to enter private property altogether. This latter approach is seldom used because of space restrictions and the additional cost to the property owner for longer building sewer connections.

Operation and Maintenance

The most significant operation and maintenance costs of projects reviewed are labor, interceptor tank pumping and system depreciation. An operator must be on call at all times, but the time required for preventive maintenance is small. Most projects do not employ full time staff, finding that 5 to 10 hours per week is sufficient for preventive maintenance.

Interceptor tank pumping is usually performed by outside contractors. Most projects are pumping each tank every 2 t 3 years which has been found to be more frequent than necessary. Pumping of residential tanks every 7 to 10 years appears to be sufficient. Commercial establishments, particularly those with food service may require pumping every 6 to 12 months.

Other operating and maintenance costs include administration, utilities, insurance and occasional repairs. These costs account for 20 to 30 percent of the total operation and maintenance costs.

User Charges/Assessments

User charges typically include administration, operation and maintenance, depreciation and debt retirement costs. In most projects, flat rates for residential connections are charged because water meters are not provided. Surcharges are usually placed on commercial connections based on assumed water use.

Flat rates are also frequently used for assessments. These may take the form of hookup charges. A two tiered system is common. The first tier is for connections made at the time of system construction. The second is for future connections. Existing users at the time of construction are usually provided the interceptor tank and service lateral while future users must pay for the tank and lateral in addition to the hookup fee.

SYSTEM MANAGEMENT CONSIDERATIONS

User Responsibilities

Typically, the user is responsible for only the building sewer from the building to the interceptor tank. If a STEP unit is included as part of the service connection, the owner is also responsible for providing power to the control panel. Beyond these limited responsibilities, the owner must also see that access to all components of the system located on the property is maintained.

Sewer Utility Responsibilities

The utility is usually responsible for the installation, operation and maintenance of the entire system commencing at the inlet to the interceptor tank. Outside contractors may be employed to perform some tasks such as installing service connections or pumping of the interceptor tanks.

DESIGN EXAMPLE

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Zanesville

ALTERNATIVE CONVEYANCE SYSTEMS

SMALL DIAMETER GRAVITY SEWERS

Figure 3.9: Interceptor Outlet Flow Control Device (Orenco, 1989)

Figure 3.10: Typical Cleanout Detail (Otis, 1986)

Figure 3.11: Drop Cleanout Detail (SABESP, 1990)

Figure 3.12: Ventilated Cleanout Detail (Otis, 1986)

Figure 3.13: Australian Boundary Trap Detail (South Australia Health Commission, 1989)

Figure 3.14: Mainline Lift Station with Drop Inlets (Otis, 1986)

Figure 3.15: Soil Odor Filter Detail

Figure 3.16: Mainline Lift Station with Emergency Storage (Otis, 1986)

Figure 3.17: Emergency Pumping Manhole (Otis, 1986)