

Manual

**Alternative Wastewater
Collection Systems**

U.S. Environmental Protection Agency

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Risk Reduction Engineering Laboratory
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Office of Wastewater Enforcement and Compliance
Washington, DC

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CHAPTER 1

Overview of Alternative Conveyance Systems

1.1 Introduction

1.1.1 History

In the late 1960's, the cost of conventional gravity collection systems in rural communities was found to dwarf the cost of treatment and disposal. In response to this condition efforts were initiated throughout the United States to develop low-cost sewerage which could serve the needs of the rural communities which constituted over 80 percent of demand for centralized collection and treatment.

In developing alternative collection systems for these small communities, engineers turned to concepts which had theretofore been either forgotten or ignored by the profession.

Pressure sewers had only recently been conceived of as a means of separating combined sewers in large cities by Professor Gordon Maskew Fair of Harvard University and installed by Mortimer Clift in a little town in Kentucky.¹ Vacuum sewers had been around since the 19th Century, but had not been seriously considered for widespread use until then. Small-diameter gravity sewers (SDGS) also found 19th Century roots in the United States, but the principles had been all but forgotten in the rush to codify urban civil engineering technology. These systems returned to the U.S. from Australia where they had been employed successfully for several years.²

After initial demonstration projects had been underwritten by the U.S. Environmental Protection Agency (USEPA) (and its predecessor agencies) and the Farmers Home Administration (FMHA), these technologies were given special status under the innovative and alternative (I&A) technology provisions of the Clean Water Act of 1977. Thus stimulated, these technologies flourished in small communities which were able to secure grants under this program. More than 500 alternative sewer systems were installed under the I&A provisions, and a significant number were also constructed with state, local and private funding during the 1970's and 1980's.

1.1.2 Approach

In developing this design manual several approaches were possible. Large committees of "experts" could have been assembled, and a consensus document developed. This approach had been used for the 1986 Water Pollution Control Federation MOP Number FD-12³, but such efforts tend to yield results of a conservative nature, reflecting only certain issues to which even the least knowledgeable can agree.

The course chosen was to utilize only the individuals with the best practical experience in each of the three major categories to prepare the sections on pressure, vacuum and small-diameter gravity systems. The result is a document which contains the most advanced state-of-the-art for each of these systems. These individual authors are:

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The materials developed by these experts have been extensively reviewed and edited for clarification and pertinence to a wide sector of the international user community.

Although the above approach was conceived to provide the best source of information, there are some negative

facets to it. The most obvious is the dearth of references cited. Since the knowledge of the authors is gained through a variety of fugitive and personal experience sources, and not to any great degree from literature presentations of varying quality and accuracy, the use of references has been minimal. For those who seek additional information on certain topical areas, lists of such references can be obtained through Reference 3 and the National Small Flows Clearinghouse in Morgantown, West Virginia.

As with any document certain issues are not discussed herein in any significant detail because of the need to concentrate on U.S. practice. Examples of these topics include flat-grade sewers which are used almost exclusively in Nebraska and "simplified sewer systems" which are used in Brazil, Ghana and other countries. Both have some degree of similarity with small-diameter gravity sewers and are described elsewhere.

1.1.3 Commonalities

Although each of the alternative sewer technologies use very different motive forces, there are many commonalities in choosing, designing, constructing and maintaining all of them. Clearly, all use lightweight plastic pipe buried at shallow depths, with fewer joints due to increased pipe lengths, when compared to conventional gravity sewers. Each has the ability to save significantly on capital investment if properly designed and installed in rural areas where their inherent advantages can be exploited. All have suffered from some misuse and misapplication in early installations, as have all new technologies. The purpose of this manual is to provide the information which will minimize future problems of this type.

A common need of all alternative collection systems (ACS) is proper administration and management. Since the needs of these technologies are different from conventional sewers and treatment facilities, operating and maintenance (O&M) staff members must be properly trained in the particular needs of the type of system employed.

A common concern with all ACS types is the shallow burial depth, which increases potential for damage from the ground surface, e.g., excavation projects. Good management and design can minimize this problem by inclusion of marking tape and toning wires in the trench and surface markers which direct excavators to the O&M staff for assistance in locating facilities. Quality as-built drawings and, possibly, geographic information systems (GIS) on software will prove invaluable for all of these systems.

The other concern is for a larger on-lot activity than normally experienced with conventional sewers. Homeowner involvement in the planning process is a requirement for success with any ACS project to minimize the potential for subsequent damage to public relations and to maximize the potential support of the homeowners for the project. Similarly, the system staff representative(s) will be considered the embodiment of management, and must be able to relate positively to the public.

1.1.4 Evaluation Issues

Each section of the manual is concerned with a specific ACS technology. Each cites a series of site conditions which favors that technology over conventional gravity sewers. Unfortunately, that list is very similar for all three types. Considering the commonalities discussed above, only a few site conditions clearly favor a given ACS over the others. The reasons why each technology has been chosen for the installed systems discussed in the manual is rarely, if ever, due to careful and comprehensive evaluation of each technology and subsequent comparison. Usually the engineer is familiar with one type of ACS and attempts to do a comparison of it to conventional sewerage. Depending on how well that is performed, the availability and rules of financial assistance programs and the municipality's desires, a system is chosen.

In reality, all alternative sewer systems should be considered for municipalities of 10,000 people or less. Those communities of 3,500-10,000 population can likely handle all ACS technologies with proper training. Small communities under 1,000 population are probably the most restrictive in terms of available O&M capability. Anything more mechanical than a small-diameter gravity sewer (SDGS) with no lift station should be given another level of scrutiny for most of these locations. Arrangements with county government, private management entities or other larger utilities may eliminate this O&M barrier for even the smallest communities, permitting an unconstrained choice of the optimum technology for each community.

In such cases all ACS systems should be fairly evaluated, and this manual allows that, since each expert author has presented the data for their ACS system. There are very few instances where one ACS would be eliminated from consideration since each can be combined with another form of collection to overcome site limitations.

The most common combination is that of SDGS with septic tank effluent pumping (STEP) sewers. This combination is sometimes called effluent sewers, since both employ septic tank pretreatment. A conventional gravity sewer and vacuum sewer combination is described

in the text, which saved a small community considerable capital expenditure. Grinder-pump (GP) pressure systems are commonly used with conventional gravity sewers to reduce total costs. Combinations of ACS, other than "effluent sewers," are more rare. Theoretically, both SDGS and STEP could feed into a vacuum or a GP sewer, but the reverse could have repercussions since the former two are designed to carry a wastewater which does not contain heavy solids and grease. Although unsubstantiated, any pressure or SDGS termination in a vacuum sewer should probably be carefully investigated to determine the need for some form of gaseous emission odor control at the vacuum station. All ACS types are compatible with conventional sewers if interfacing precautions described in the manual are followed.

Cold-weather conditions have not been dealt with to a great degree in the manual, but all three ACS types have been successfully employed in Canada. The primary difference lies in insulation of piping and mechanical components from severe winter temperatures.

The most serious omission is that of treatment subsequent to conveyance by an ACS. Both SDGS and STEP systems yield an effluent which is for all intents and purposes the same as septic tank effluent. It is quite biodegradable, weaker in terms of suspended and settleable solids and all matter associated with this fraction, e.g., organics and grease, than conventional raw wastewater. It is generally anaerobic, contains reduced sulfur species and readily emits the H_2S form upon stripping.^{1,3} GP systems contain a highly concentrated form of raw wastewater since infiltration and inflow (I/I) are generally negligible.^{1,3} Vacuum sewers are quite violent in their internal action yielding a wastewater similar in strength to conventional raw wastewater, but highly aerated in terms of dissolved oxygen content.

Conservative engineers have designed ACS treatment systems identically to those for conventional wastewater. Given the rural nature of these systems, most treatment facilities have been stabilization ponds which are somewhat insensitive to the wastewater characteristic variance between ACS types. Some mechanical treatment systems (extended aeration and oxidation ditches) have been used without significant difficulty for larger ACS installations. Also, some subsurface soil absorption systems have been successfully employed for some smaller ACS sites.

Readers are referred to numerous other textbooks for further information on wastewater characteristics vs. treatment plant design. Given the variable nature of available ACS wastewater data, use of pilot studies may

be prudent if treatment more sophisticated than subsurface soil absorption or stabilization ponds with effluent polishing is contemplated.

1.1.5 Perspective

The timing of this manual is such that experience with the first generation of ACS has been documented. Problem areas have been identified, and solutions generally have been attempted and documented. This manual conveys these experiences in a practical manner which permits the engineering profession to design reliable systems which small communities can manage.

Indeed there are some unknown or unresolved issues in ACS technology, but these should disappear with time. None are considered serious enough to retard continued application of these systems. This manual is intended to stimulate consideration of ACS technology and minimize its misuse where it is inappropriate to the problem solution.

1.2 Pressure Sewers

1.2.1 Description

Pressure sewers are an outgrowth of the Congressional directive in Section 104(q) of the Clean Water Act of 1972, to develop wastewater systems where implementation of conventional practices is impractical, uneconomical, or otherwise infeasible. Pressure sewers have emerged as one of the most popular and successful of the collection system alternatives.

A pressure sewer is a small diameter pipeline, shallowly buried, and following the profile of the ground. Typical main diameters are 5 cm (2 in) and 15 cm (6 in). Polyvinyl chloride (PVC) is the usual piping material. Burial depths usually are below the frost line, or a 75-cm (30-in) minimum, whichever is greater. In northern areas insulated and heat-traced piping offer relief from these criteria.

Each home uses a small pump to discharge to the main. This may be a grinder pump (GP), which grinds the solids present in wastewater to a slurry in the manner of a kitchen sink garbage grinder, or a septic tank and effluent pump (STEP) system may be used. The septic tank of a STEP system captures the solids, grit, grease, and stringy material that could cause problems in pumping and conveyance through the small diameter piping.

Grinder pumps to serve individual homes are usually 2 hp in size, but 1-hp units are also used. Some installations use 3-5 hp motors, but these are usually used when serving several homes with one pumping unit. STEP pumps are usually fractional horsepower.

The service line leading from the pumping unit to the main is usually 25-38 mm (1-1.5 in) diameter PVC. A check valve on the service line prevents backflow, which is insured with a redundant check valve at the pumping unit.

If a malfunction occurs, a high liquid level alarm is activated. This may be a light mounted on the outside wall of the home, or it may be an audible alarm which can be silenced by the resident. The resident then notifies the sewer service district which responds to make the necessary repair.

Installation of a pressure sewer main is shown in Figure 1-1. General sketches showing GP and STEP installations are shown in Figures 1-2 and 1-3.

1.2.2 Potential Applications

The primary reason for the use of pressure sewers is economic, but in some cases the decisions are environmentally motivated.

In areas where rock is encountered when excavating to install mainline sewers, pressure sewers can be cost effective. The deep, wide trenches required to install conventional sewers are expensive to construct. Pressure sewers require only shallow, narrow trenches.

Where groundwater is high, the deep excavations for conventional sewers may enter that groundwater. In some cases dewatering is not achievable. When conventional sewers are installed under these conditions the cost is high and the quality of installation is questionable. Shoring can also add considerably to the cost of conventional sewers.

Some topography does not favor gravity collection. One typical example is around lakes where the homes are built fronting the lake. The road serving these homes, and often the only practical location for the sewer, may be upslope from the homes. The profile of that route may go up and down as it circles the lake; numerous and costly pumping stations would be necessary if conventional sewers were used.

Conventional sewers have a high cost per foot of sewer installed. Where homes are sparse, the resulting cost can be exorbitant. Pressure sewers can be installed less expensively on a per foot basis.

Extremely flat terrain poses a problem to gravity sewer installations since the gravity sewer must continually slope downward. This causes the sewer to become increasingly deep until a lift station is necessary. Both the deep excavations and the lift stations are expensive, and

the latter represents a considerable operation and maintenance (O&M) expense.

Damage consequential to the installation of deep sewers is a factor. In some cases blasting is required to install sewers. This may cause upheaval of the road, damage to nearby buried utilities and homes, and disruption to the community. Deeply buried conventional sewers may intercept and drain groundwater. In many cases the groundwater will enter the gravity sewer as unwanted infiltration.

Developments experiencing slow growth find pressure sewers economically attractive. The front-end infrastructure (mainline) is inexpensively provided. The cost of the pumping units is deferred until the homes are built and occupied. The cost for the pumping units may also be financed with the home. Time value of money considerations make this feature particularly attractive.

Pressure sewer equipment is also used in conjunction with conventional systems. Where a low lying home or basement is too low to allow gravity flow into a fronting conventional sewer, a grinder pump or pressure sewer type solids handling pump may be used at that home to discharge to the sewer. Similarly, STEP units are used to discharge to high lying drainfields, sand filters, mounds, and other forms of on-site wastewater disposal.

1.2.3 Extent of Use in the United States

The pressure sewer market size is large and growing. No comprehensive lists have been kept to document pressure sewer projects, but hundreds of systems are known to exist throughout the United States. Locations of major projects range from Florida to Alaska, and from Texas to New York.

Many of these systems serve 50-200 homes. A few systems serve over 1,000 homes each, and some systems are now being designed that will serve over 10,000 homes. A few examples of larger projects are:

Horseshoe Bay, TX	GP	1,700 homes served
Kingsland, TX	GP	1,600 homes served
Saw Creek, PA	GP	1,800 homes served
Anne Arundel Co., MD	GP	1,500 homes served
Port St. Lucie, FL	STEP	3,000 homes served
Buckeye Lake, OH	STEP	1,500 homes served
Palm Coast, FL	STEP	650 homes served
(planned for 20,000 homes to be served ultimately)		

The use of pressure sewer components to serve low lying homes fronting gravity sewers is substantial, but no records have been kept to document the extent. Pressure sewer components used with on-site disposal practices

Figure 1-1. Installation of pressure sewer main.

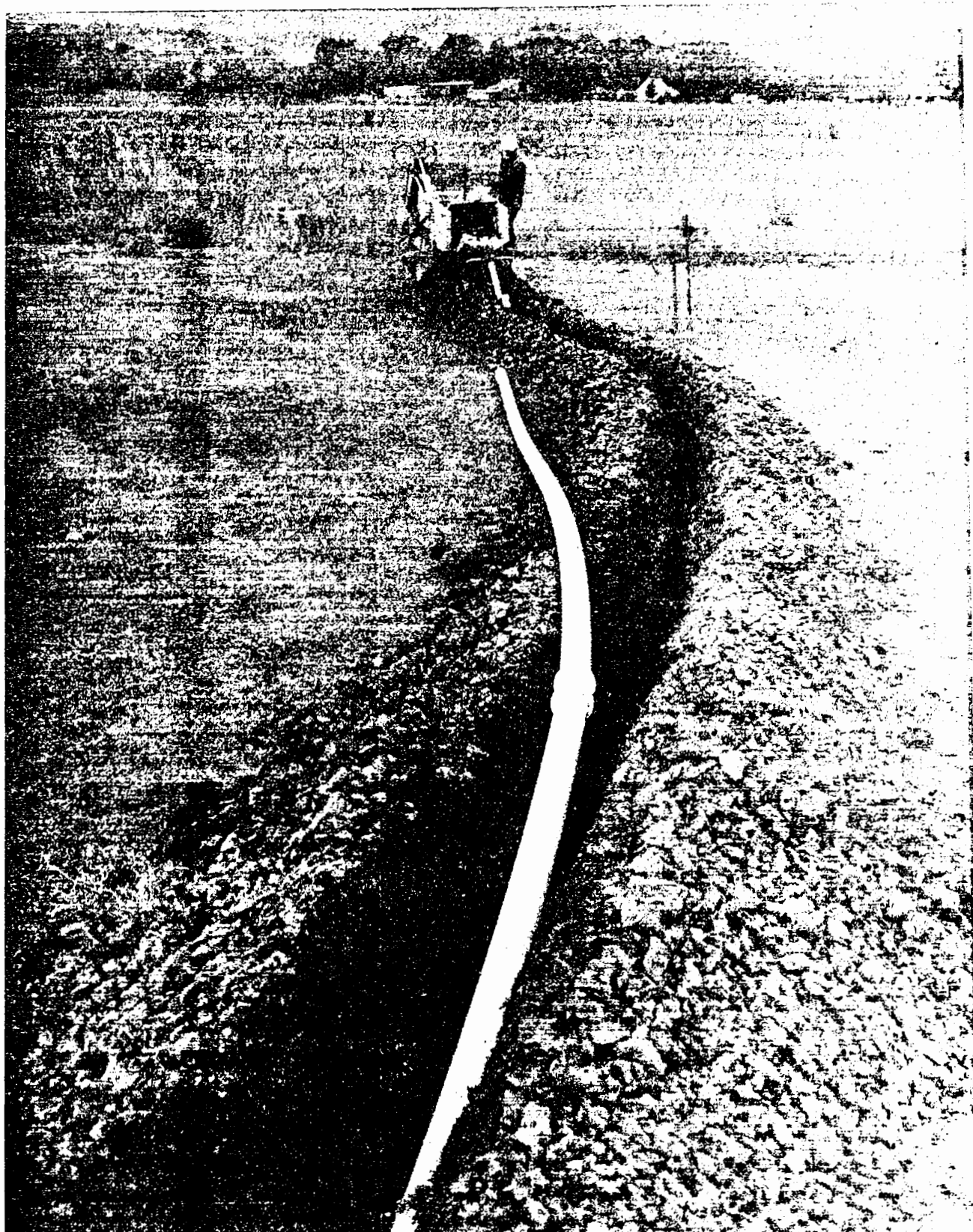


Figure 1-2. Grinder Pump (GP) system.

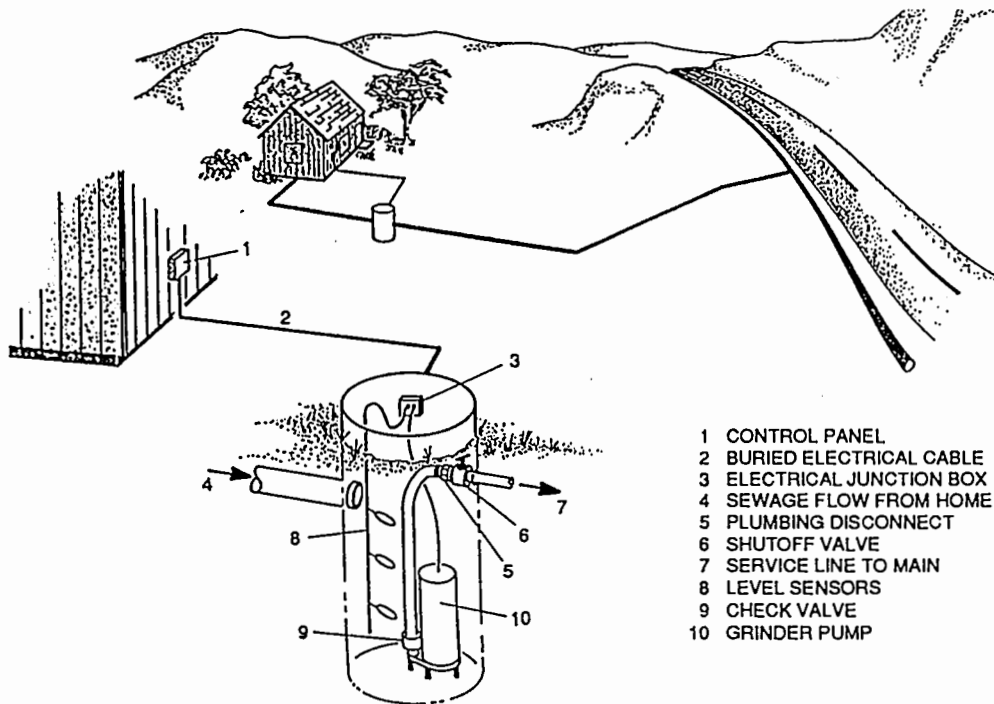
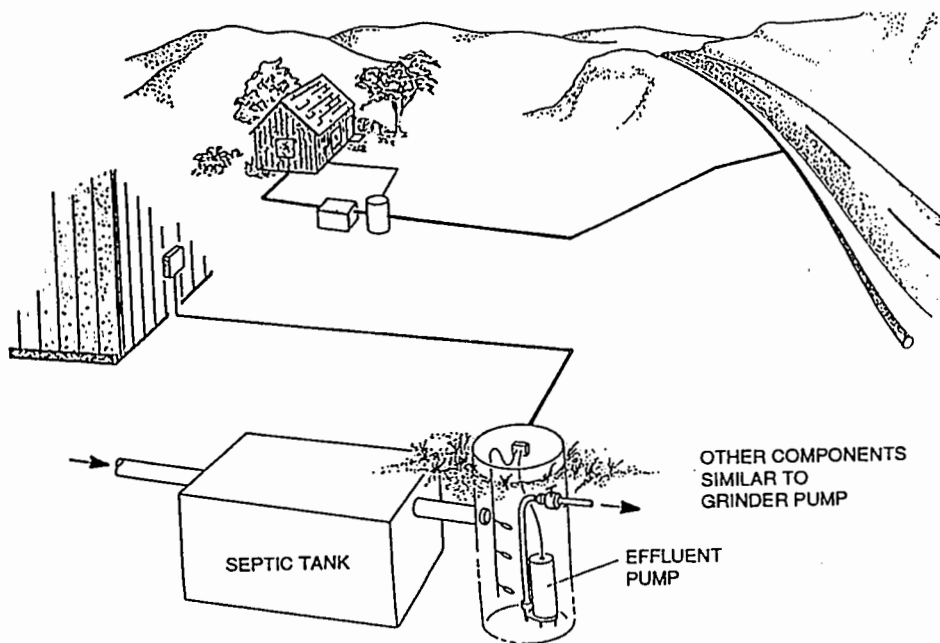


Figure 1-3. Septic Tank Effluent Pump (STEP) system.



has become commonplace. Canada also uses pressure sewers, as do several European and Asian countries.

Considering that pressure sewer technology emerged in the late 1960s, the practice has indeed grown quickly.

1.2.4 Myths vs. Reality

Pressure sewers should not be glamorized as a panacea. The endeavor should be to use the technology appropriate for the setting. If the appropriate technology is the use of conventional sewers, or the use of septic tank - drainfield systems, that should be used. Conventional practices are mature, well understood, and well accepted. Because of particular grant funding conditions there have been cases where the inappropriate use of alternative technologies has occurred.

It has been a common error for people to learn of excellent operating performance from especially well designed and well built pressure sewer systems, and, oddly, to expect the same performance from a shoddy installation. Too often engineers inexperienced with the technology have been employed. Components have often been chosen without their having demonstrated competence. Inspection has frequently been inadequate. The result is a poor system, likely to be replaced in the near future, and poor reputation gained undeservedly for the pressure sewer concept.

Experience specific to pressure sewers is vital to provide a good installation. A small system should be built first, preferably with guidance from experienced people. Then, performance of the operating system should be closely observed to close the loop between planning, design, construction, and long-term O&M.

The attitude and talent of the district owning and operating the system are major factors. If the maintenance forces or the management reluctantly accept pressure sewers, or do not have the ability to work with new concepts, the project will probably be a failure.

A frequently held misunderstanding is that pressure sewers are inherently maintenance intense. Experience has not supported that opinion. Well designed pressure sewers, made easy to maintain by design and attended by qualified personnel, have been relatively easy to maintain. However, they are not tolerant of withheld maintenance, and incorrect operation and maintenance can be worse.

The engineer and the district must be willing to interface closely with the homeowners, and personnel assigned to the task must be knowledgeable and skillfully diplomatic. Each installation causes disruption to the homeowners

yard and inconvenience to them personally. The time required for public relations is usually poorly conceived and underestimated.

1.3 Vacuum Systems

1.3.1 History of Vacuum Sewer Technology

1.3.1.1 System Types

Vacuum sewer collection systems were patented in the United States in 1888, when Adrian LeMarquand invented a system of wastewater collection by barometric depression.⁴ The first commercial applications of such systems were by the Liljendahl Corporation (now known as Electrolux) of Sweden in 1959.⁵ Since that time, three other companies have been active in this market: Colt-Envirovac, Vac-Q-Tec, and AIRVAC. There are significant differences among these in terms of design concepts. The major differences lie in the extent to which the systems use separate black (toilet) and gray (the balance) water collection mains. Electrolux uses a separate system for these sources; Envirovac uses vacuum toilets and one main; and AIRVAC and Vac-Q-Tec take the normal household combined wastes. Other differences relate to the location of the gravity/vacuum interface and to the design of pumps, valves, lines, etc.

The Liljendahl-Electrolux system (Figure 1-4) was first used in the Bahamas in the 1960s. In this concept, separate black and gray water collection mains are used. The black water is discharged to one of the vacuum mains through a vacuum toilet (Figure 1-5) while the gray water enters the other through the use of a specially designed vacuum valve. The separate vacuum mains are connected to the vacuum station. For critically water-short areas, such as the Bahamas, the reduction in toilet wastewater volume was a definite factor in the selection of vacuum transport.¹ The Bahama system was removed from service in 1990.

A Vac-Q-Tec system, serving the Lake of the Woods development near Fredericksburg, Virginia, was the first residential vacuum collection system in the United States. This system uses concepts of the Liljendahl system but has many important differences.⁶ The Vac-Q-Tec system requires no inside vacuum toilets or vacuum plumbing. This system employs a single combined black and gray water collection main. Large (2,840-L [750-gal]) storage tanks are required at each residence. Finally, an external power source is required for each valve since they are electrically operated. In addition to the Lake of the Woods system, several other Vac-Q-Tec residential systems have been used by private developers.

Figure 1-4. Liljendahl-Electrolux vacuum sewer system.

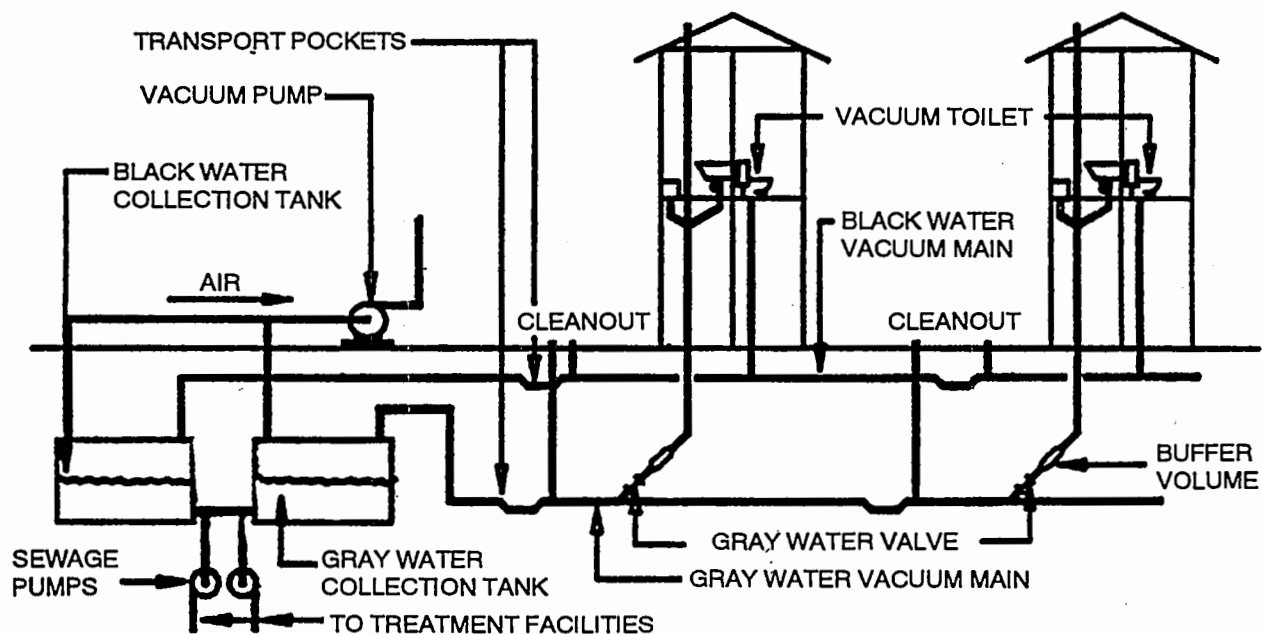
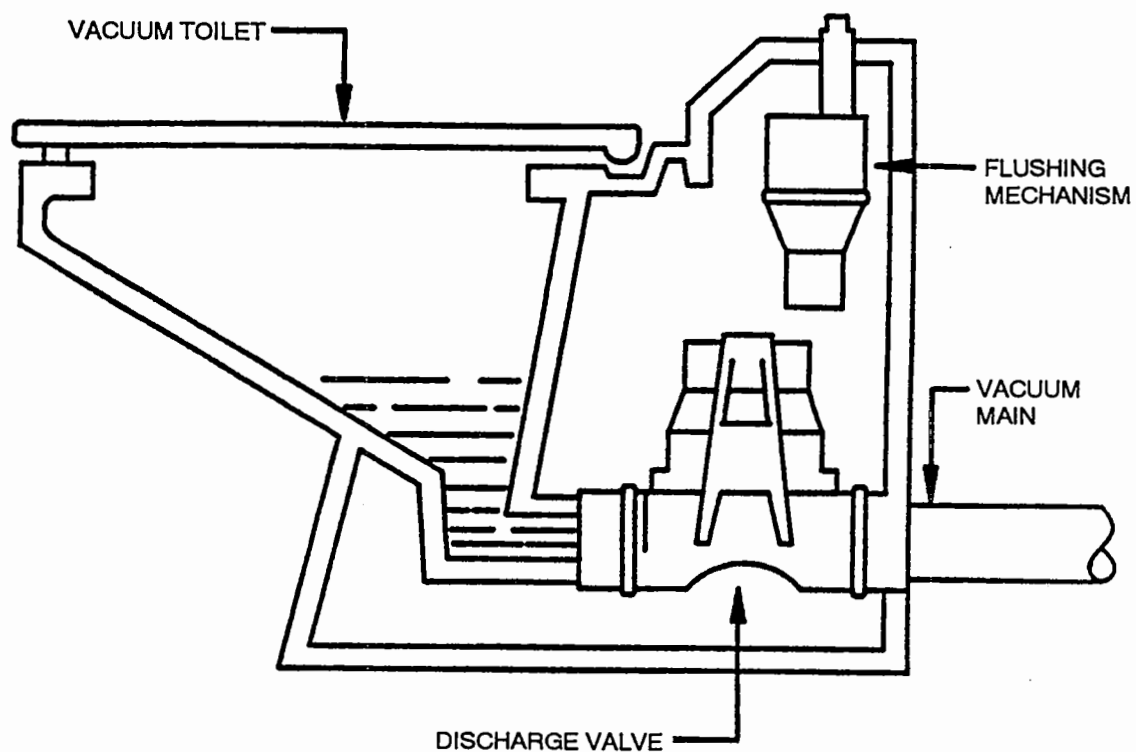


Figure 1-5. Vacuum toilet.



The Colt-Envirovac system is the direct descendent of the Liljendahl-Electrolux system (Figure 1-6). The Colt system at South Seas Plantation near Fort Meyers, Florida, served 33 residences. The houses had separate black and gray water plumbing. The black water piping from the vacuum toilet joined the gray water piping immediately downstream of the gray water valve. A single pipe with the combined contents transported the wastewater to the vacuum station. The South Seas Plantation system was removed from service a few years after installation.

AIRVAC markets a pneumatically controlled and operated vacuum valve which is used for combined grey and black water systems (Figure 1-7). The AIRVAC system allows for use of conventional plumbing in the house, with the wastewater flowing by gravity to a combined sump/valve pit. The valve starts its cycle when it senses that approximately 38 L (10 gal) has accumulated in the sump. It opens for a few seconds, which is enough to evacuate the contents of the sump as well as to allow atmospheric air to enter the system. The wastewater/air mixture then travels to the vacuum station.

AIRVAC's first system was installed in Mathews Courthouse, Virginia, in 1970. Since then AIRVAC has more than 35 additional systems operating in the United States with many more currently being planned, designed, or in construction. AIRVAC has also been very active in the foreign market with operating systems in Australia, Canada, Japan, Holland, and some other European countries.

1.3.1.2 System Comparison

Each of the four systems has unique design features. The major differences between these systems are shown in Table 1-1. The water-saving feature of the Electrolux and Colt systems is reported to be as much as 27 percent of the total in a domestic application with the use of vacuum toilets.^{7,9} AIRVAC and Vac-Q-Tec systems can be altered to accommodate these and other water-saving devices.

a. Services

Vacuum valves operate automatically, based on the volume of wastewater behind the valve. Provided that sufficient vacuum is available in the main, the valves will open after a predetermined volume of wastewater has accumulated. Wastewater enters the mains through these valves, followed by a volume of atmospheric air. The valve is actuated by a pneumatic controller in all systems except the Vac-Q-Tec system.¹

The Vac-Q-Tec's gravity-vacuum interface valve assembly is unique in that it requires an external power source.¹ The valve can be monitored and operated from the vacuum station through an extra set of contacts in the controller. A separate cycling mode, called AutoScan, can be added, which offers flexibility to the Vac-Q-Tec system. This mode locks out the accumulated volume-cycle command from each valve, and subsequently operates each valve during low-flow periods. This flexibility allows the system to store flows during peak periods and release them later during low flow periods. All of the other systems must be designed to handle peak flows. This feature does, however, add costs to the base system. Also, additional operating and skilled electronics technicians are required to maintain these complex systems.¹

Depending on the manufacturer, the amount of water entering the system with each valve operation varies. The vacuum toilet admits approximately 1.1-1.5 L (0.3-0.4 gal)/flush, whereas the pneumatically controlled vacuum valves admit 38-57 L (10-15 gal)/cycle.¹

U.S. Navy research¹⁰ has reported that good transport characteristics are found with sufficient inlet air and small enough slug loadings for the available pressure differential to overcome the liquid's inertia. This results in rapid slug breakdown, re-establishing vacuum quickly at upstream valves.

b. Collection Piping

Piping profiles differ, depending on uphill, downhill, or level terrain. The pipe profiles recommended by each manufacturer also differ. Only AIRVAC offers a complete piping design program at this time.¹¹

There have been two different concepts used in vacuum design. In the first concept, the bore of the pipe is purposely sealed during static conditions. This is accomplished through the use of reformer pockets. In the other concept, the bore of the pipe is not sealed. The reformer pocket concept has been used by all four of the manufacturers, although AIRVAC has since changed, with all of their recent systems being designed using the latter principle.¹¹

All systems use PVC pipe. Both solvent-weld and gasketed O-Ring pipe have successfully been used.

c. Vacuum Station

Vacuum stations, sometimes referred to as collection stations, vary from manufacturer to manufacturer. Table 1-2 shows the varying design parameters of each type. Electrolux and Colt vary their use of vacuum reserve tanks with each installation, while Vac-Q-Tec and AIRVAC

Figure 1-6. Colt-Envirovac vacuum sewer system.

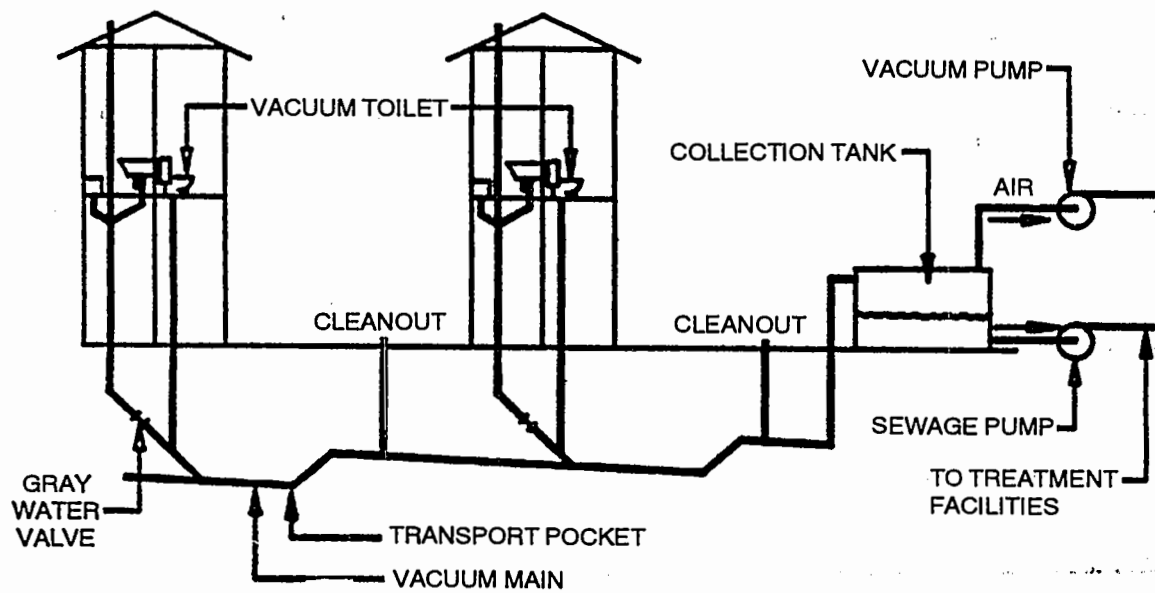


Figure 1-7. AIRVAC vacuum sewer system.

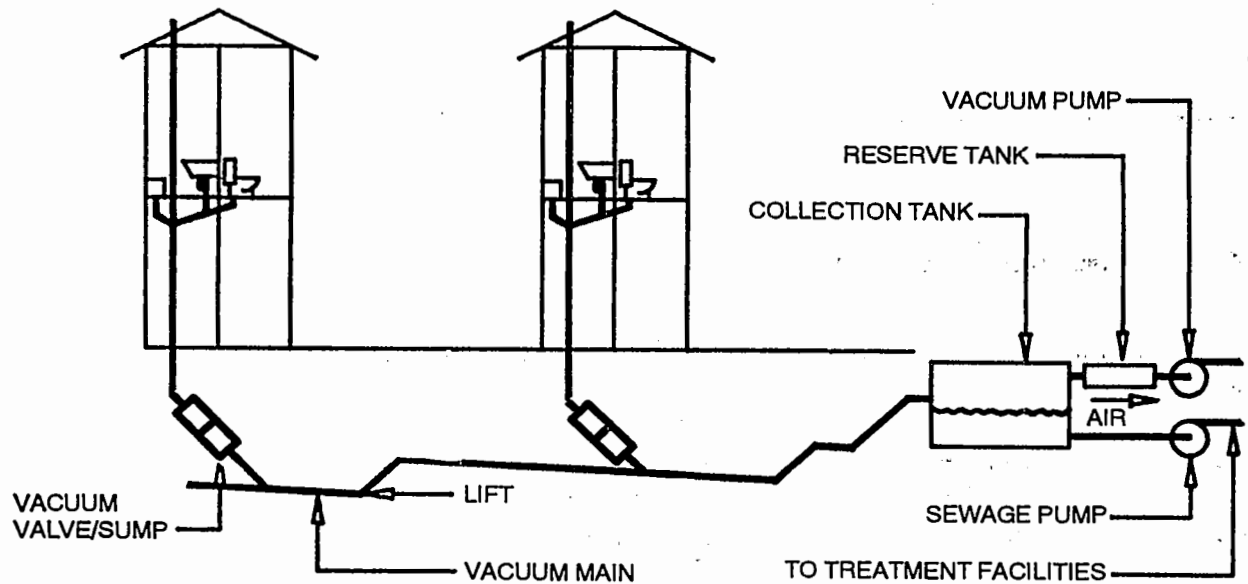


Table 1-1. Vacuum Collection System Parameters

System Type	House Piping	Valve Type	Piping Profile	Collection Line
Electrolux	Black and gray separate	Black: vacuum toilets; gray: pneumatic valves	Set configuration with traps	Black: 1-1/2" & 2"; gray: 2" & 3; PVC solvent weld
Colt-Envirovac	Black and gray separate	Black: vacuum toilets; gray: pneumatic valves	Set configuration with traps	Single main, 3", 4", & 6"; PVC, special "O" ring
Vac-Q-Tec	Conventional plumbing	Electrically actuated, pneumatic valve	Parallels terrain with traps	Single main, 4"; PVC Solvent Weld
AIRVAC	Conventional plumbing	Pneumatic valve	Set configuration with profile changes	Single main, 4", 6", & 8; PVC, solvent weld or "O" ring

Table 1-2. Vacuum Station Parameters

System Type	Receiving Tank	Receiving Tank Evacuation Device	Valve Monitoring and Control Capability
Electrolux	Separate black and gray water vessels. Reserve tank use varies by installation.	Sewage pumps	No
Colt-Envirovac	Common receiving vessel. Reserve tank use varies.	Sewage pumps	No
Vac-Q-Tec	One receiving vessel plus reserve tank.	Pneumatic ejectors	Yes
AIRVAC	One receiving vessel plus reserve tank.	Sewage pumps	No

Table 1-3. Summary of Vacuum System Types

System Type	Target Market	Current Status	No. U.S. Systems	Design Approach
Electrolux	Residential	Sold license to Colt in 1970s	0	In-house No design manual
Colt-Envirovac	Shipbuilder Industrial	Now a subsidiary of Evak	5	In-house No design manual
Vac-Q-Tec	Residential	Ceased operation in recent years	5	In-house No design manual
AIRVAC	Residential	Active	30	Published design manual

always use reservoir tanks between the collection tank and the vacuum pumps.¹

1.3.1.3 Summary

Four manufacturers have played a major role in the development of vacuum sewer systems. There are significant differences in overall system philosophy, design concepts, system components, and marketing approaches (Table 1-3). While all four were active 20 years ago in the United States, only AIRVAC has continued to place residential systems into operation on a regular basis. Some of the early systems of Colt-Envirovac and Vac-Q-Tec are currently being retrofitted with AIRVAC valves.

1.3.2 Simplified System Description

1.3.2.1 Basic System Sketch

Figure 1-8 shows the basic vacuum sewer system layout, including the major components. This layout is based on an AIRVAC type of system since it is the most common.

1.3.2.2 Components

A vacuum sewer system consists of three major components: the vacuum station, the collection piping, and the services. Each is described below:

a. Services

Wastewater flows by gravity from one or more homes into a 114-L (30-gal) holding tank. As the wastewater level rises in the sump, air is compressed in a sensor tube which is connected to the valve controller. At a preset point, the sensor signals for the vacuum valve to open. The valve stays open for an adjustable period of time and then closes. During the open cycle, the holding tank contents are evacuated. The timing cycle is field adjusted between 3 and 30 seconds. This time is usually set to hold the valve open for a total time equal to twice the time required to admit the wastewater. In this manner, air at atmospheric pressure is allowed to enter the system behind the wastewater. The time setting is dependent on the valve location since the vacuum available will vary throughout the system, thereby governing the rate of wastewater flow.

The valve pit typically is located along a property line. AIRVAC'S valve pit/holding tank arrangement (Figure 1-9) is usually made of fiberglass, although modified concrete manhole sections have been used for special situations (deep basements, large user, pressure/vacuum interface, etc.). A non-traffic lightweight aluminum or cast iron lid is available for yard installations. Where the installation will be subjected to vehicular loading, a flush-mounted cast iron lid is used. An anti-flotation collar may be required in some cases.

b. Collection Piping

The vacuum collection piping usually consists of 15-cm and 10-cm (6- and 4-in) mains, although more recent installations also include 25-cm (10-in) mains in some cases. Smaller (7.5-cm [3-in]) mains used in early vacuum systems are no longer recommended, as the cost savings of 7.5-cm vs. 10-cm (3-4 in) mains are considered to be insignificant.

Both solvent welded PVC pipe and rubber gasketed pipe have been used, although past experience indicates that solvent welding should be avoided when possible. Where rubber gaskets are used, they must be certified by the manufacturer as being suitable for vacuum service. The mains are generally laid to the same slope as the ground with a minimum slope of 0.2 percent. For uphill transport, lifts are placed to minimize excavation depth (Figure 1-10). There are no manholes in the system; however, access can be gained at each valve pit or at the end of a line where an access pit may be installed. Installation of the pipe and fittings follows water distribution system practices. Division valves are installed on branches and periodically on the mains to allow for isolation when troubleshooting or when making repairs. Plug valve and resilient wedge gate valves have been used.

c. Vacuum Station

The vacuum station is the heart of the vacuum sewer system.¹¹ It is similar to a conventional wastewater pumping station. These stations are typically two-story concrete and block buildings approximately 7.5 m x 9 m (25 x 30 ft) in floor plan. Equipment in the station includes a collection tank, a vacuum reservoir tank, vacuum pumps, wastewater pumps, and pump controls (Figure 1-11). In addition, an emergency generator is standard equipment, whether it is located within the station or outside the station in an enclosure or is of the portable, truck-mounted variety.

The collection tank, made of either steel or fiberglass, is the equivalent of a wet well in a conventional pumping station. The vacuum reservoir tank is connected directly to the collection tank to prevent droplet carryover and to reduce the frequency of vacuum pump starts and thereby extend their life. The vacuum pumps can be either liquid ring or sliding vane type. These pumps are usually sized for 3-5 hr/d run-time. The wastewater discharge pumps are non-clog pumps with sufficient net positive suction head to overcome tank vacuum. Level control probes are installed in the collection tank to regulate the wastewater pumps. Vacuum switches on the reservoir tank regulate the vacuum pumps. A fault monitoring system alerts the system operator should a low vacuum or high wastewater level condition occur.

Figure 1-8. Major components of a vacuum sewer system.

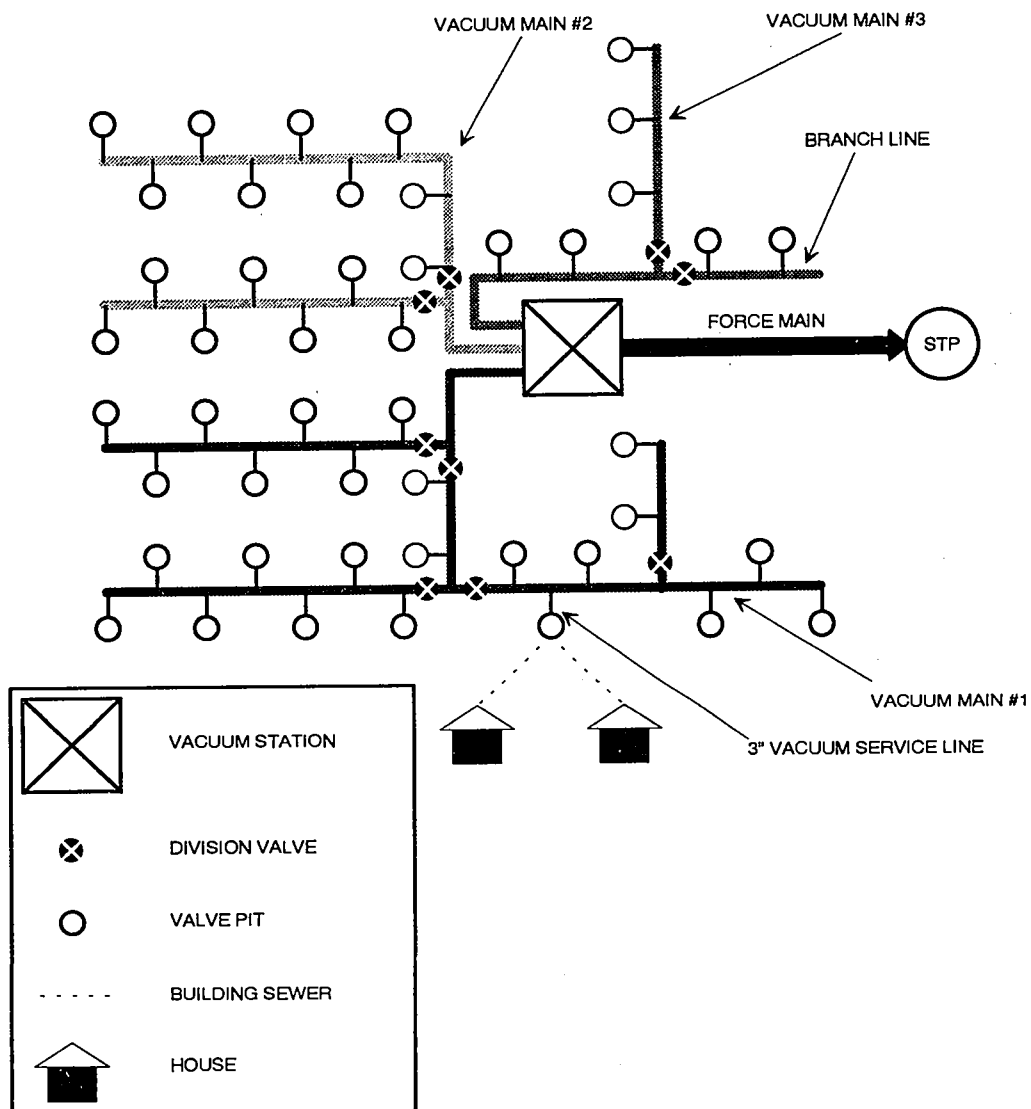


Figure 1-9. AIRVAC valve pit/sump arrangement.

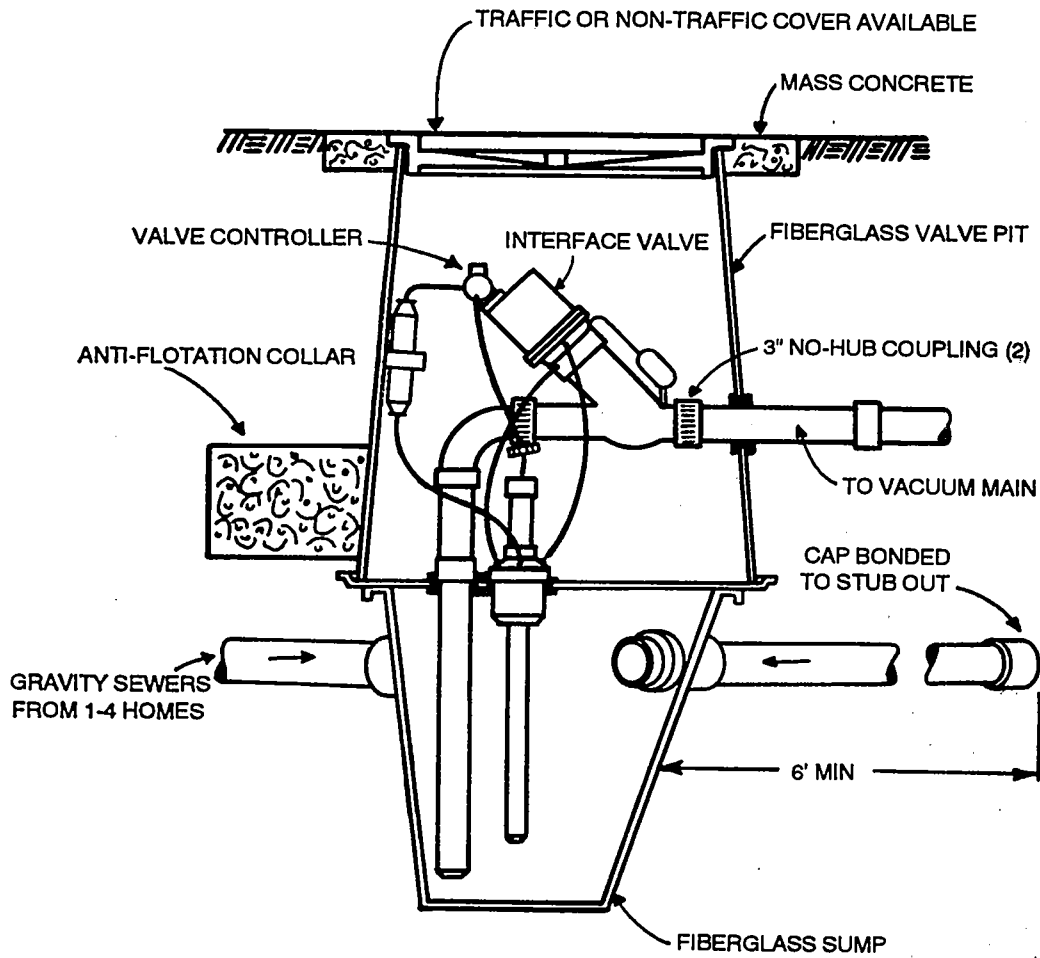
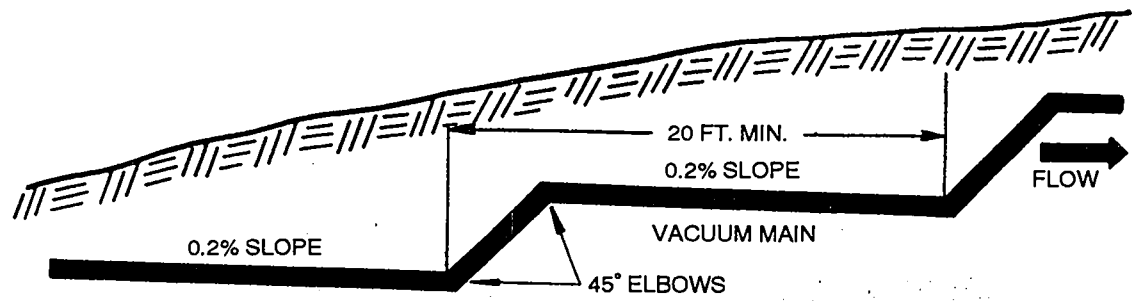
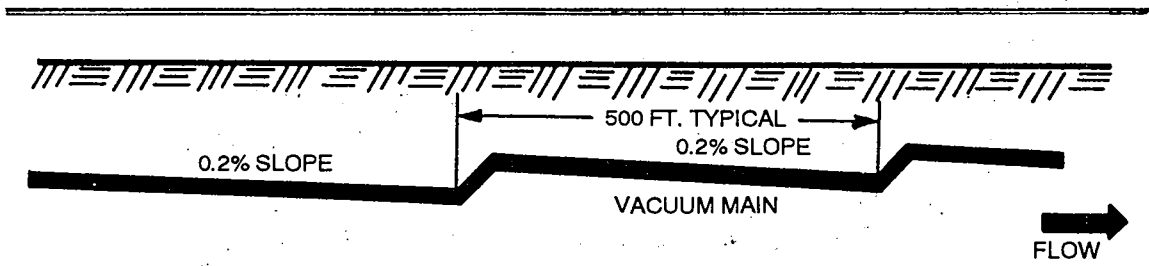


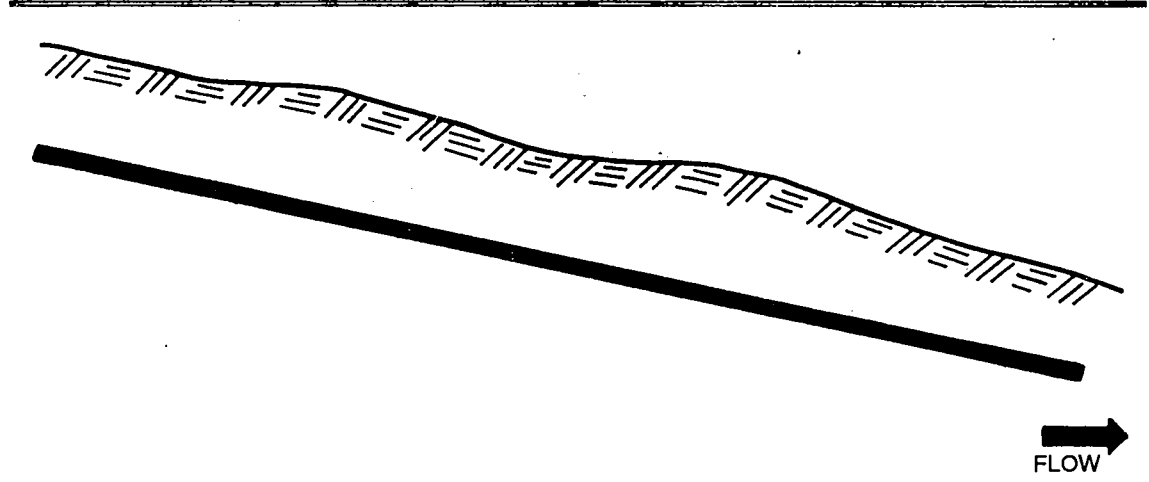
Figure 1-10. Upgrade/level/downgrade transport. (Reprinted courtesy of AIRVAC)



UPGRADE TRANSPORT

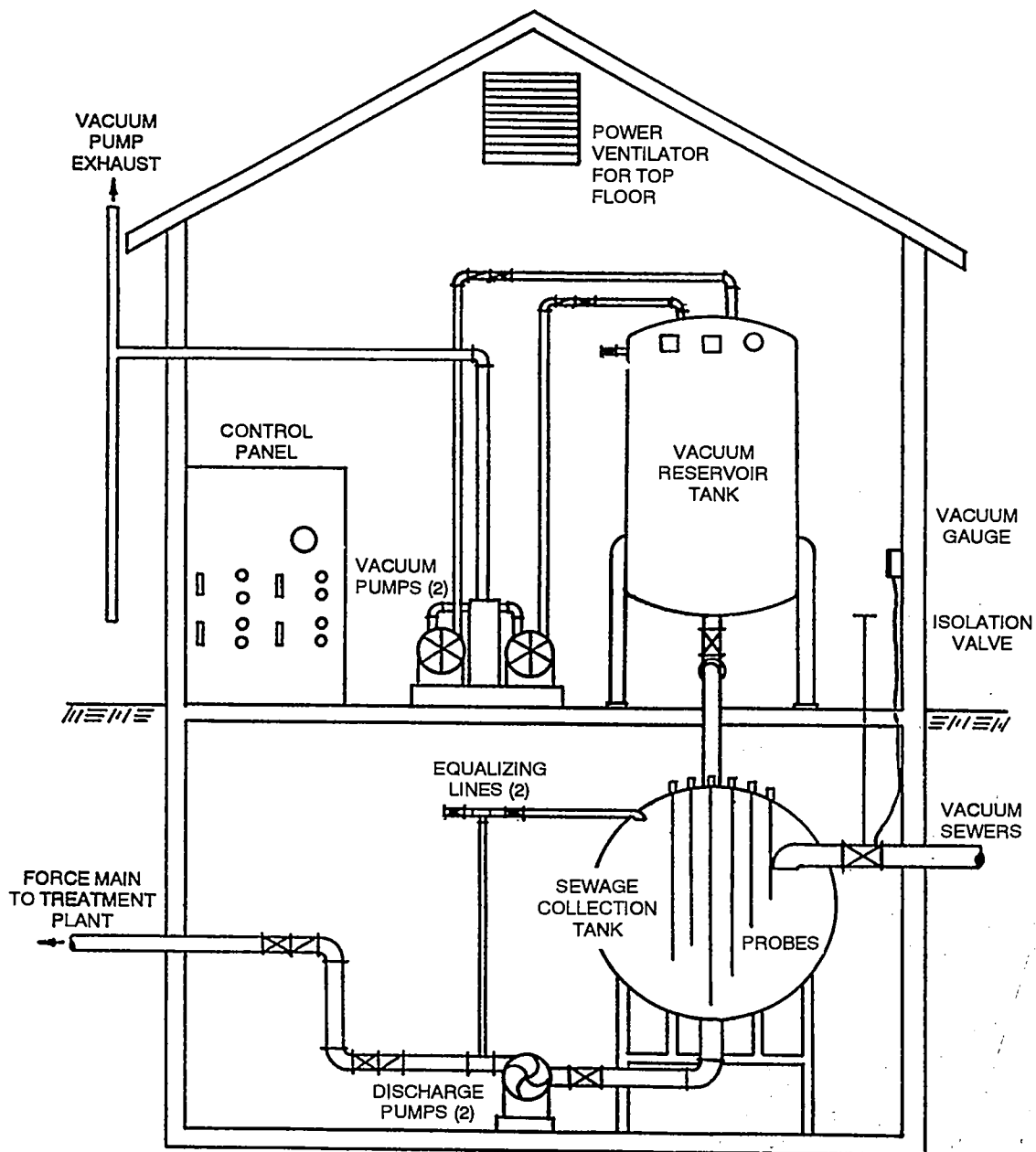


LEVEL GRADE TRANSPORT



DOWNGRADE TRANSPORT

Figure 1-11. Diagram of a typical vacuum station. (Reprinted courtesy of AIRVAC)



1.3.2.3 Operation

Vacuum or negative-pressure sewer systems use vacuum pumps at central collection stations to evacuate air from the lines, thus creating a pressure differential.¹¹ In negative pressure systems, a pneumatically operated valve serves as the interface between the gravity system from the individual user and the vacuum pipelines. Pressure sensors in a wastewater holding tank open and close the interface valve to control the flow of wastewater and air into the vacuum system.

The normal sequence of operation is as follows:

- Wastewater from the individual service flows by gravity to a holding tank.
- As the level in the holding tank continues to rise, air is compressed in a small diameter sensor tube. This air pressure is transmitted through a tube to the controller/sensor unit mounted on top of the valve. The air pressure actuates the unit and its integral 3-way valve which allows vacuum from the sewer main to be applied to the valve operator. This opens the interface valve and activates a field adjustable timer in the controller/sensor. After a set time period has expired, the interface valve closes.¹¹ This happens as a result of the vacuum being shut off, allowing the piston to close by spring pressure.
- The wastewater within the vacuum sewer approximates the form of a spiral rotating hollow cylinder traveling at 38-45 cm/s (15-18 fps). Eventually, the cylinder disintegrates from pipe friction, and the liquid flows to low points (bottom of lifts) in the pipeline.
- The next liquid cylinder and the air behind it will carry the liquid from the previously disintegrated cylinders up over the sawtooth lifts designed into the system. In this manner, the wastewater is transported over a series of lifts to the vacuum station.

The principles of operation of a vacuum sewer system are not completely understood. An early concept was that of liquid plug flow. In this concept, it was assumed that a wastewater plug completely sealed the pipe bore during static conditions. The movement of the plug through the pipe bore was attributed to the pressure differential behind and in front of the plug. Pipe friction would cause the plug to disintegrate, thus breaking the vacuum. With this being the situation, reformer pockets were located in the vacuum sewer to allow the plug to reform and thus restore the pressure differential (Figure 1-12). In this concept, the re-establishment of the pressure differential for each disintegrated plug was a major design consideration.

In the current design concept, the reformer pockets are eliminated so that the wastewater does not completely fill or "seal" the pipe bore. Air flows above the liquid, thus maintaining a high vacuum condition throughout the length of the pipeline (Figure 1-13). In this concept, the liquid is assumed to take the form of a spiral, rotating, hollow cylinder. The momentum of the wastewater and the air carries the previously disintegrated cylinders over the downstream sawtooth lifts. The momentum of each subsequent air/liquid slug and its contribution to the progressive movement of the liquid component of the previous slugs are the major design considerations.

Both of the above design concepts are approximations and oversimplifications of a complex, two-phase flow system. The character of the flow within the vacuum sewer varies considerably. The plug flow concept is probably a reasonable approximation of the flow as it enters the system, whereas the progressive movement concept is probably a better approximation of the flow throughout the vacuum main.

The significance of the air as a driving force cannot be overemphasized. The atmospheric air expands within the vacuum sewer, thus driving the liquid forward. The air affects not only the liquid in the associated air/liquid slug, but also the liquid downstream.

1.3.3 Potential Applications

Below are the general conditions that are conducive to the selection of vacuum sewers.

- Unstable soils
- Flat terrain
- Rolling terrain with small elevation changes
- High water table
- Restricted construction conditions
- Rock
- Urban development in rural areas

Experience has shown that for vacuum systems to be cost effective, a minimum of 75-100 customers is needed per custom vacuum station. Package vacuum stations have proven to be cost-effective for service areas of 25-150 customers. The average number of customers per station in systems presently in operation is about 200-300. There are a few systems with fewer than 50 and some with as many as 2,000/station. There are communities which have multiple vacuum stations, each serving hundreds of customers.

Hydraulically speaking, vacuum systems are limited somewhat by topography. The vacuum produced by a vacuum station is capable of lifting wastewater 4.5-6 m (15-20 ft), depending on the operating level of the system.

Figure 1-12. Early design concept- reformer pockets.

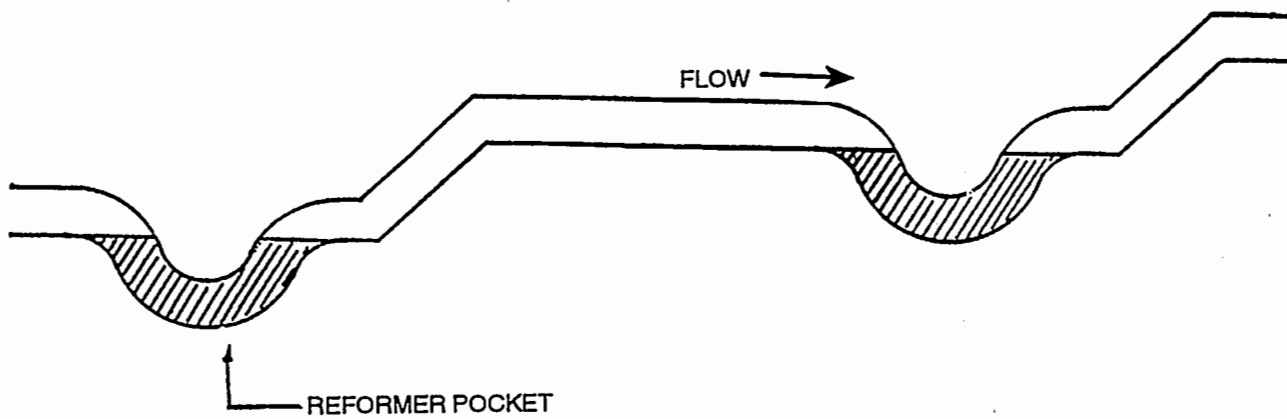
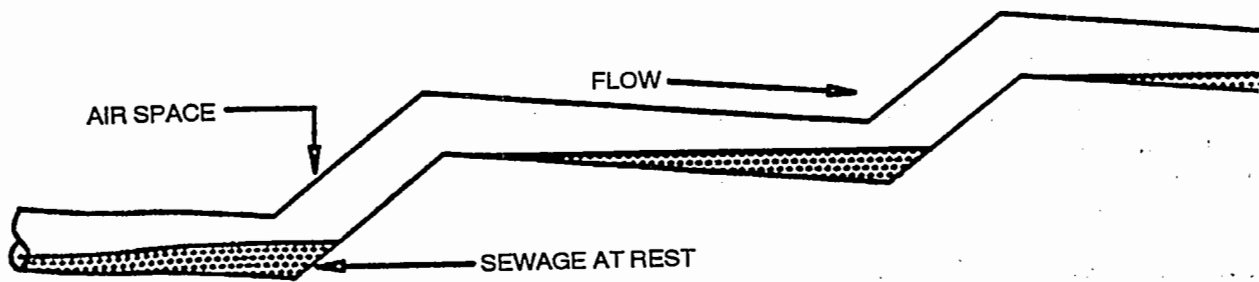


Figure 1-13. Current design concept - pipe bore not sealed.



This amount of lift many times is sufficient to allow the designer to avoid the lift station(s) that would be required in a conventional gravity system.

1.3.4 Extent of Use in the United States

Table 1-4 shows the operating residential vacuum sewer systems in the United States as of January 1990. There are another dozen or so presently in the construction phase, with more being planned and designed.

In addition to the above residential systems, several industrial facilities use vacuum systems to collect wastewater.³ These companies include the Scott Paper Company pulp and paper mill in Mobile, Alabama, with 25 AIRVAC valves; Stauffer Chemical Company in Baton Rouge, Louisiana, with 7 AIRVAC valves; and Keystone Steel and Wire Company in Peoria, Illinois, with 29 AIRVAC valves. ENVIROVAC type systems using vacuum toilets are used in remote construction camps and park restroom facilities, and along with another vacuum system manufacturer, Jered Industries, in many shipboard installations. These types of installations are beyond the scope of this report and will not be addressed.

1.3.5 Myths vs. Reality

Many myths exist concerning vacuum sewer systems. In reality, a vacuum system is not unlike a conventional gravity system. Wastewater flows from the individual homes and utilizes gravity to reach the point of connection to the sewer main. The equipment used in the vacuum station is similar in mechanical complexity to that used in a conventional lift station. The most common myths concerning vacuum sewer technology are discussed below.

MYTH: Vacuum sewers are only to be considered where flat terrain exists.

REALITY: Vacuum sewers should be considered in level, downhill, and uphill terrain. The practical limit of uphill transport historically has been 4.5-6 m (15-20 ft) of vertical lift, although experimental systems are being tested which may increase the feasible vertical lift limit.

MYTH: Vacuum sewers should not be considered when the potential for gravity flow exists.

REALITY: Many times a broad view of an area's terrain automatically rules out vacuum sewers as an alternative to be considered. However, a closer look may reveal many small advantages, that, when considered collectively, add up to a significant savings.

Table 1-4. Operating Vacuum Systems in the United States

Project Name	Project Location	System Type
Martingham	St. Michaels, MD	AIRVAC
Foxcliff Estates	Martinsville, IN	AIRVAC
Country Squire Lakes	North Vernon, IN	AIRVAC
Mathews Courthouse	Mathews, VA	AIRVAC
Plainville	Plainville, IN	AIRVAC
Eastpoint	Eastpoint, FL	AIRVAC
Westmoreland	Westmoreland, TN	AIRVAC
Fallen Leaf Lake	South Lake Tahoe, CA	AIRVAC
Falmont	Somerset County, MD	AIRVAC
Queen Anne's County	Queen Anne's Co., MD	AIRVAC
LaFargeville	LaFargeville, NY	AIRVAC
Charlotte	Charlotte, TN	AIRVAC
Ohio Co. - Cedar Rocks	Wheeling, WV	AIRVAC
Ohio Co. - Peters Run	Wheeling, WV	AIRVAC
Ohio Co. - Short Creek	Wheeling, WV	AIRVAC
Friendly PSD	Friendly, WV	AIRVAC
Central Boaz PSD	Parkersburg, WV	AIRVAC
Red Jacket PSD	Red Jacket, WV	AIRVAC
Washington Lands PSD	Washington Lands, WV	AIRVAC
Cedar Grove	Lexington Park, MD	AIRVAC
Lake Chautauqua	Celeron, NY	AIRVAC
Lag Marina	Norfolk, VA	AIRVAC
Emmonak	Emmonak, AK	AIRVAC
Swan Point	Swan Point, MD	AIRVAC
Alton	Alton, KY	AIRVAC
White House	White House, TN	AIRVAC
Morristown	Morristown, NY	AIRVAC
Lake Manitou	Rochester, IN	AIRVAC
Theresa	Theresa, NY	AIRVAC
Sanford	Sanford, FL	AIRVAC
Claywood Park	Parkersburg, WV	AIRVAC
New Cumberland	New Cumberland, WV	AIRVAC
Big Sandy	Charleston, WV	AIRVAC
Lanark Village	Lanark Village, FL	AIRVAC
Pattersontown	Pattersontown, FL	AIRVAC
Beallsville	Beallsville, PA	AIRVAC
Salmon Beach	Puget Sound, WA	AIRVAC
Noorvik	Noorvik, AK	ENVIROVAC
Big Bear Lake	Big Bear Lake, CA	ENVIROVAC
Centertown	Centertown, KY	ENVIROVAC
Stafford Township	Manahawkin, NJ	ENVIROVAC
Ocean Pines	Berlin, MD	VAC-Q-TEC
Lake of the Woods	Locust Grove, VA	VAC-Q-TEC
Shipyard Plantations	Hilton Head Island, SC	VAC-Q-TEC
Palmetto Dunes	Hilton Head Island, SC	VAC-Q-TEC
Captain's Cove	Greenback, VA	VAC-Q-TEC

An example of this occurred in the Ohio County PSD-Peters Run project in Wheeling, West Virginia. In that project, it only seemed logical to the designer to use conventional gravity sewers. The area was rural with residential development following a creek. However, upon closer inspection, it was evident that the gravity main would be required to cross the creek in various places, since the development was on both sides. With the creek bank being 3-m (10-ft) deep and the creek crossing requiring 1 m (3 ft) of cover, the gravity sewer would have been 4-m (13-ft) deep for most of its length (Figure 1-14). At the terminus of the system, a lift station was needed to pump the wastewater to a plant, which was located above 100-yr flood elevation.

By utilizing vacuum, the designer used "lifts" to raise the main above the bedrock level to a depth of 1.2-1.5 m (4-5 ft) (Figure 1-15). The vacuum station that was required was nothing more than the lift station that was required in the gravity layout, with the exception of the addition of vacuum pumps. This additional expense was more than offset by the savings of the line installation. The "inexpensive" conventional gravity system would have required deep, difficult excavations with much rock. The vacuum alternative had much shallower excavations with little rock. In essence, the vacuum system was installed as a "vacuum assisted-gravity sewer" with significant cost savings.

MYTH: Since vacuum sewers are mechanized, they undoubtedly are unreliable.

REALITY: Early vacuum systems were not without their problems. However, component improvements, design advancements, and experience with the technology have resulted in systems that are very reliable.

MYTH: Vacuum sewers are operation and maintenance intensive.

REALITY: In general, vacuum sewers may be less costly to construct than conventional sewers, but may be more expensive to operate and maintain. However, the magnitude of the O&M effort has been greatly overstated. This is due largely to the little historical data that exist coupled with the conservative nature of most engineers.

MYTH: Replacement parts are expensive.

REALITY: The components of the vacuum station are not unlike those of a conventional pumping station. The small parts of the vacuum valve that are subjected to

wear are very inexpensive. A vacuum valve and controller can be rebuilt for about \$30. Rebuild frequency is 5-10 yr.

MYTH: The vacuum pumps must run 24 hr/d to keep vacuum on the system.

REALITY: The typical vacuum station is designed so that the vacuum pumps operate about 3-5 hr/d.

MYTH: It takes a tremendous amount of energy to keep constant vacuum on the systems.

REALITY: The average sized vacuum station contains 20-hp vacuum pumps. Considering a run-time of 5 hr/d and the cost of electricity at \$0.08/kWh, the cost of power for the vacuum pumps is about \$185/month. A system this size can and typically does serve 200-300 customers.

MYTH: The operation of a vacuum system requires a person with a college degree.

REALITY: Any person that is mechanically inclined can operate a vacuum system. Most of the systems in operation in the U.S. have operators with no more than a high school education.

MYTH: If the vacuum valve fails, wastewater will back up into my house.

REALITY: Vacuum valves can fail in either the open or closed position. One failing in the closed position will result in backups. This would be analogous to a blockage or surcharging of a gravity sewer. Fortunately, failure in this mode is rare. Almost all valve failures happen in the open position. This means that the vacuum continues to try to evacuate the contents of the pit. The vacuum pumps usually run continuously to keep up, as this failure simulates a line break. In these cases, a telephone dialer feature available in vacuum stations notifies the operator of this condition. Correction of the problem can generally be made in less than an hour after the operators arrive at the station.

In short, many of the major objections to the use of vacuum systems are not well founded. These systems have been acceptable in a variety of applications and locations. Any hypothetical or abstract difficulty that can be applied to the vacuum system can also be applied to the more conventional systems. In any event, the vacuum system offers the same convenience as any other type of

Figure 1-14. Gravity sewer system example.

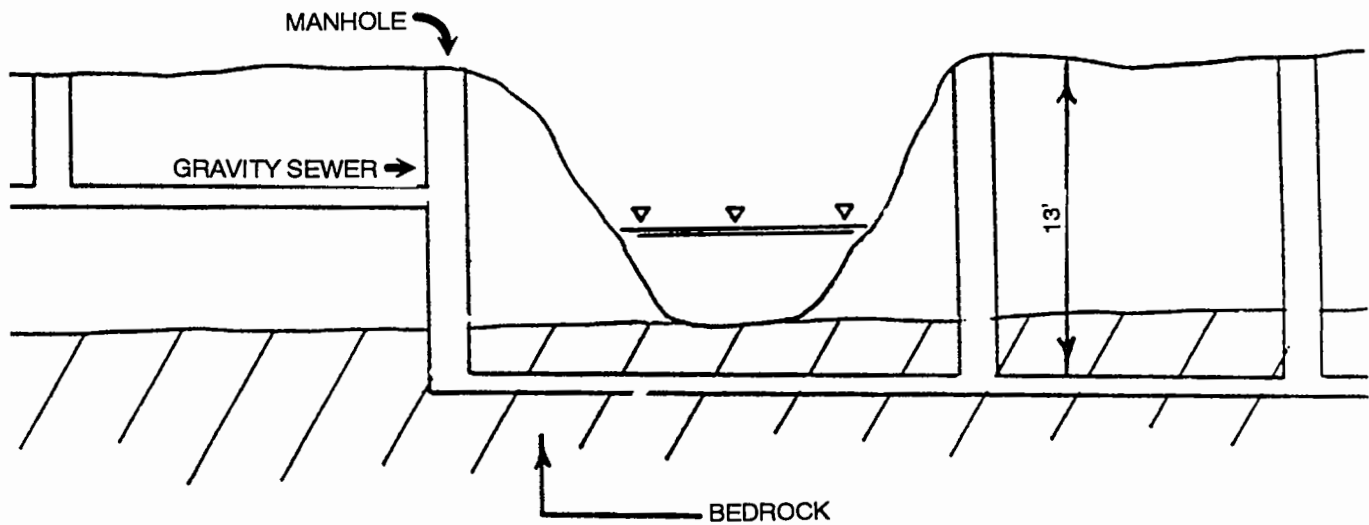
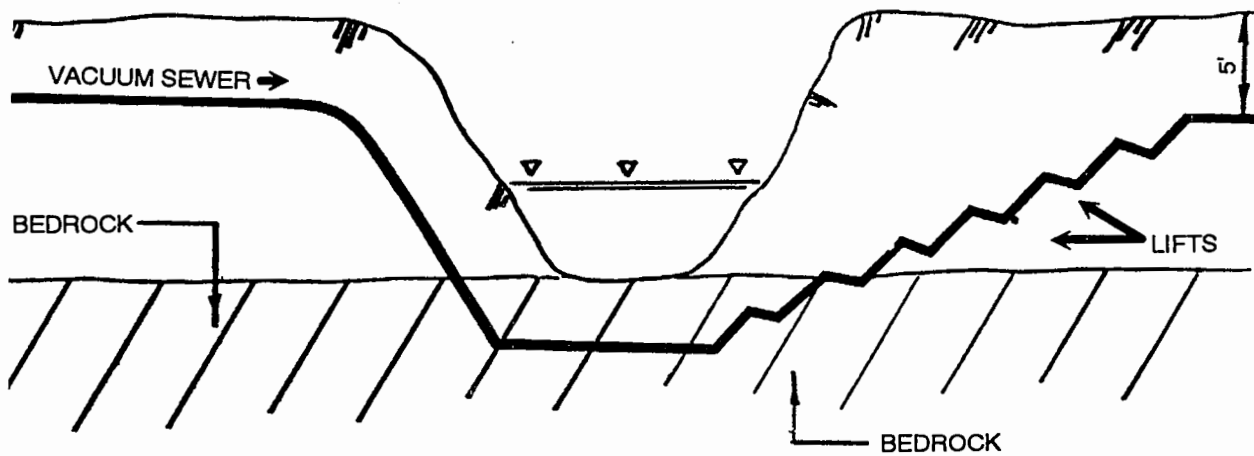


Figure 1-15. Vacuum-assisted gravity sewer system example.



public sewer system with reference to the actual discharge from the home and meeting the needs of the particular locality.

1.4 Small Diameter Gravity Sewers

1.4.1 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 or septic tanks installed upstream of each connection (Figure 1-16). 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. Fewer manholes are used and most are replaced by cleanouts except at major junctions to limit infiltration/inflow (I/I) and entry of grit. The required size and shape of the mains is dictated primarily by hydraulics rather than solids carrying capabilities as with conventional gravity sewers.

Designers must still, however, be cognizant of I/I and ultimate growth in sizing these systems. 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 or maintained by the utility districts so that regular pumping to remove the accumulated solids for safe disposal is ensured.

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 10 cm (4 in) in diameter, laid on a uniform gradient sufficient to maintain only a 45 cm/s (1.5 fps) flow velocity were permitted. This alternative has been estimated to reduce construction costs by 30-65 percent. 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 system.¹²

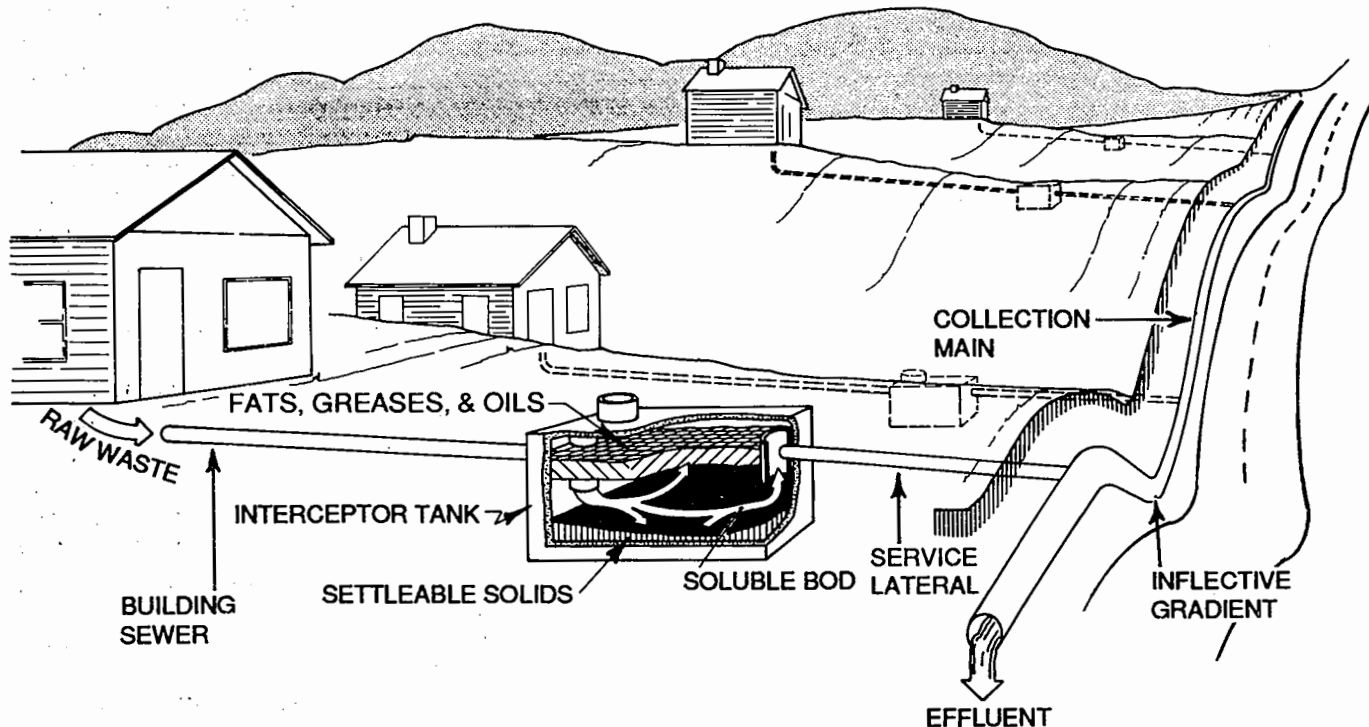
In the United States, small diameter gravity sewers were not introduced until the mid-1970's.² The first systems, located in Mt. Andrew, Alabama and Westboro, Wisconsin, were small demonstration systems with 13 and 90 connections respectively. The Mt. Andrew system was constructed as a variable grade system with sections of sewer depressed below the static hydraulic grade line.¹³ The Westboro system was designed with uniform gradients using the more conservative Australian guidelines.¹⁴ The Westboro system was estimated to be 30 percent 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. 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 tank 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:

- **House Connections** are made at the inlet to the interceptor tank. All household wastewaters enter the system at this point.
- **Interceptor Tanks** are buried, 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 12-24 hr. 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, vented through the house plumbing stack vent, is used as an interceptor tank.
- **Service Laterals** connect the interceptor tank with the collector main. Typically, they are 7.5-10 cm (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.

Figure 1-16. Schematic of a SDGS system.



- **Collector Mains** are small diameter plastic pipes with typical minimum diameters of 7.5-10 cm (3-4 in), although 3-cm (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.
- **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 may be necessary at the high points of the main.

- **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 wastewater solids. The most significant feature of small diameter sewers is that primary pretreatment is provided in interceptortanks 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 interceptortank also

attenuates the wastewater flow rate from each connection which reduces the peak to average flow ratio, below what is typically used for establishing design flows for conventional gravity sewers. Yet, except for the need to evacuate the accumulated solids in the interceptor tanks periodically, SDGS operate similarly to conventional sewers.

1.4.2 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 mainline 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.

1.4.3 Extent of Use in the United States

The use of small diameter gravity sewers has been rapidly increasing in the United States. They have been referred to by different names including Australian sewers, 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 the Australian sewers or CED typically are designed to have uniform gradients with a minimum flow velocity of 0.30 cm/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 have 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, which have sometimes been called "effluent sewers" or "solids-free sewers."

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

1.4.4 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 "second-rate" systems. 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. Several early systems did have odor problems due to ignorance of the odor potential of free-falling interceptor tank effluent and problems due to improper house and tank sealing. By minimizing turbulence in the mains and at lift stations and providing proper venting, odor problems have been easily overcome. With proper planning, expansion can be accommodated and with proper design, odor 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.

1.5 Comparison with Conventional Collection

The following features of the various sewerage alternatives are considered in planning a project.

1.5.1 Population Density

Conventional sewers are typically costly on a lineal foot basis. Where housing is sparse, resulting in long reaches between services, the cost of providing conventional sewers is often prohibitive.

Pressure sewers, small diameter gravity sewers, and vacuum sewers are typically less costly on a lineal foot basis, so often prove to be more cost-effective when serving sparse populations.

Conversely, where the required length of sewer between service connections is comparatively short, the cost of providing conventional sewers is usually affordable unless some other obstacle is present, such as adverse slopes or rock excavation. Even when conventional sewers are slightly more expensive than alternative sewers, their use may be preferred as conventional sewerage is an old and mature practice.

1.5.2 Growth Inducement

The minimum allowed size of conventional sewers is generally 20-cm (8-in) diameter, to accommodate sewer cleaning equipment. Being comparatively large in diameter (and capacity), conventional sewers are often seen as being growth inducing. This is especially true if assessment costs to fronting properties are high, which prompts property owners to develop the property for housing. This is often the most profitable alternative for the property owner and as such provides the greatest financial relief from the assessment.

Pressure sewer, small diameter gravity sewer, and vacuum sewer mains may be intentionally downsized to limit growth. Innovation in assessment rates can reduce the need for property development as a means of escaping imposed charges. However, designer/owners may wish to allow for some level of growth. This can be incorporated with alternative sewers as well as conventional ones.

1.5.3 Ground Slopes

Where the ground profile over the main slopes continuously downward in the direction of flow, conventional or small diameter gravity sewers are normally preferred. If intermittent rises in the profile occur, conventional sewers may become cost-prohibitively deep. The variable grade gravity sewer variation of small diameter gravity sewers, by use of inflective gradients and in conjunction with STEP pressure sewer connections, can be economically applied. Vacuum sewers may be particularly adaptable to this topographic condition, so long as head requirements are within the limits of available vacuum (see vacuum sewer section).

In flat terrain conventional sewers become deep due to the continuous downward slope of the main, requiring frequent use of lift stations. Both the deep excavation and the lift stations are expensive. SDGS are buried less deep, owing to the flatter gradients permitted. Pressure sewers and vacuum sewers are often found to be practical in flat areas, as ground slope is of little concern. In areas

where the treatment facility or interceptor sewer are higher than the service population, pressure sewers and vacuum sewers are generally preferred, but should be evaluated against SDGS systems with lift stations.

1.5.4 Subsurface Obstacles

Where rock excavation is encountered, the shallow burial depth of alternative sewer mains reduces the amount of rock to be excavated.

Deep excavations required of conventional sewers sometimes encounter groundwater. Depending on severity, dewatering can be expensive and difficult to accomplish.

1.5.5 Discharge to Gravity Sewers

Where homes are in proximity to a conventional gravity sewer, but where conventional service is impractical, alternatives may often be used. Grinder pumps or solids handling pumps are used at individual homes to discharge from low-lying homes to the conventional sewer. Vacuum sewers are used to serve large enough groups of homes to justify the cost of the vacuum station.

STEP pressure sewers are commonly used in conjunction with SDGS. Such hybrid installations are more common than strictly STEP or strictly SDGS, even though these sewers are usually classified as one of these types. Their discharge into some conventional sewers may be feasible, but the discharge of sulfides to the sewer must be evaluated when such discharges are large enough to constitute a significant portion of the total flow.

1.5.6 Discharge to Subsurface Disposal Fields

STEP pressure sewer equipment is commonly used to discharge septic tank effluent to subsurface disposal fields that are distant or located at higher elevations than the homes served. SDGS may also be used for conveyance of effluent to subsurface disposal facilities so long as ground slopes are favorable for gravity flow.

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National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

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CHAPTER 2

Pressure Sewer Systems

2.1 Introduction

2.1.1 Background

Historically there have been only two choices for the disposal of domestic wastewater: either conventional sewers were used, usually having lift stations as needed within the system, and discharging to municipal treatment works, or septic tanks and drainfields were used. Conventional sewers were generally used in cities and larger towns, and septic tanks and drainfields were more common in rural areas.

These technologies are mature and time honored, but there are cases where neither method is well suited. Where rock excavation is encountered the deep excavations for conventional sewers can result in excessive costs. Similar obstacles to conventional sewer construction include high groundwater, and terrain that does not slope favorably for gravity collection. Where homes are spaced distantly the resulting long length of sewer between homes results in unacceptably high costs.

Septic tank drainfields encounter difficulties when located in tight clay soils that have low absorption rates, or in areas of high groundwater. In these cases effluent often surfaces above the drainfields. Where soils are too porous the effluent may flow too freely and enter the groundwater without sufficient treatment.

In instances such as described above, pressure sewers and other alternate technologies should be considered.

2.1.2 History

Lift stations have long been used with conventional sewers, and occasionally household pumps having solids handling capabilities have been used to lift wastewater from low lying homes to conventional sewer mains. Pumps have long been used to discharge effluent from septic tanks to distant or elevated drainfields, but until the last 15 years there has been no widespread use of pressure sewer systems.

Mortimer Clift was among the first to report on pressure sewer technology regarding a system serving 42 homes in Radcliff, Kentucky.¹ Solids handling pneumatic ejectors were used which discharged via 7.5-cm (3-in) diameter service lines to a 10-cm (4-in) main, following the concepts of a patent issued to him in 1965. The system was eventually abandoned due to equipment problems, but no uncorrectable obstacles were apparent regarding the pressure sewer concept.

With concern for the limited capacities of the numerous combined storm - sanitary sewers existing in the United States., Gordon M. Fair proposed a solution announced publicly in 1965. Fair suggested conveying domestic wastewater in a pressure sewer main separate from storm water, with the main being hung from the crown of the existing combined sewer. His patented "converted sewer system", issued in 1968, was assigned to the public.

Fair's proposal prompted a study of the concept by the American Society of Civil Engineers (ASCE), for the Federal Water Pollution Control Administration. During this time General Electric subcontracted with the ASCE to develop a grinder pump package following the directives of the ASCE engineers. The final report, published in 1969, concluded unfavorably toward the concept due to costs associated with placing a sewer within a sewer, but the pressure sewer concept using grinder pumps was otherwise endorsed.²

Paul Farrell was a project engineer with General Electric and was highly involved in the ASCE study and in development of the grinder pump package. He continued his efforts with a pressure sewer demonstration project in 1970 at Albany, New York, which served 12 townhouses. This was probably the most extensively monitored system ever built, and was the subject of detailed and thorough analyses³.

General Electric withdrew from further involvement while Environment-One Corporation continued the grinder pump development and went on to other demonstration projects, such as Grandview Lake, Indiana, which served 93 homes. Mr. Farrell is still with Environment-One Corporation. Other pioneers in pressure sewers included Harold Schmidt, who proposed the use of septic tank-effluent pump (STEP) pressure sewers. His first STEP installation was made serving subdivision homes in Port Charlotte, Florida, in 1970. That system now serves over 1,000 homes. Ken Durtschi also proposed a STEP pressure sewer system to serve over 500 homes at Priest Lake, Idaho. With his design and under his direction, the system was built in the early 1970s. Gary Klaus also proposed a system that involved the use of a solids handling pump which discharged via a flexible hose to a pipeline mounted on the dock. The wastewater was conveyed from there to a floating septic tank which discharged chlorinated effluent to the river. Beginning in the early 1970s, Cecil Rose, then chief engineer for the Farmers Home Administration, became a proponent of pressure sewers, especially those conveying septic tank effluent.

USEPA's Office of Research and Development provided support for several early demonstrations of pressure sewers, including Grandview Lake; Indiana, Phoenixville, Pennsylvania; Albany, New York; and Bend, Oregon.³⁻⁶ Subsequently, the Agency produced a Small Community Technology Transfer Seminar series which included a report on pressure and vacuum sewer systems in 1977.⁷

When the Clean Water Act of 1977 gave increased Federal funding to all projects that incorporated these alternative collection systems, the number of documented installations proliferated in the United States from approximately 100 to more than 600 by the end of the Construction Grants Program in 1990. This number may be significantly larger today if all the systems not funded by the Federal Government are also included. Of the documented total, pressure sewers constitute the most numerous class, followed closely by small diameter gravity sewers; vacuum sewers systems are well behind.

2.2 Detailed System Plan and Elevation Views Showing Location(s) of All Components

A simplified sketch showing a section of pressure sewer main is shown as Figure 2-1. In the figure, discharge is presumed to a treatment and disposal facility. If discharge is made to a conventional sewer, pretreatment facilities may be required.

Pretreatment facilities are located and sized in accordance with the contact time required for the particular method of pretreatment. For example, chlorine reacts almost immediately whereas aeration may require several hours. Another parameter dictating pretreatment station location is the flow regime in the main. For example, air injection into a main could only be feasible if the main were steeply rising, and if there were substantial pressure in the main to cause the dissolution of oxygen into the waste stream.

Isolation valves (IVs) are located about the same as in water line practice. At the intersection of mains two IVs are usually placed as shown in the figure, although some engineers prefer using a valve cluster of three IVs. Isolation valves are sometimes placed at the upstream end of mains, to facilitate subsequent main extensions.

IVs are also placed on each side of areas where subsequent disruption of the main can be anticipated, such as at bridge or stream crossings, where future road construction is foreseen, or in areas of unstable soils. Where reaches between IVs become long, intervening IVs are sometimes used to divide the long reach into shorter lengths.

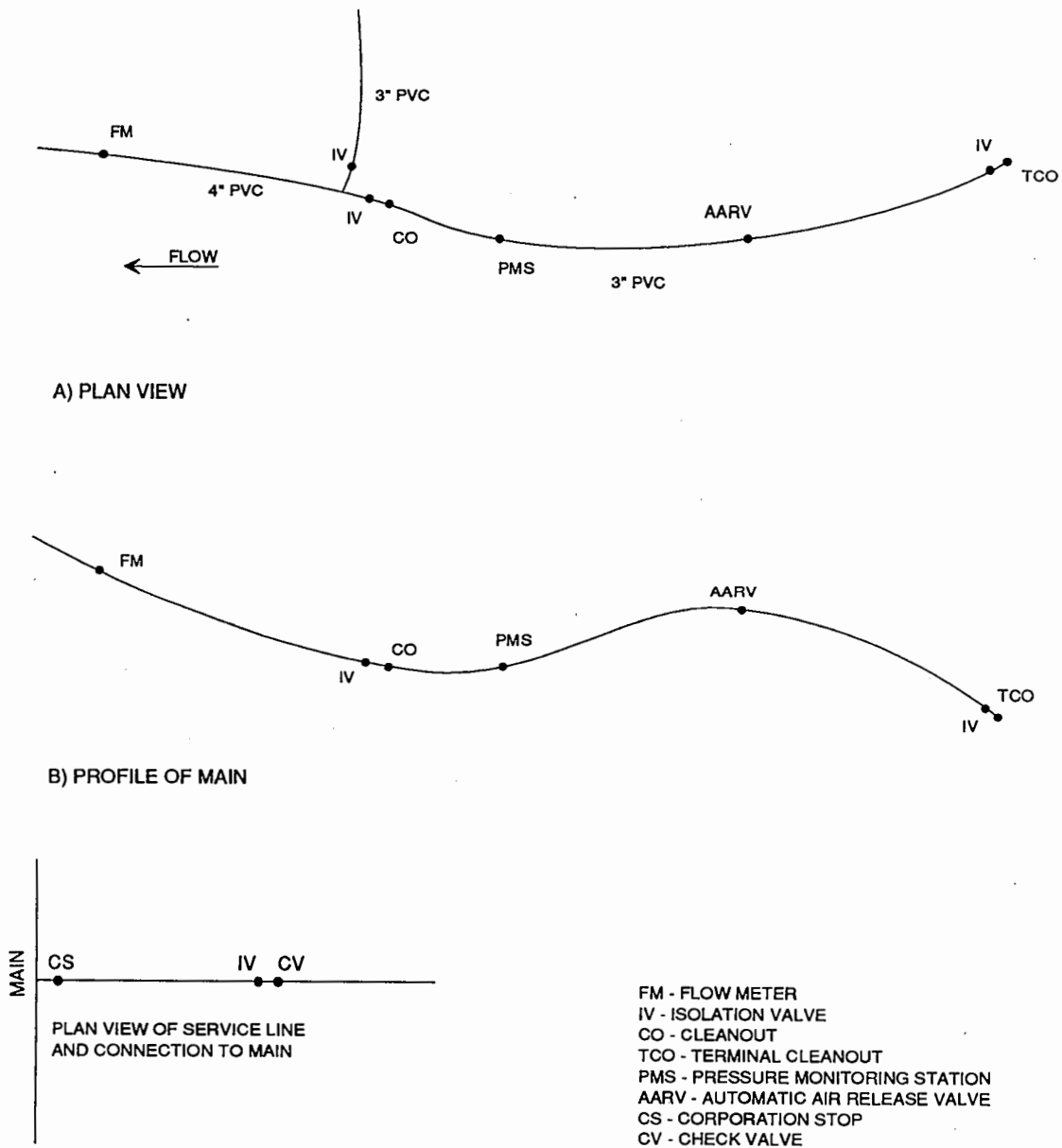
On long, steep grades, IVs are located to accommodate pressure testing requirements. Other IVs may be used as a part of the design of other facilities, such as with cleanouts or with flow meters.

Cleanouts (COs) are sometimes provided and when provided, in-line cleanouts are most typically placed where pipe sizes change. This is in anticipation of cleaning the main using a pipe cleaning pig. Terminal cleanouts (TCOs) may be located at the ends of mains. If the design of the cleanout is such that it rises to ground surface, a manual or automatic air release valve is often fitted to the high point.

Air release valve stations may be manual (MARV) or automatic (AARV). When the main is submerged under a static head the air release valves are normally located at summits. If the upstream end of a main terminates on a rising grade, an air release valve is used there. In two-phase flow regimes the air releases are placed as described elsewhere. A soil bed or other facility for odor absorption is sometimes provided at AARV stations, especially if located where odors would be a nuisance or if the particular station is expected to release much gas.

Service saddles, tees, or tapped couplings are used to join the service line to the main. A corporation stop is often provided there, and a check valve if the main is accessible. An isolation valve and check valve may be provided on the service line, sometimes located at the

Figure 2-1. Piping system appurtenances.



road shoulder or at the road right-of-way line. The location is chosen based on anticipated damage caused by such activities as road grading or snow plowing, and based on subsequent accessibility. For example, service line IVs and CVs are usually located outside of paved areas.

Flow meters are valuable, particularly when assessing capacity of the system and when quantifying the extent of VI the system receives. They are also used to flow-pace pretreatment facilities using chemical injection. For economic reasons, however, they are often not provided. They are generally of greater benefit on larger systems serving several hundred homes but should be considered for small systems as well. Most large systems use permanent installations. In smaller systems portable meters may be used to determine flows at particular points in question.

Pressures within the system can be measured in the GP or STEP pump vault if the discharge piping will accommodate the meter, and providing no check valve is used between the gauge and the main. However, most systems use service line check valves, which precludes this practice and makes necessary the provision of pressure monitoring stations (PMS).

Pressure monitoring stations are simple, inexpensive, and should be provided on systems where there may be questions as to operating conditions. The recording pressure gauge is usually moved from station to station as needed. PMSs can help reveal air-caused headlosses, and unexpectedly high or low flows. This is done by comparison of the theoretical hydraulic grade line versus that measured.

2.3 Detailed Description of On-Lot System Components

2.3.1 Available Systems

The pressure sewer pumping unit periodically discharges flow from the home or homes served to a pressure sewer main where the flow is conveyed to a point of treatment and disposal.

With a grinder pump (GP) system, the purpose of the grinding action is to reduce the size of troublesome solids present in wastewater making a pumpable slurry to be conveyed in the small diameter service lines and mains.

Solids handling (SH) systems rely on user cooperation to ensure that particularly troublesome solids are not discharged to the pumping unit. Such matter includes hard solids, plastics, rags, sanitary napkins, and stringy material.

Effluent pumps (STEP) are merely open-impeller pumps which are capable of pumping wastewater from which troublesome solids have been removed by the septic tank.

2.3.2 Detailed Descriptions

The septic tank of a STEP system captures most grit, grease, and other troublesome solids, and retains the sludge and floatable matter. The effluent is also reduced in strength in terms of BOD, SS and certain other parameters. This is of major benefit when drainfield or sand filter treatment is used, and may be a secondary benefit when mechanical forms of treatment are used.

The pump vault provides storage for a working volume between the "pump on" and "pump off" liquid levels, so the pump does not cycle on and off too frequently. The storage volume between "pump on" and "high level alarm" allows the inflow rate from the home to temporarily exceed the discharge rate of the pump without triggering an alarm.

The "reserve space" between the high level alarm and the point where the pump vault is full and overflow is impending is particularly important. A small reserve space volume will not store sufficient flow to avoid overflow or backup in the home, causing inconvenience to the user prior to the time that service personnel can arrive and correct the malfunction.

When STEP systems are used the reserve space provided by the septic tank is usually quite large, in the order of one day's average flow, which allows the service personnel to attend to maintenance calls less urgently.

Emergency overflows are sometimes provided when grinder pumps are used owing to limited storage capacity of the pump vault. When using STEP systems the septic tank encompasses a large storage volume above the normal water level and such overflows are rarely required. However, overflows can be easily disposed of to the drainfield. The raw wastewater overflow of GP or SH systems should go to a drainfield via a septic tank or be discharged to a holding tank. Any overflow management should be limited to short-term emergencies and should not permit inflow back into the system.

Pump manufacturers provide preassembled packages of pressure sewer components, including the pump, pump vault, in-vault piping and valves, liquid level sensors, electrical control panel, electrical junction box, and associated equipment. The availability of such packages greatly simplifies the duties of the application engineer, and often has the distinct advantage that the assembly has been refined as dictated by prior experience. There

is also a single source of responsibility in the event of malfunction.

In some cases, component systems have been designed by the application engineer and built by the owner or the contractor's supplier. There have been two distinct motives for the site-specific component approach. One is economic: the assembly can often be produced at less expense if the components are purchased separately and assembled by the owner or contractor. However, inferior components are often used, the components selected may not work well together, and quality control has been known to suffer.

The second reason site-specific component systems have been used has been the view that a better system can be built, custom made for the particular project needs. This approach has been successful on only a few projects where prototypes were fully developed, tested and refined over a period of time, or where the design engineer had considerable experience with pressure sewer technology.

A typical simplex GP package is shown in Figure 2-2. The pump vault is typically fiberglass and usually 60-90 cm (2-3 ft) in diameter. The depth varies with the dictates of ground topography and the volume of reserve space to be provided. Typically specified depths of basins are usually 1.5-2.4 m (5-8 ft).

The pump is shown to be suspended, and aligned with a slide-away coupling by guide rails. This design has historically been favored by most centrifugal pump manufacturers. A long-handled operating wrench is used to reach the shutoff valve from ground surface. A lifting chain is provided to aid in removing the pump.

Three mercury-float-switch liquid level sensors are within the pump vault: "Pump off", "pump on", and "high level alarm". In some cases a redundant off float is added, which may not only stop the pump but sometimes activates a low level alarm. If a duplex installation is made, an additional float switch is used for the lag pump-duplex cycle.

Wiring is extended from the electrical junction box in the pump basin to an electrical control panel. The control panel is usually mounted on the outside wall of the home, but in some cases it is pedestal mounted adjacent to the basin.

Figure 2-3 shows a centrifugal grinder pump suspended from the basin cover, rather than using the guide rail-slide away coupling arrangement. This system is intended for

installation within the home, often in a basement. A duplex grinder pump station is shown in Figure 2-4.

One popular semi-positive displacement (SPD) grinder pump package differs considerably from the centrifugal pump GP packages shown previously. A typical design is shown in Figure 2-5.

The progressing cavity type of semi-positive displacement pump is suspended into the basin. The pumping core is comprised of the pump, motor, grinder, piping, valving, and electrical controls. Liquid levels are sensed using a trapped air type of pressure sensor, somewhat like a bubbler system, but without the compressor. This system has no moving parts in contact with the wastewater. The components are shown in Figure 2-6.

An external control panel is not needed with this type of pump, but an external branch circuit disconnect is sometimes used, and an external high level alarm annunciator (horn or light).

Figure 2-7 depicts a STEP pump in a pump vault external from the septic tank. Some GP installations are the same and would only vary in that the pump has a slightly different appearance. When a GP is used as shown in this figure, stainless steel legs are screwed into the bottom of the pump since most GPs are made to be suspended.

This installation does not employ guide rails. Instead of connecting the discharge via a slide away coupling, a discharge hose is used which extends to within a few inches of the top of the basin where a quick-connect coupling and the isolation valve can be reached from ground surface. This is the type of installation usually favored by makers of GP component systems. STEP systems are usually of a different type, shown below.

SH systems are typically as shown in Figure 2-7.

A STEP system is shown in Figure 2-8. This concept employs a pump vault internal in the septic tank, as contrasted against the external pump vault shown in Figure 2-7. Both approaches are widely used for STEP systems.

The effluent pump rests on the floor of the pump vault, and discharges via a flexible discharge hose that connects to the service line piping with a quick-connect coupling near ground surface. Three mercury float switches are used, and an external electrical control panel (not shown) is employed, as in GP practice.

Figure 2-2. Typical simplex GP package using slide away coupling and guide rails. (Courtesy F.E. Myers Pump Co.)

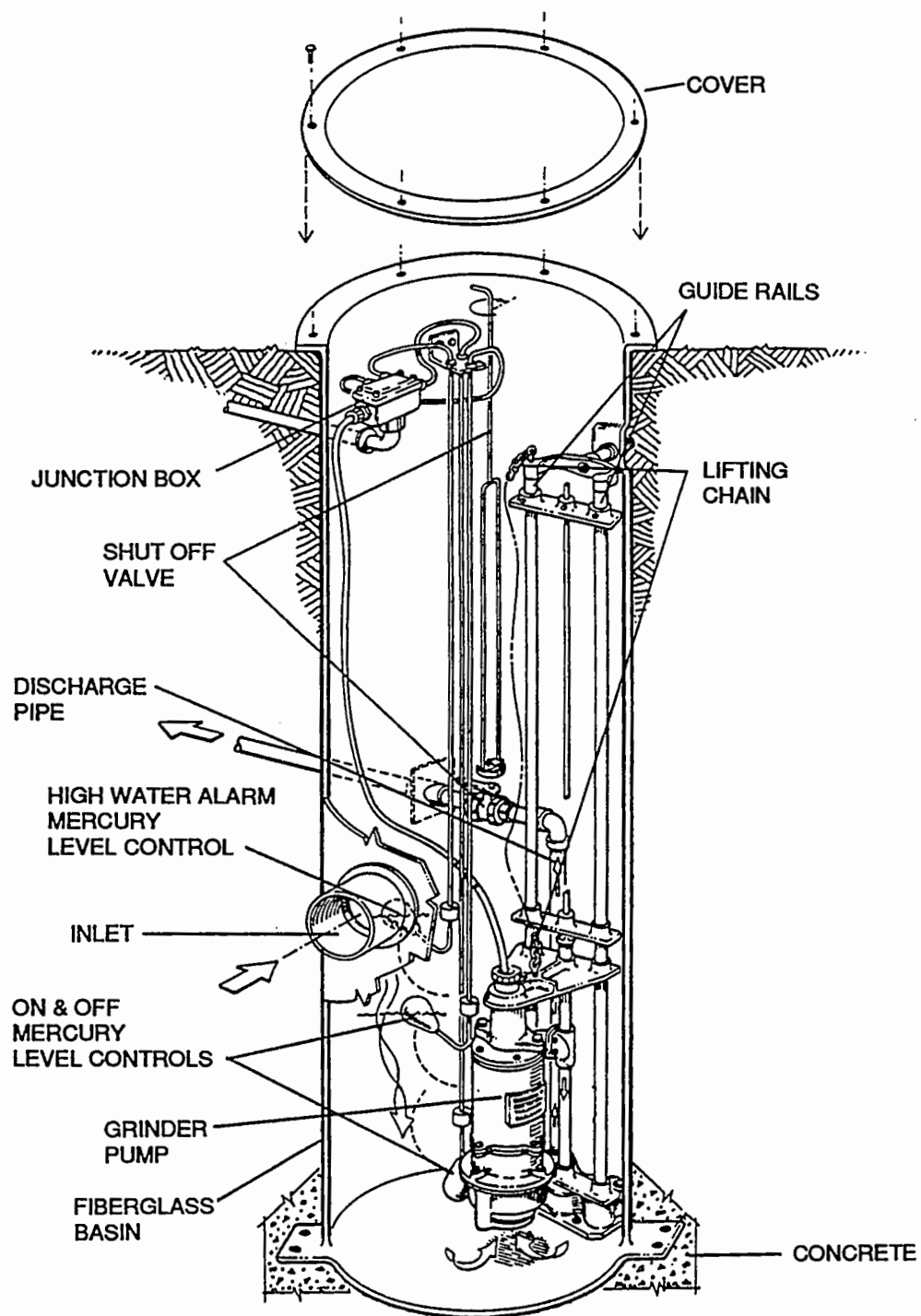


Figure 2-3. Typical centrifugal GP package with pump suspended from basin cover. (Courtesy Barnes Pump Co.)

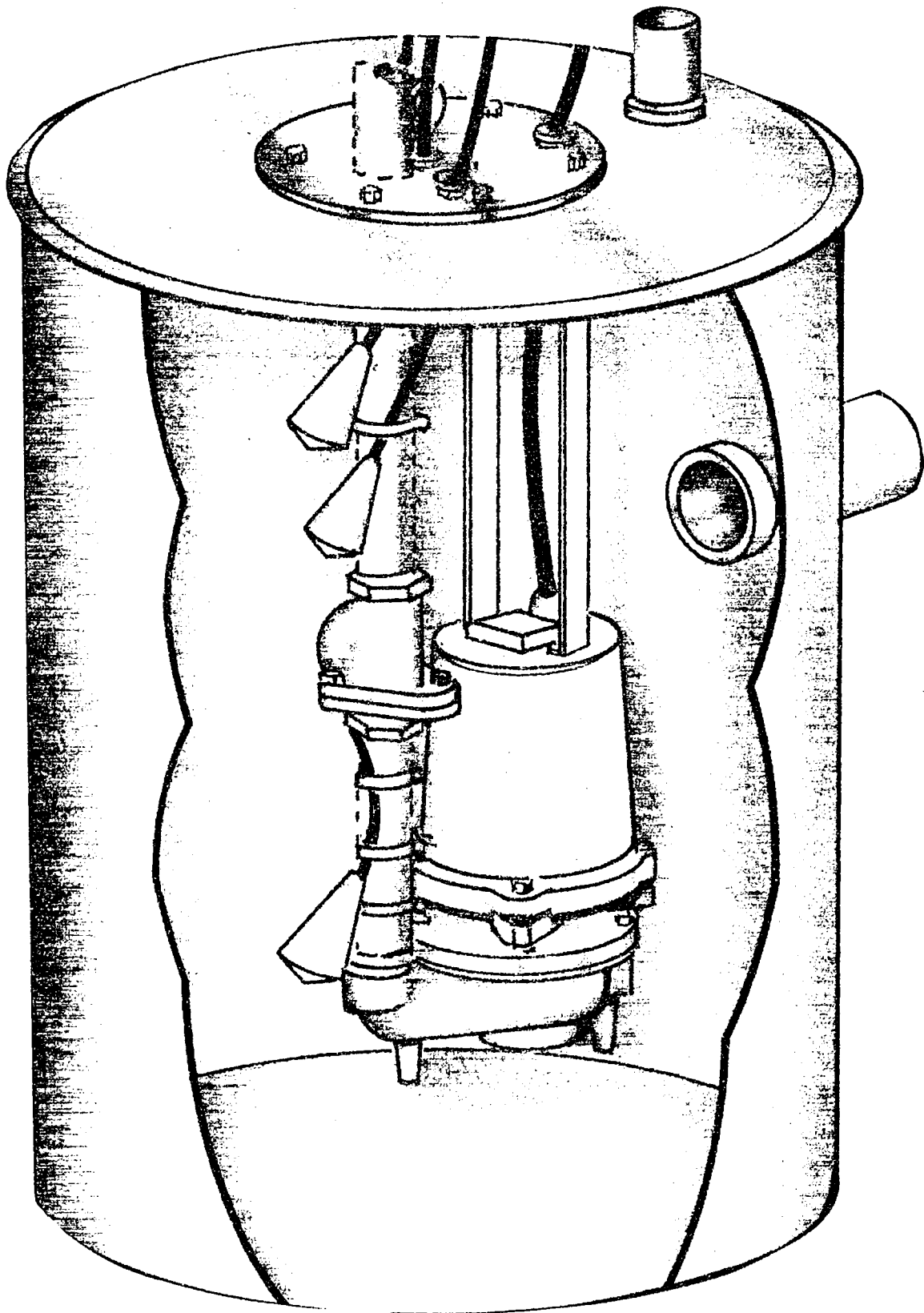


Figure 2-4.

Duplex GP station. (Courtesy Barnes Pump. Co.)

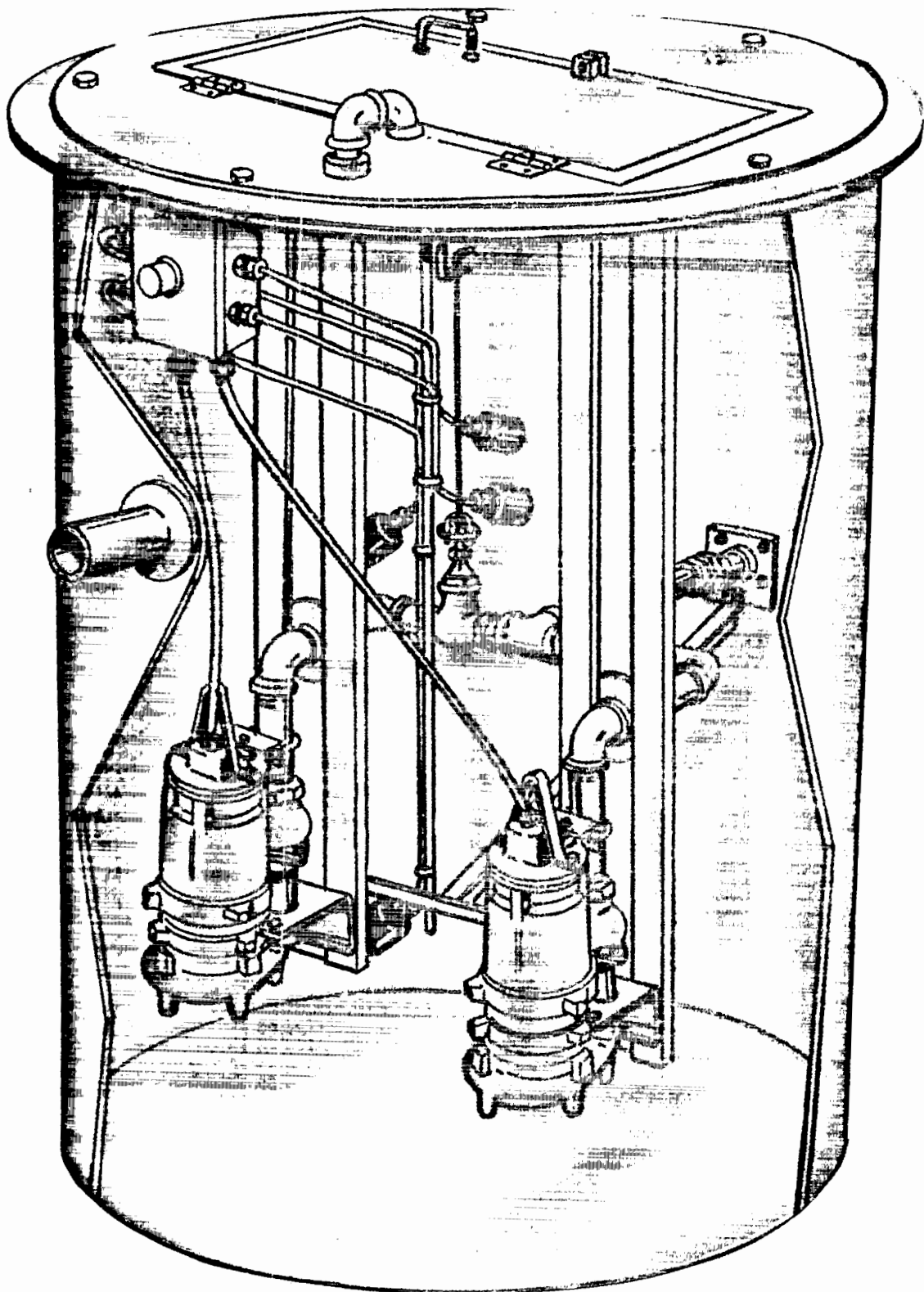


Figure 2-5.

Typical progressing cavity-type GP package. (Courtesy Environment/One Corp.)

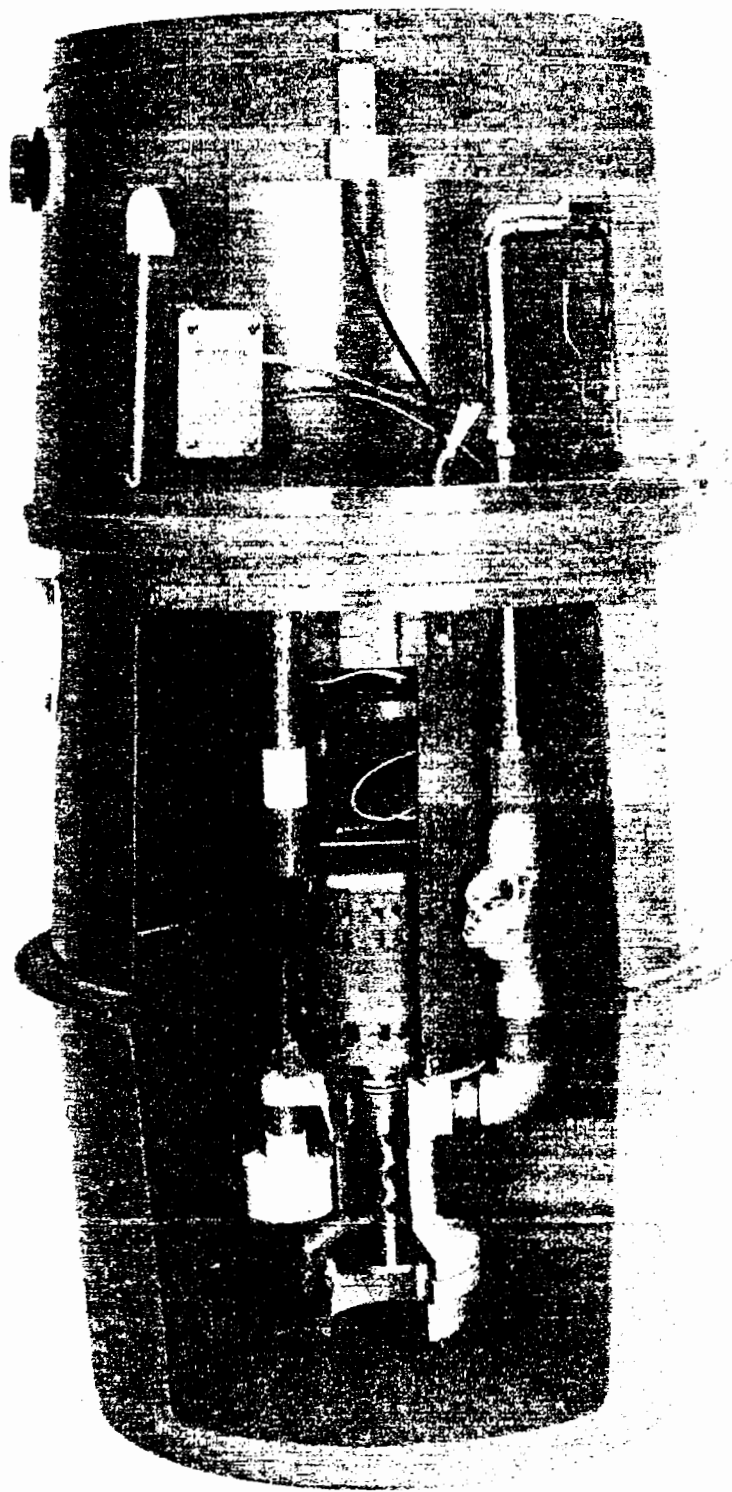


Figure 2-6. Basic components of a progressing cavity grinder pump. (Courtesy Environment/One Corp.)

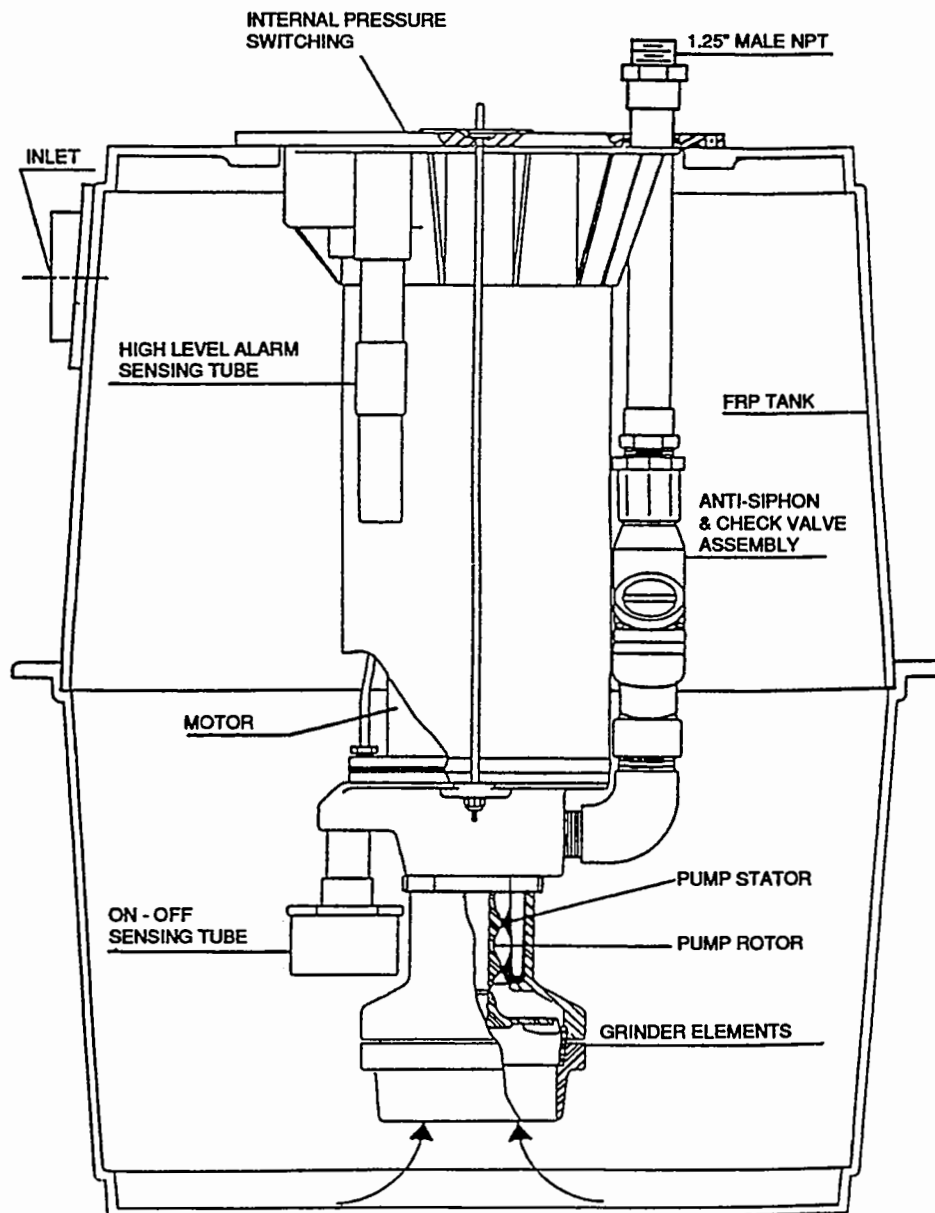


Figure 2-7. STEP pump in external vault. (Courtesy Barnes Pump Co.)

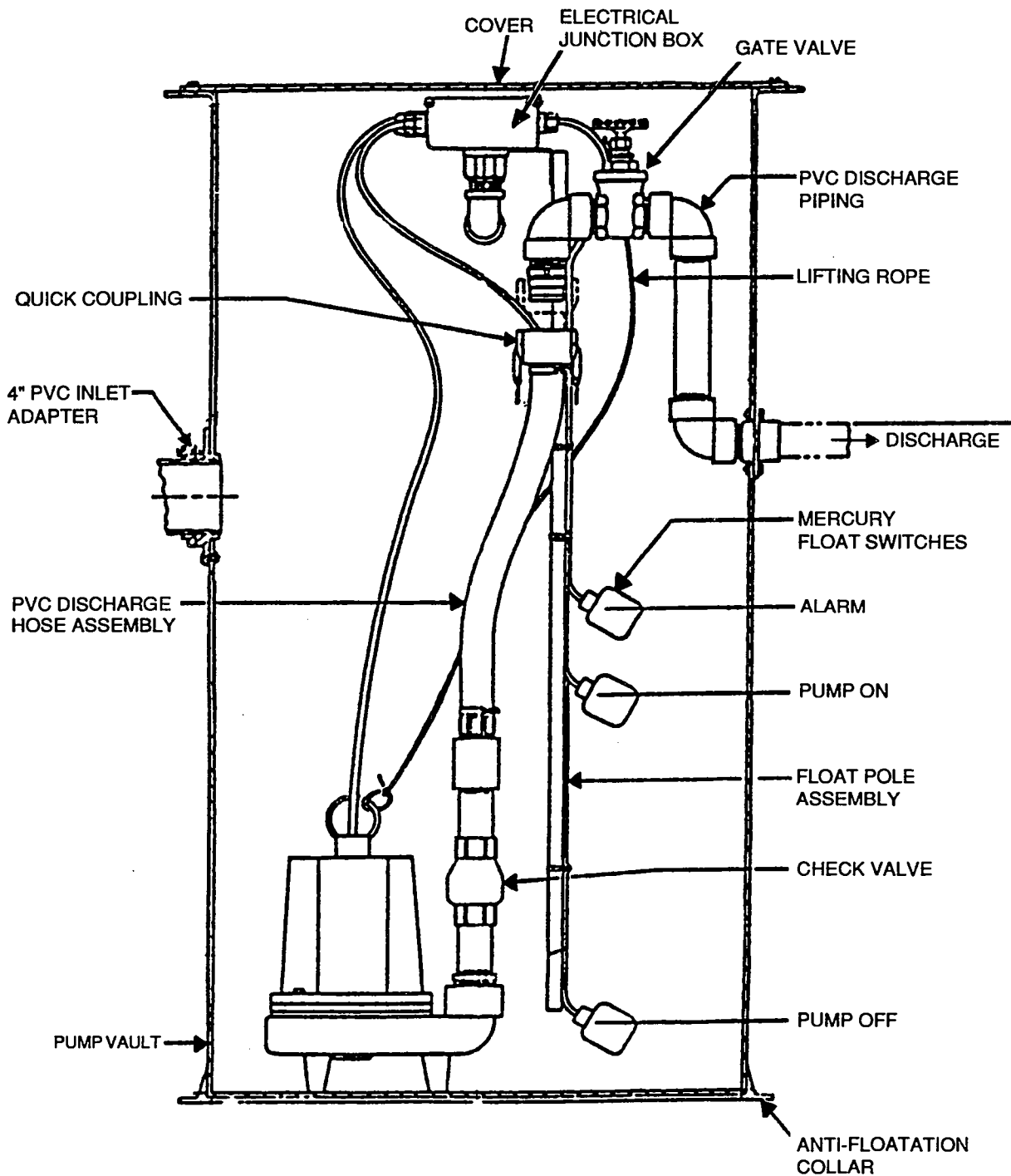
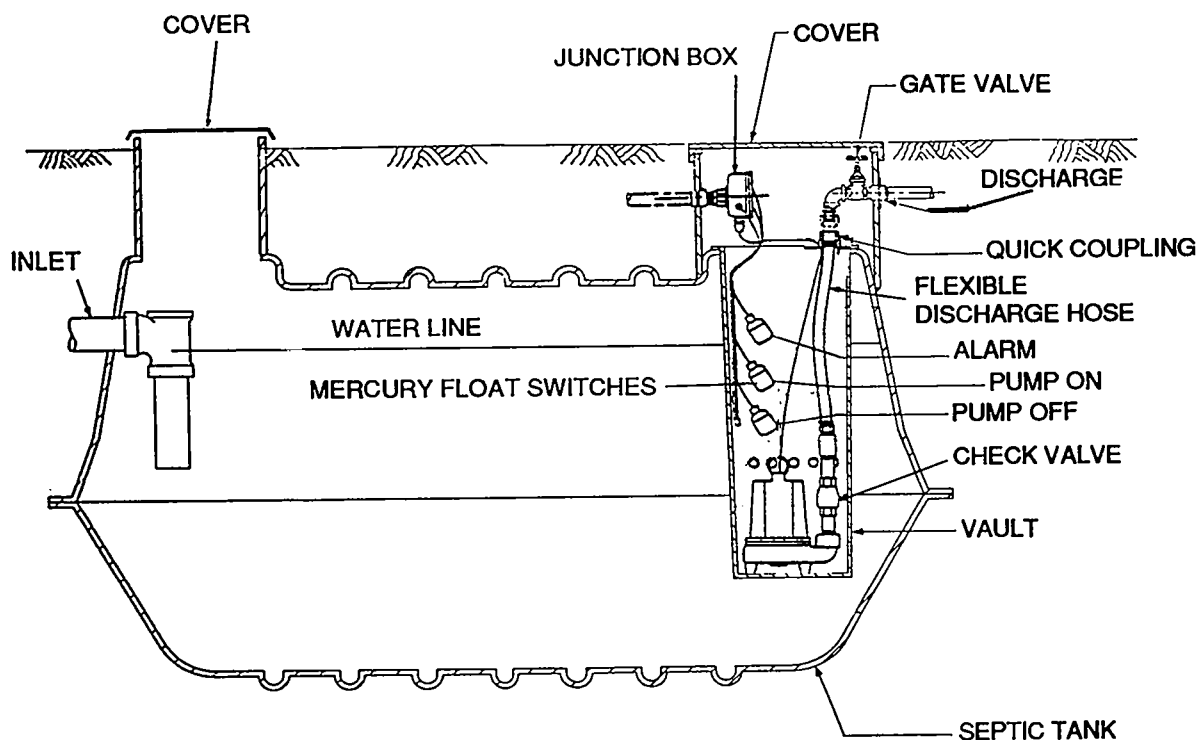


Figure 2-8. Typical STEP package with internal pump vault. (Courtesy Barnes Pump Co.)



A riser extends to ground surface, providing access to the pump vault. In some designs the pump vault is removable through the riser, for access to the tank. In other designs the pump vault and riser are integral in which case access to the tank is made through the cover on the inlet end of the tank which may be buried or may also have a riser extending to ground surface.

Inlet holes (ports) are provided in the pump vault as shown, which are located below the lowest predicted elevation of the scum in the tank during the lowest water level condition, but above the maximum height of the sludge layer.

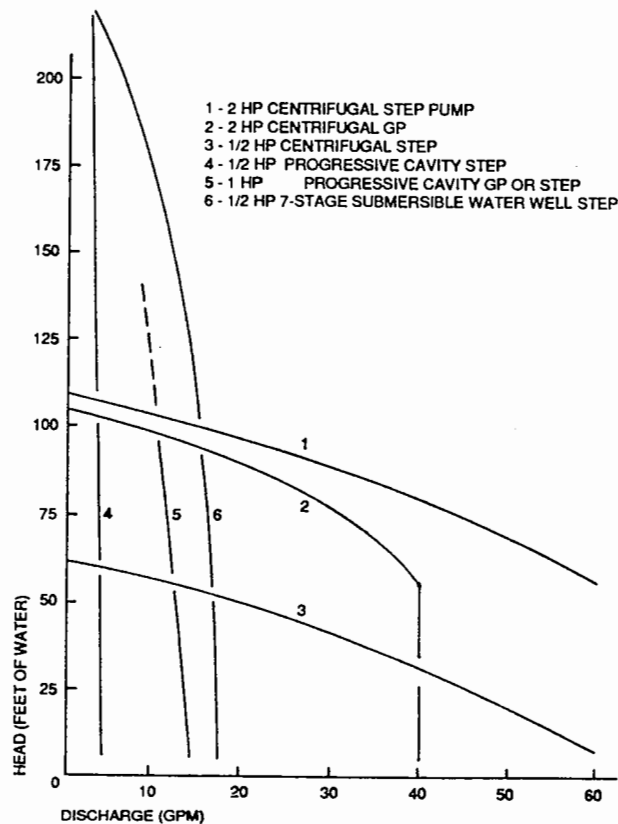
The liquid level in the entire septic tank rises and falls in response to flows from the home and the pumping cycle. When the liquid level rises for example 7.5 cm (3 in) (about 50 gal), the pump turns on and pumps down the whole tank 7.5 cm (3 in). If a malfunction occurs and the liquid level rises sufficiently above the pump-on level, a high level alarm is activated. The reserve space is

located between the top of the floating scum and the soffit of the tank.

The GP, SH, and STEP systems shown in the figures are available as simplex units, intended to serve one home, or perhaps up to 3 homes. Larger systems are also used, to serve many homes. The designs vary from duplex versions of the designs shown to full-scale wastewater lift stations. When large STEP installations are made, either large septic tanks are used, or several tanks are placed in series, with the final tank being the pump tank.

Pneumatic ejectors have been used to a limited extent on STEP systems, but none are now known to be marketed. Some STEP installations use submersible water well pumps, which must be used in conjunction with an inlet screen since well pumps have no solids handling capability. Well pumps also must be placed in a tube to simulate a well casing, to cause water entering the pump to flow past the motor, providing cooling. Progressive cavity pumps

Figure 2-9. Head-discharge curves for typical GP and STEP systems.



have been used some on STEP systems as well as on GP systems.

The pump characteristics vary with the manufacturers, but a general overview of the head - discharge curves is shown in Figure 2-9.

2.3.3 Materials of Construction

The use of proper tankage is particularly important. If a tank fails, the contractor must re-enter the homeowner's property with heavy equipment, excavate to remove the failed tank, and place the new tank. It is a most costly and visible mistake.

Pump vaults are most commonly made of FRP (fiberglass reinforced polyester). Those provided by the pump manufacturers are usually quality products, having a minimum wall thickness of about 6 mm (1/4 in). Some are gel coated which provides a smooth protective surface, and those that are not gel coated have resin

rich surfaces intended to prevent glass fibers from being exposed that could cause wicking.

Some FRP vaults may be as thin as 1.5 mm (1/16 in) in places. The product may not be produced from quality materials or with quality workmanship, and fibers may be exposed. These are usually produced by other than the original pump manufacturer (aftermarket items).

Other pump vaults have been made of both high density and low density polyethylene (PE). PE is more flexible than FRP, so where the vaults are intended as a structural member, they must be thicker than FRP. PVC has also been used, usually made from sewer pipe.

Septic tanks on STEP systems have been made of reinforced concrete, FRP, and PE. Depending on the quality of the product, all of these materials have been successful, and in other cases all have been unsuccessful. In certain instances reinforced concrete tanks have cracked badly, admitting groundwater. FRP tanks have cracked or

split open, in some cases have collapsed, and in other cases water seeped through the walls. Some PE tanks have deformed so badly as to not be functional and to demand replacement. In other instances they have collapsed totally.

Where the liquid level in the septic tank is lower than the groundwater, infiltration can occur if the tank is not water tight. There are numerous projects where I/I into the upstream sewer and septic tank has more than quadrupled flows, pushing the pressure sewer system beyond its capacity and rendering it a failure.

Judging structural integrity by observation of the tank being used as a part of an existing septic tank - soil absorption system has proven misleading. First, it is often impossible to know if a septic tank used with an absorption system leaks or not. Secondly, tanks which apparently do not leak in septic tank-soil absorption service may leak under pressure sewer service owing to potentially lower groundwater levels.

To evaluate the septic tank structurally, it is necessary to prepare a loading diagram depicting the loads the tank will be subjected to, commensurate with burial depth, groundwater depth, soil types, foundation, bedding and backfill to be used, and other parameters. Following this task the tank is designed by usual engineering analyses.

Generally, concrete tank designs follow American Concrete Institute standards, assuming one-way hinged slabs spanning the shorter dimension. Non-traffic load designs usually result in concrete tanks having an equivalent of 10-cm (4-in) walls and top and bottom slabs, with #5 bar reinforcement at about 20-cm (8-in) centers. A thickness of sacrificial concrete above the water line may be provided in anticipation of corrosion by H_2SO_4 .

The thickness required of FRP tanks varies considerably with tank shape and the quality of the FRP product. When this has been evaluated, the usual conclusion has been to require an average wall thickness of 6 mm (1/4 in), with a minimum thickness at any point of 5 mm (3/16 in).

Because polyethylene is so flexible the shape of PE septic tanks is crucially important. Flexible tanks can deform to a shape of structural weakness if not properly designed. PE tank designs generally rely considerably on empirical refinement, taken from monitored experience on numerous installations under varying conditions.

Quality control of the tank manufacturing process must be assured. It has been common for tank construction to be poorly executed.

Septic tank effluent and the septic tank atmosphere are corrosive due to the hydrogen sulfide present above the water line and the potential for sulfuric acid formation. The wastewater in a grinder pump vault may also become septic due to the wastewater being sometimes held in the pump vault for extended periods. Exposed appurtenances must be suitably corrosion resistant.

In most cases where the pumping package has been supplied by a manufacturer with considerable pressure sewer experience, the engineer can be reasonably assured that acceptable materials have been used.

When component systems are built the engineer must pay strict attention to materials choices.

The materials chosen for corrosion resistance vary according to the material properties needed for structural and other reasons.

Austenitic stainless steel, particularly Type 316 and in some cases Type 304 have proven to give excellent service. Fasteners are produced from this material, also such items as hose clamps. Martensitic stainless steel, such as Type 416, has generally proved unacceptable.

Some plastics are virtually unaffected by exposure to H_2S while others are not. PVC, ABS, and PE, all materials that have long been used in sewerage service, appear acceptable. Nylon, however, is affected by H_2S and H_2SO_4 , and is not acceptable.

Copper products, e.g., alloys of brass or bronze, provide limited success. Besides corrosion considerations brass is subject to dealloying, while some bronze, such as 85-5-5-5, will give better performance. The terms brass and bronze are used loosely despite having different meanings; the engineer is advised to evaluate these materials with caution.

2.4 System Design Considerations

2.4.1 Hydraulics

2.4.1.1 Design Flows and Their Variability

a. Average Daily Flows

Fundamental to the design of a sewer system is the determination of design flows. Where actual flow characterization data are available they should be used. An allowance of 380 L/cap/d (100 gpcd) has been used as a general rule in the design of conventional sewer systems.⁸ However, that general rule may allow for more infiltration than may occur when pressure sewers are

used, and it allows for some amount of commercial and industrial use that may not be present in pressure sewer design. Experience with pressure sewerage has shown a lower allowance to be more in order.

During the early stages of pressure sewer development extensive investigations were made into domestic water consumption during periods of low outside water use, with the correlation that water consumption would closely parallel sewer flows. These studies showed flows of 150-230 L/cap/d (40-60 gpcd). Flow measurements were made on conventional sewers serving residential communities during periods when I/I was not occurring, with the same conclusions.

At this time, thousands of flow measurements have been made on pressure sewer systems with wide demographic spread.⁹ The result of these measurements has corroborated findings of the earlier studies; that flows are typically 150-230 L/cap/d (40-60 gpcd), with little weekly or seasonal variation.

The availability and quality of water affects water use and consequently sewer flows, as does water pressure, community affluence, nature of occupancy, and attitudes of the users regarding water conservation. Because of these variables and to provide a safety factor, the flow rate normally assumed for design is 190-265 L/cap/d (50-70 gpcd).

While pressure sewers are sometimes thought to be free of I/I, it can occur in the non-pressurized portions of the system, e.g., the building sewer and the tank. In some cases I/I has been extreme, due to leaking building sewers or house roof drains being connected to the building sewer, due to pump vault risers being set below ground level which allows surface water to enter, or in the case of STEP systems due to leaky septic tanks. It is prudent to make an allowance for I/I when adopting a design flow, based on the extent of I/I control given to the project.

Daily peak flows may exceed design values by several times and occur several times per day but these are of little importance due to their short duration. There are also periods of zero flow.

Flow variations are related to mainline sizing and pump selection. That is, an oversized system will tend to have more peaky flows than a system with smaller diameter mains, where the pumps run longer per cycle at lower discharge rates.

On the Glide, Oregon STEP system, peak hour flows were found to occur about twice/day, at flow rates of 40-

65 percent of design peak flows. The Glide system at that time served 560 equivalent dwelling units (EDUs) and was sized to serve an ultimate population of 2,380 EDUs. The 32-km (20-mi) piping system is 7.5-30 cm (3-12 in) in diameter.

b. Peak Flows From Homes and Required Pumping Rates

Besides average daily flow rates and their variabilities it is important to consider other factors, such as the rate of flow from the individual home to the septic tank or GP vault. This flow rate can be quite high at times.

The American Society of Civil Engineers² reported peak flows that may occur about twice per year as being 98 L (26 gal) in a 4-min period, or 408 L (108 gal)/hr. They go on to describe the simultaneous discharge from a bathtub and clothes washer resulting in a 174-L (46-gal) discharge over a 2-min period, and having a high probability of occurrence.

Bennett¹⁰ reported surge flows of 230 L (60 gal) in a 7-min period. Jones¹¹ reported findings similar to those of ASCE and Bennett and applied the data to regression analyses. The results of the various studies are shown on Figure 2-10.

If the purpose of the pressure sewer pump was to discharge flows as fast as they enter the tank, required pumping rates would be quite high to accommodate these instantaneous peak flows. However, the purpose of the pressure sewer pump is to discharge flows at a rate such that the level in the tank will not reach the high water alarm level, and with a high degree of confidence, will not overflow the basin. The reserve volume within the tank between pump on and high level alarm is used to attenuate peaks and is a factor in establishing required pumping rates.

Required pumping flow rates should not be confused with design flow rates used for sizing mains, as the latter does not consider attenuation of peak flows from the home provided by the volume held between pump on and alarm levels in the pump vault.

Figure 2-11 adopts the 1-percent regression of Reference 11 and Figure 2-10 and presents pumping rates required given four different volumes of reserve space. The curves on Figure 2-11 have been calculated based on the following equation:

$$Q = (V-S)/t \quad \text{Equation 2-1}$$

Where,

Figure 2-10. Wastewater flows for one home.

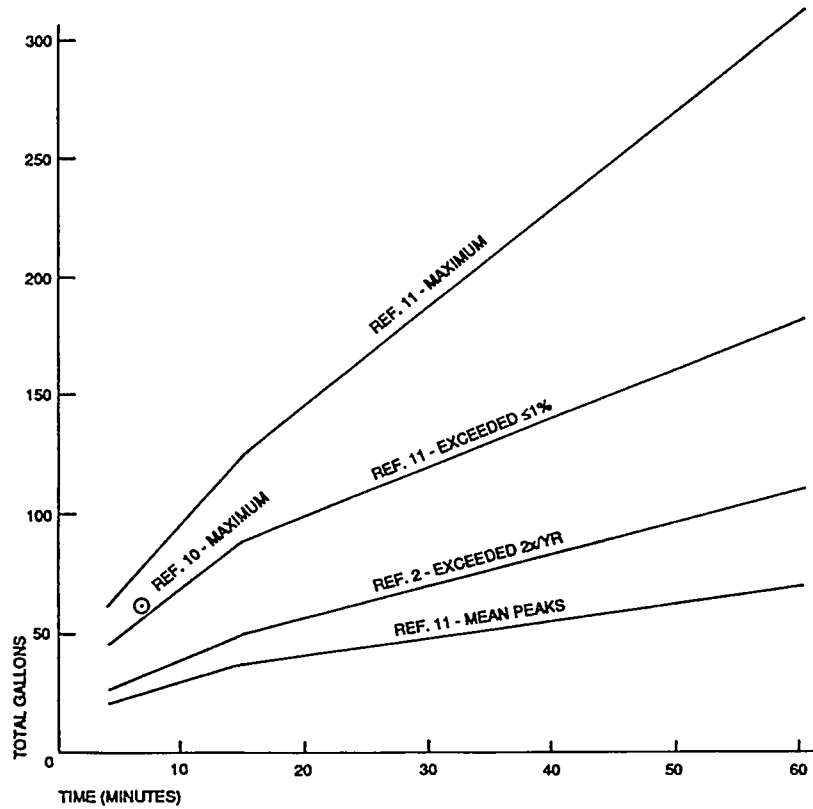
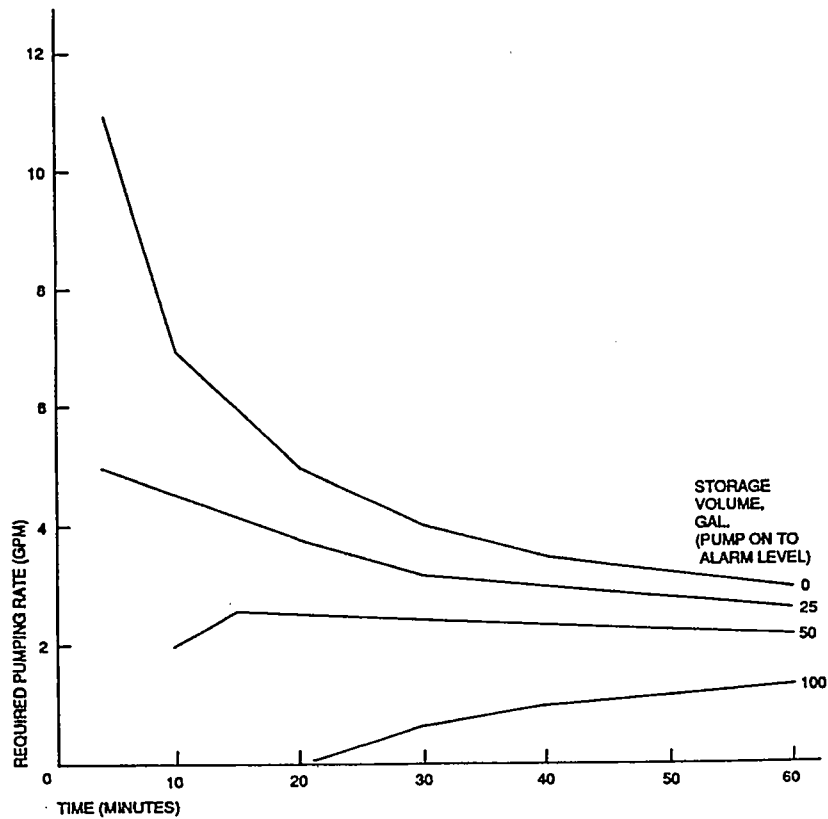


Figure 2-11. Required pumping rates using flows from Reference 11, <1-percent regression.



- Q = Minimum required pump discharge rate (gpm)
V = Volume of peak wastewater flow from the home (gal)
S = Storage volume between pump on and alarm (gal)
t = Time (minutes)

Figure 2-11 shows, for example, a minimum required pumping rate of 10 L/min (2.6 gpm) if 132 L (50 gal) of reserve is provided. However, a higher pumping rate is not detrimental in most cases. When using a grinder pump system where pipeline cleansing velocities are required, a higher pumping rate may be needed for that purpose.

c. Design Flows

Design flows are maximum flow rates expected to occur once or twice per day, and are used to size the pressure sewer mains. Flow rates in excess of design flows can occur under certain situations to be described later, so design flows should not be taken as the maximum flow rate possible to occur.

Two design approaches have been used; the probability method and the rational method.

The probability method proposes the maximum number of pumps theoretically expected to be running at any time. Then, with the discharge rate of the pumps being known or assumed, the design flow is the product of the number of pumps running times the pump discharge rate.

Many pressure sewer pumps are centrifugal, having gradually sloping head-discharge curves, so the discharge rate varies considerably depending on the discharge pressure. Consequently the pumping rate in the probability method is only loosely assumed when centrifugal pumps are used. The probability method would best apply to pumps having vertical or near vertical head-discharge curves, such as semi-positive displacement pumps, e.g., progressing cavity types.

The rational method can logically be applied when either centrifugal pumps or semi-positive displacement pumps are used. The rational design has almost exclusively become the accepted method of practice.

The rational method proposes a design flow corresponding to the number of homes served by the pressure sewer, which is used to size the mains and to construct the design hydraulic grade line. Pumps are then selected that can discharge into the main at an acceptable flow rate given the design discharge pressure.

Environment One. The design handbook of Environment One Corporation, manufacturers of progressing cavity type grinder pumps and effluent pumps, tabulates the number of pumps expected to be running simultaneously versus the number of pump cores connected to the system.¹² Design flow rates as shown in Figure 2-12 are then determined by the product of 11 gpm (the discharge rate of their pump) times the number of pumps running.

Information from a study by ASCE² was used to derive the E-1 design flow rate curve which was then refined by operating experience with projects using their equipment.³ The ability of their pumps to operate at least 25 percent above design pressure accommodates occasional peak flow needs in excess of design.

ASCE. A study by the ASCE² was accomplished early in the history of pressure sewer development, based on water supply demand rates in northern latitudes and during periods when outside water use was minimal.

Based on Johns Hopkins University data and referencing work by McPherson, tables of flow were prepared. Measurements of 15 systems in the northeastern United States were shown, serving 44-410 EDUs. In northern California, measurements were made of 13 systems serving 63-295 EDUs. Curves were drawn from these data expressing a ratio of maximum peak hour of any day to average annual use.

Hydromatic. Hydromatic pump company sponsored a study and report by Battelle Institute which explored the use of centrifugal grinder pumps.¹³ A number of information sources were cited, including that from the Grandview Lake,⁴ Indiana pressure sewer project, the Albany, New York study,³ and work by Watson, Farrell, and Anderson.¹⁴

A specific equation for peaking factor was taken from Fair and Geyer's text,¹⁵ citing Harmon's measurements of conventional wastewater flow:

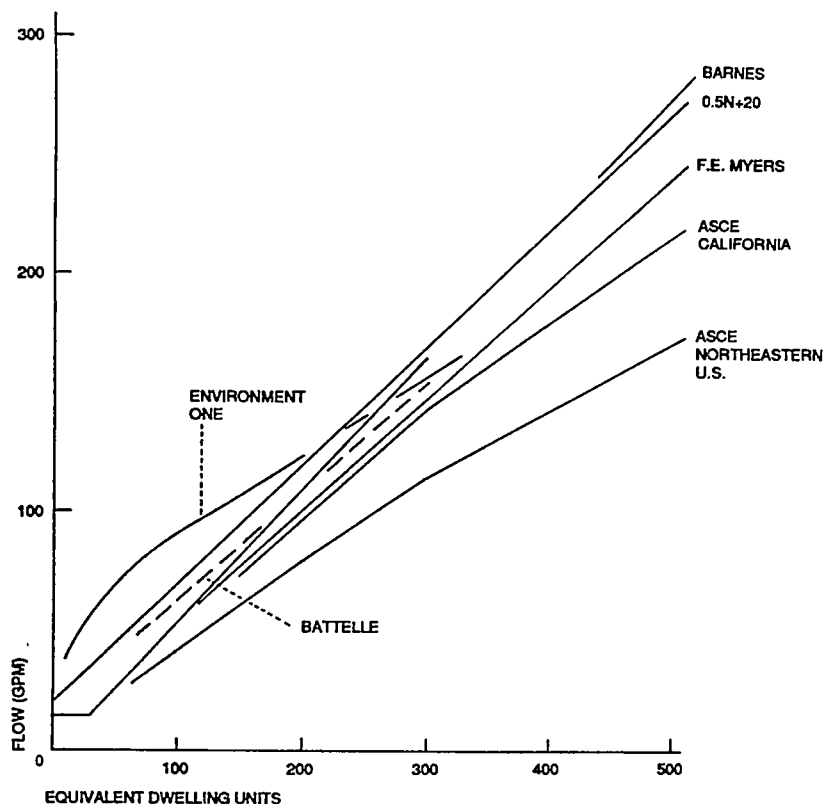
$$Q_p/Q_a = (18+P)^{0.5}/(4+P)^{0.5} \quad \text{Equation 2-2}$$

Where,

- Q_p = Peak flow
Q_a = Average flow
P = Population in thousands

Eight tables were presented ranging from flows of 660-1,515 L/s (175-400 gpd)/EDU. Although not stated within the report, Equation 2-2 fits the data in Battelle's tables exactly, excepting for low flows where departure was apparently regarded as necessary owing to the differing nature of pressure sewer collection as contrasted against

Figure 2-12. Design flows.



gravity sewer collection. A design flow of 1 L/s (15 gpm) was suggested for one home, and 1.6 L/s (25 gpm) for 5 homes.

Flows shown in the tables are reported to be recurring peak flows, to occur once or twice per day.

The table corresponding to average flows of 740 L/s (195 gpd), and occupancy of 3.5 people/EDU has been used most frequently in pressure sewer design, and was used for the curve shown in Figure 2-12.

Battelle's tables have been widely used for both GP and STEP designs.

Barnes. The design manual provided by this manufacturer of centrifugal grinder pumps and effluent pumps proposes a peaking factor of 3, and assumes that flows occur over an 18-hr period, which results in a peaking factor of 4 over a 24-hr period.¹⁶ Their equation is re-expressed as Equation 2-3. A minimum flow of 1 L/s (15 gpm) is suggested. The Barnes recommended design curve as presented in Figure 2-12 assumed an average flow of 760 L/s (200 gpd)/EDU.

$$Q_p = 4 Q_a \quad \text{Equation 2-3}$$

F.E. Myers. This pump manufacturer's design handbook provides a plot of peaking factor versus the number of dwellings served, with the peaking factor varying from 4.8 at zero EDU to 3.4 at 700 EDUs.¹⁷ They suggest an average daily flow expected when serving 3-bedroom homes of 950-1,510 L/s (250-400 gpd).

Simplified Equation. By examination of the curves shown in Figure 2-12, a simplified equation has been fitted. The reasoning in proposing a simplified equation is that a precise determination of flows is not possible to achieve anyway, especially with regard to infiltration allowance. The simplified equation is easy to use and easy to modify to suit project needs.

$$Q = AN + B \quad \text{Equation 2-4}$$

Where,

- Q = Design flow (gpm)
- A = A coefficient selected by the engineer, typically 0.5
- N = Number of EDUs
- B = A factor selected by the engineer, typically 20

In the usual form, the equation is $Q = 0.5N + 20$, but may be varied to account for anticipated high water use (and

correspondingly high wastewater flows), to allow for a greater safety factor, and especially to allow for I/I. Varying the coefficient A steepens or flattens the curve while varying the factor B raises or lowers the curve.

The design curves proposed by the various manufacturers have been widely used. In the vast majority of cases the systems have performed well, indicating that the design curves are adequate. However, many systems have been sized for growth that has not yet occurred, so these systems have not yet been fully tested. Most systems are not equipped with flow meters that would measure peak flows, nor are pressure readings routinely taken, so acceptable performance is only judged by the lack of nuisance high water alarms during peak periods.

Systems that have proven inadequate typically received I/I far in excess of that anticipated.

2.4.1.2 Minimum Flow Velocities in Pipes

The term "self cleaning velocity" refers to the flow velocity required to convey solids along with the water carrier. To maintain an unobstructed pipeline, that velocity should be sufficient to transport grit that may be present in the wastewater, to prevent grease plating on the crown of the pipe, and to scour and resuspend previously settled matter.

When force mains are used to convey conventional wastewater or when a grinder pump pressure sewer is used, the typically ascribed self cleaning velocity is usually taken as about 60-90 cm/s (2-3 fps). That velocity should occur once or twice daily. The higher velocity of 90 cm/s (3 fps) is preferred with regard to scouring concerns, but the higher flow rates correspond with higher headlosses and the need for higher head pumps.

The septic tank of a STEP system is effective at capture of grit and grease. It is logical that the required self cleaning velocity would be much reduced when septic tank effluent is pumped. Assuming values of $s = 1.1$ and $D_g = 0.2$ mm for septic tank effluent, and applying Camp's equation for sediment transport,¹⁸ results in a self-cleaning velocity of less than 30 cm/s (1 fps).

Experience has shown that if GP flow velocities are too low grease collects at the crown of the pipe, restricting the cross sectional area and interfering with the transfer of air to air release valves, and increasing headlosses against which the GPs must pump.³ Grit can also collect at the invert of the pipe.

There have been occasional reported instances where velocities on small portions of GP systems have been so

low that pipeline clogging has occurred, necessitating pipeline cleaning.

Experience with STEP systems has shown that solids are not deposited even when velocities are less than 30 cm/s (1 fps). However, a self-cleaning velocity of 30 cm/s (1 fps) may be conservatively used.

With either GP or STEP systems, sand and other debris can enter the pipeline during construction which can become cemented due to contact with the septic wastewater, and difficult to remove. The pipeline should be kept capped at all times during construction except when pipe laying is being actively accomplished, and other measures taken to insure that the pipe is kept clean.

Mains should be designed to withstand the forces of pipeline cleaning by pigging, should that become necessary. The more common need for pigging is to remove debris that entered the pipe during construction. Pig launching stations have been provided on a few projects, but usually they are regarded as an unnecessary expense and encumbrance.

Pressure monitoring stations have occasionally been used on large projects. The methodical and routine taking of pressure readings can help reveal progressive pipeline clogging, but more often it shows effects of air binding.

2.4.1.3 Applicable Equations

The Hazen-Williams Equation is most often used to forecast headloss, but the Manning Equation is acceptable. When the Hazen-Williams Equation is used the C factor is selected by the engineer, typically being 130-140 for plastic pipe. A corresponding Manning n value is 0.010.

Hazen-Williams:

$$V = 1.318C R^{0.63} S^{0.54} \quad \text{Equation 2-5}$$

Manning:

$$V = 1.486/n R^{2/3} S^{1/2} \quad \text{Equation 2-6}$$

Where,

- V = Velocity of flow (fps)
- C = Hazen-Williams flow coefficient
- R = Hydraulic radius
- S = Slope of energy gradient
- n = Manning flow coefficient

Where pipelines flow partly full, as in some gravity reaches within a combined pressure sewer-small diameter gravity sewer, the velocity can be easily calculated by the Pomeroy Equation:

$$V = 6.8 S^{0.41} Q^{0.24} \quad \text{Equation 2-7}$$

Where,

V = Velocity of flow (fps)
S = Slope of energy gradient
Q = Flow rate (gpm)

2.4.2 Pipelines

2.4.2.1 Mainlines

a. Geometry

The geometry of a pressure sewer system is similar to that of a water distribution system, but normally in dendriform pattern, as opposed to a network in which the pipelines are looped. The purpose of the branched layout is to have a predictable minimum self-cleaning velocity in the mains, but a disadvantage is that redundancy is not provided as it is in a looped system. With a network, a section of the piping system can be shut down for repairs without interrupting flow from all upstream inputs, as flow from them is naturally redirected.

In some pressure sewer designs a network pattern is used with mainline isolation valves in the normally closed (NC) position. These isolation valves are located such that the system operates the same as a dendriform layout would, excepting during a period when a portion of the main is shut down for repairs, in which case the normally closed valve is temporarily opened and flows are redirected. The practice of network layout using NC valves is more common with STEP system design than with GP systems owing to their reduced need for cleansing velocities.

Pressure sewer geometry also differs from most water supply systems in that some reaches of the pressure sewer may flow part full (by gravity). In profile, pressure sewer systems are sometimes arranged to pump only upslope, or to confine downslope piping to steep and distinct reaches where hydraulic conditions are more predictable.

b. Pipe Sizing

For rough planning purposes the Equation 2-8 may be used, and a velocity of flow assumed at 60 cm/s (2 fps). Table 2-1 shows the resulting number of homes that could be served by various mainline sizes.

Table 2-1. Approximate Main Sizes Required to Serve Number of Homes Shown (Using $Q = 0.5N + 20$, and $V = 2$ fps)

Pipe diameter (in)	No. Homes Served
2	6
3	60
4	120
6	240
8	560

$$Q = 0.5N + 20 \quad \text{Equation 2-8}$$

Where,

Q = Design flow, gpm
N = Number of homes served

There is little economy in using 5-cm (2-in) mains. 7.5-cm (3-in) pipes can be installed in the same trench, with the same backfill, labor, and engineering, yet the 7.5-cm (3-in) main has considerably more capacity. Also, saddle-type, "wet-tap" 32-mm (1-1/4 in) service line connections can be made to the 7.5-cm (3-in) main, but 32-mm (1.25-in) wet taps cannot be made to the 5-cm (2-in) main. 7.5-cm (3-in) pipe is readily available in gasketed joint, but 5-cm (2-in) is commonly available only in solvent weld joint. For these reasons 7.5-cm (3-in) is becoming the smallest preferred main size. An exception to this practice is when 5-cm (2-in) pipe is needed to maintain cleansing velocities.

c. Routing

In most cases pressure sewer mains are located outside of and adjacent to the edge of pavement and approximately parallel to the road or street, which reduces the expense of pavement repair and traffic control. In areas subject to unusual erosion, the preferred location is often within the paved area. This location is also favored by some municipalities as being an area where subsequent excavation is less likely and more controlled, and therefore being a location more protected from damage.

An advantage to the use of pressure sewers is that the small diameter plastic pipe used is somewhat flexible and can be routed around obstacles. This feature allows pressure sewers to follow a winding path as necessary. The pipe should be bent in a long radius if possible, not in a radius less than that recommended by the pipe manufacturer. The minimum radius recommended by the Uni-Bell Handbook of PVC Pipe¹⁹ for classes of pipe most used as pressure sewer main is given by Equation 2-9. In diameters larger than about 10 cm (4 in), the pipe

is stiff and the practicality of achieving the allowed radius must be considered.

$$R_b/OD = 200$$

Equation 2-9

Where,

R_b = Minimum radius of the bending circle.

OD = Outside diameter of the pipe.

Pressure sewer mains are normally buried with a cover of about 75 cm (30 in). In a few cases where economy is paramount and subsequent damage is unlikely, they are buried more shallowly. In colder climates the depth of bury may be dictated by frost penetration depths. In the northern U.S. they are often placed at 1.2-1.5 m (4-5 ft), and in arctic conditions as deep as 2.4 m (8 ft) or deeper. In cases where these depths result in excessive capital/installation costs, alternative pipe materials which incorporate insulation and even heat tracing have been successfully employed.²⁰

When using large diameter mains, the height of the isolation valves may dictate a minimum burial depth so the valve operator is sufficiently below ground surface. The height of air release valves can also dictate burial depth if the valves are to be fully underground.

The separation of pressure sewers from water supply mains and laterals often requires that the pressure sewer be buried deeper than would be required for other reasons. In most instances the separation requirements between the sewer and private wells and streams are dictated by state health departments, and the requirements differ throughout the United States. Typical requirements are shown in Table 2-2.

Profiles of mains are recommended and usually, but not always, shown on the plans. They may be omitted if the mains are only a few hundred feet long, if air release stations are not needed, and if there are no obstacles to be crossed.

Culvert and utility crossings often dictate numerous variations in the burial depth of pressure sewer mains, with many resulting sags and summits in the pipeline profile. In some cases these variations in the profile are hydraulically detrimental regarding the accumulation of air at the summits. When the variations are regarded as detrimental, reaches of the pressure sewer main may be placed at a particular depth to allow for the crossings, or otherwise profiled to minimize summits.

To minimize damage to the pressure sewer main caused by subsequent excavation, ground surface route markers

Table 2-2.

Typical Requirements for Separation of Pressure Sewer Lines From Water Lines²¹

Parameter	Requirement
Parallel Installations	Locate sewer as far as practical from water main. Minimum separation 3 m (10 ft). If sewer is closer than 3 m (10 ft) from water main, sewer is to be located 30 cm (12 in) lower than the water main. In some jurisdictions, when closer than 3 m (10 ft), sewer is to be of water main materials or encased. Other jurisdictions allow water and sewer in the same trench if the sewer is 30 cm (12 in) lower.
Crossings	Crossing is to be as nearly perpendicular as practical. Sewer to be 30 cm (12 in) lower than water main. Some jurisdictions require that no joints be used in the sewer main within 3 m (10 ft) of the crossing.

are sometimes placed adjacent to or above the main, warning excavators of its presence. Good as-constructed plans are helpful in identifying the pipeline location, and a cable buried with the main can be induced with a tone so the main can be field located using common utility locating equipment.

A warning tape marked "pressure sewer" is sometimes placed shallowly in the pipeline trench to further notify excavators. When the tape is placed lower in the trench, e.g. adjacent to the pipe, it is called an "identification" tape. The tape can be metalized so it can be detected with utility locating devices, but most tape cannot be induced with a tone, so metalized tape should be placed shallowly to be detected.

d. Trench Section

Trenching may be accomplished using a backhoe, wheel trencher, or chain-type trencher. The choice of equipment is usually dictated by the contractor based on equipment availability and the material to be excavated.

Imported material termed "pipe zone backfill" is often placed to surround the main several inches if material excavated from the trench is regarded as unsuitable for use as that material. Pipe zone backfill is usually granular, as pea gravel or coarse sand. Fine sand or soil is generally not as desirable as it bulks rather than flowing into place densely under the pipe haunches.

The remaining backfill material required is often specified by the agency controlling the road or street, especially if the mains are located within the pavement.

In some cases a lean cement-sand slurry is used for backfill. This option is particularly attractive when a narrow trench is used, the mains are located within the pavement, and prompt restoration for traffic is important.

e. *Pipe Materials*

PVC is most widely used. Polyethylene has also been used, especially when the number of joints must be minimized, or when it is selected for visual identification in contrast to PVC water mains. Polyethylene has also been used for lake crossings, and in insulated and heat-traced form for arctic installations.

The commonest PVC mains are iron pipe size (IPS) 1,400 kPa (200 psi) working pressure rated, standard dimension ratio (SDR) 21, or 1,100 kPa (160 psi), SDR 26. Even though the operating pressures in the mains may be far lower than the working pressure rating of the pipe, lower rated pipe is not normally recommended. Thinner wall pipe is more likely to be seriously damaged during installation. Also, the mains should be built to withstand the pressure of hydraulic cleaning using a pipe cleaning pig. SDR 26 pipe has been reported to suffer damage when used with high-head pumping units.⁴ In some cases SDR 26 is used only in sizes 10 cm (4 in) and larger, to avoid the thin wall characteristic of smaller pipes.

On small diameter gravity sewer projects, PVC sewer pipe, ASTM D-3033 or D-3034 is often used. This pipe has a different outside diameter than IPS, and in some sizes, the outside diameter of D-3033 is different from that of D-3034, so the availability of fittings should be investigated.

When PVC mains larger than about 20 cm (8 in) are used, AWWA C-900 pipe is sometimes specified, often for reasons of the availability of proper fittings. This pipe is available in two types, iron pipe size, and cast iron pipe size, the latter being a different outside diameter than either IPS or sewer pipe.

Pressure irrigation pipe (PIP) is often used to fabricate pump vaults and other appurtenances, and has a different outside diameter than any of the other pipes mentioned.

See Table 2-3 for an abbreviated listing of pipe dimensions.

Refer to the Unibell Handbook of PVC Pipe¹⁹ for a more thorough listing. Checking with manufacturers for availability is required as many companies do not produce all the pipes said to be available.

PVC pipe has a high coefficient of thermal expansion; about 3/8-in of length variation/100 ft of pipe/10°F temperature change.

$$\text{Coefficient} = 3.0 \times 10^{-5} \text{ in/in/}^{\circ}\text{F} \quad \text{Equation 2-10}$$

Considerable temperature changes will be experienced during pipeline installation, and some degree of temperature change will occur during operation, with climate changes and effluent temperature changes. To reduce expansion and contraction induced stresses, flexible elastomeric ("rubber ring") joint pipe is preferred for use as mains.

If solvent weld joint pipe is used, the pipe manufacturer's recommendations for installation regarding temperature considerations should be followed. The Uni-Bell Handbook of PVC Pipe¹⁹ also provides guidance as to proper practices.

Fittings most often used are of the solvent-weld joint type. They are more commonly available than gasketed joint fittings, and expansion and contraction are allowed for in the remaining pipe joints. Care must be taken for proper solvent welding, especially when using larger pipe sizes that are difficult to handle.

f. *Appurtenances*

Isolation valves (IVs) are used on pressure sewer mains much as they are on water mains. Gate valves may be used, or resilient-seated gate valves, and occasionally ball valves are used. Typical locations for IVs are at intersections, both sides of bridge crossings, both sides of areas of unstable soil, and at periodic intervals on long routes. The intervals vary with the judgment of the engineer, but are typically about 0.8-1.6 km (0.5-1 mi).

Cleanouts are occasionally provided. The most common type consists of a valved wye extending to ground surface that can launch a pipe cleaning pig. When cleanouts are provided, they are typically placed at the ends of mains, and where main diameter sizes change.

Thrust anchors should be used as they are in water main practice. Even though the operating pressure in the main may be low enough that thrust anchors may not seem to be required, the main should be hydrostatically tested following installation at a pressure of about 1,400 kPa (200 psi). A properly installed PVC pipeline will easily pass that pressure test, but a poor installation will be revealed. Thrust anchors and a quality installation may also be required if pipeline cleaning by pigging is anticipated.

Table 2-3. Abbreviated Listing of PVC Pipe Dimensions

IRON PIPE SIZE (IPS)

Nom. (in)	O.D.	Min. wall			
		SDR-26 CL. 160	SDR-21 CL. 200	Sch. 40	Sch. 80
1/2	0.840			0.109	0.147
3/4	1.050			0.113	0.154
1	1.315			0.133	0.179
1-1/4	1.660			0.140	0.191
1-1/2	1.900		0.090	0.145	0.200
2	2.375		0.113	0.154	0.218
2-1/2	2.875		0.137		
3	3.500		0.167		
4	4.500	0.173	0.214	Note: Other thicknesses include SDR-13.5, SDR-32.5, and SDR-41.	
6	6.625	0.255	0.316		
8	8.625	0.332	0.410		
10	10.750	0.413	0.511		
12	12.750	0.490	0.606		

SEWER PIPE PSP ASTM D-3033

Nom. (in)	O.D.	Min. wall		
		SDR-41	SDR-35	
4*	4.215	0.125	0.125	* 4" is SDR 33.5
6	6.275	0.153	0.180	
8	8.160	0.199	0.233	
10	10.200	0.249	0.291	
12	12.240	0.299	0.350	
15	15.300	0.375	0.437	

SEWER PIPE PSM ASTM D-3034

Nom. (in)	O.D.	Min. wall	
		DR-42	DR-35
4*	4.215	-	0.125
6	6.275	-	0.180
8	8.400	0.200	0.240
10	10.500	0.250	0.300
12	12.500	0.300	0.360
18	18.700	-	0.536

AWWA C-900 CAST IRON PIPE SIZE (CIPC)

Nom. (in)	O.D.	Min. wall		
		DR-25 PC.100	DR-18 PC.150	DR-14 PC.200
4	4.800	0.192	0.267	0.343
6	6.900	0.276	0.383	0.493
8	9.050	0.362	0.503	0.646
10	11.100	0.444	0.617	0.793
12	13.200	0.528	0.733	0.943

Table 2-3. Abbreviated Listing of PVC Pipe Dimensions (continued)

AWWA C-900 IRON PIPE SIZE

Nom. (in)	O.D.	Min. wall		
		DR-25 PC.100	DR-18 PC.150	DR-14 PC.200
4	4.500	0.180	0.250	0.321
6	6.625	0.265	0.368	0.473
8	8.625	0.345	0.479	0.616
10	10.750	0.430	0.597	0.768
12	12.750	0.510	0.708	0.911

PIP IRRIGATION PIPE

Nom. (in)	O.D.	Min. wall		
		SDR-100 50' Hd.	SDR-32.5 125 psi	
4	4.13	0.065	0.127	Note: Other thicknesses include SDR-41, SDR-51, and SDR-93.
6	6.14	0.070	0.189	
8	8.16	0.080	0.251	
10	10.20	0.100	0.314	
12	12.24	0.120	0.377	
15	15.30	0.150	0.471	
18	18.36	0.180	-	
20	20.40	0.200	-	

Air release valves are required on major systems and require hydraulic analysis for placement. Water-system-type air release valves have been tried, mostly without success due to corrosion or clogging with sludge. Wastewater-type air release valves are recommended.

On pressure sewer systems serving more than about 500 homes, the provision of pressure monitoring stations (PMS) is advised. These consist of a small diameter service line connected to the side of the main, and extending to a terminus in a valve box or vault. An isolation valve is provided at the terminus, and a fitting necessary for connection to a mobile pressure sensor-recorder that may be moved from station to station. PMS are used to occasionally record pipeline pressures (the hydraulic gradient), to measure how the piping system is performing. This is particularly of interest over time, or it may be of interest if the placement or performance of air release assemblies are in question.

Flow meters are of considerable value, especially on large systems. Magnetic-type flow meters are the most common.

2.4.2.2 Service Lines**a. Geometry**

Pressure sewer service lines are typically arranged similar to water services. A typical location is near and

parallel to property lines, but where property line locations are not well known, it is advisable to maintain some distance from them.

It is good practice to field mark the location of the service line with boldly identified lath a few days prior to installation. This serves as a reminder to the property owner about the intended location and may cause the owner to recognize some reason that the location should be changed. It also serves as an advance notice to neighbors if property boundaries are in dispute.

Most municipalities prefer locating the service line where it will not be driven over, but other jurisdictions prefer locating the service line within the paved driveway. The reasoning is that subsequent excavation and associated damage to the service line may be less likely within the pavement.

Service lines should be located distant from potable water lines to reduce possibility of cross contamination. They should also be distant from other buried utilities if possible, due to the possibility of damage caused by the subsequent excavations for maintenance or repair of those utilities.

Service line profiles may normally undulate without much concern. The velocity and duration of flow and the typical diameter and length of service lines are such that air rarely collects in the summits to such an extent as to cause hydraulic problems.

b. Pipe Sizing

Typical service lines serving individual homes are 32 mm (1.25 in) in diameter, but have varied from 19 to 38 mm (0.75-1.5 in). A primary reason for what might seem to be over sizing is to limit headloss, so head-limited pumps can discharge at an adequate rate. A second reason for the seemingly large 32-mm (1.25-in) diameter is that check valves in that size will easily pass any solids that the pump can discharge.

Multiple EDU (MEDU) service lines are often 5-cm (2-in) diameter or larger and should be separately evaluated for hydraulic capacity.

To evaluate service line sizing, ordinates are subtracted from the pump curve for various discharge rates corresponding to headlosses in the service line. The resulting plot is the effective pump curve, that is, the characteristics of the pump at the main.

c. Trench Section

Where soil types allow the use of chain-type trenchers, use of trenchers is sometimes specified for service line

installations as they cause less disruption to the property owners yard than backhoes. Rocky soils and some clayey soils that will not self-clean from the trencher teeth may be impractical to excavate using a trencher.

Street crossings are often accomplished by pushing a steel conduit under the street to act as a sleeve for the service line that is installed inside. Other street crossings are bored, or use a "hog." Open cutting of the street is done where other means are impractical.

Service lines are buried below the frost penetration depth, and usually at a minimum of 45-60 cm (18-24 in), as a measure of protection from subsequent excavations. In rocky settings in moderate climates, service lines are sometimes buried only 30 cm (12 in).

Bedding and backfill materials for service lines are usually the native material taken from the trench excavation, especially when a trencher is used and the material is well broken up. When the service lines are installed under travelled ways or when rock excavation is encountered, surrounding the service line with imported pipe zone backfill is advised.

d. Pipe Materials

Schedule 40 PVC is the most commonly used service line material. In small sizes, such as the normal 32-mm (1.25-in), conventional 1,100-kPa (160-psi), PVC pipe has a thin wall that is subject to damage during construction. It is for this reason that the heavier walled schedule 40 pipe is normally used, while lower-pressure-rated pipe is used for the larger diameter mains.

PVC service lines usually use solvent-weld-type fittings. Rubber ring fittings are not commonly available in small diameters. Also, service lines are short as compared to mains so thermal expansion and contraction is a lesser concern. The manufacturers instructions should be followed regarding pipe laying where substantial temperature changes are expected. Expansion joints are available as a separate fitting, intended for use on solvent-weld-joint pipe.

Polybutylene and polyethylene have also been used. Either of these materials can be installed without joints and are favored to place within conduits at street crossings. Compression fittings are used in preference to insert fittings which reduce the size of the opening in the pipe.

The service line should be pressure-tested. A common practice is to hydrostatically test the line while visually examining all joints prior to backfilling.

e. Appurtenances

Connections to the main can be made by tee or by service saddle. Tees can only be used when they are installed while the main is being placed. Service saddles can be used to make wet taps to the main in service. To place tees, the service line location must be accurately and reliably known at the time the main is installed.

Intuitively, wyes are sometimes thought to be preferable to tees, for connection of the service line to the main. However, wyes are not hydraulically superior. Neither are wyes available in pressure rated PVC. There has been limited use of non-pressure rated drain, waste, and vent (DWV) wye fittings, but they are available only in limited sizes, and their use is seldom seen.

Connections to the main should be of high quality, considering the large number of them, considering that they are buried, and that a small error can be compounded to be a large problem.

A corporation stop is typically used at the service saddle, and a gate valve or ball valve also used for isolation, sometimes placed at the street right of way line. A buried, redundant check valve is also often used on service lines. So the check valve can be later found, it is placed adjacent to the isolation valve which has a valve box riser to ground surface.

Alternately, the check valve and isolation valve are placed in a valve box. The valve box is usually too small to allow field personnel to remove and reinstall a valve, so the box has to be dug up to provide access. The box allows operation of the isolation valve handle, and marks the location of the facilities. When a valve box is used, consideration should be given to frost protection.

A toning wire or metalized marker tape buried with the service line facilitates future location.

2.4.2.3 Building Sewers

The term building sewer refers to the gravity flow pipe extending from the home to the interceptor tank or pump vault. In many cases state or local authorities regulate installations of building sewers. The Uniform Plumbing Code is often referenced.²¹

The building sewer should slope continuously downward as specified by state code, usually at a slope of not less than 0.25 in/ft, or 2 percent grade. Desirably, the pumping unit should be located near the home so the building sewer is short, with less need for maintenance and less opportunity for I/I.

If an existing building sewer does not have a cleanout, one should be placed outside and close to the home. Some agencies prefer having a cleanout at the dividing line where agency maintenance begins. For example, if a sewer district had placed 6 m (20 ft) of new building sewer to join an existing building sewer and if that point marked where district maintenance begins, a cleanout may be used there.

When GP or SH systems are used and the building sewer enters the pump vault without a tee or ell, maintenance of the building sewer may be accessed via the pipe end. However, some agencies prefer discouraging the pipe cleaning contractors from entering the pump vault.

Bends in building sewers should be avoided where possible, and a cleanout used for each aggregate change in direction exceeding 57°.²¹

Infiltration via leaking building sewers has been common, as has the connection of roof or yard drains. A quality installation is advised, which determines the existence of these and eliminates them during construction. Smoke testing has been effectively used to reveal sources of extraneous water, but care must be taken to keep the smoke from entering homes.

PVC or ABS piping materials are most widely used. Some regulatory agencies require ABS in certain locations, such as in proximity to the home, or under driveways where external loads may be high.

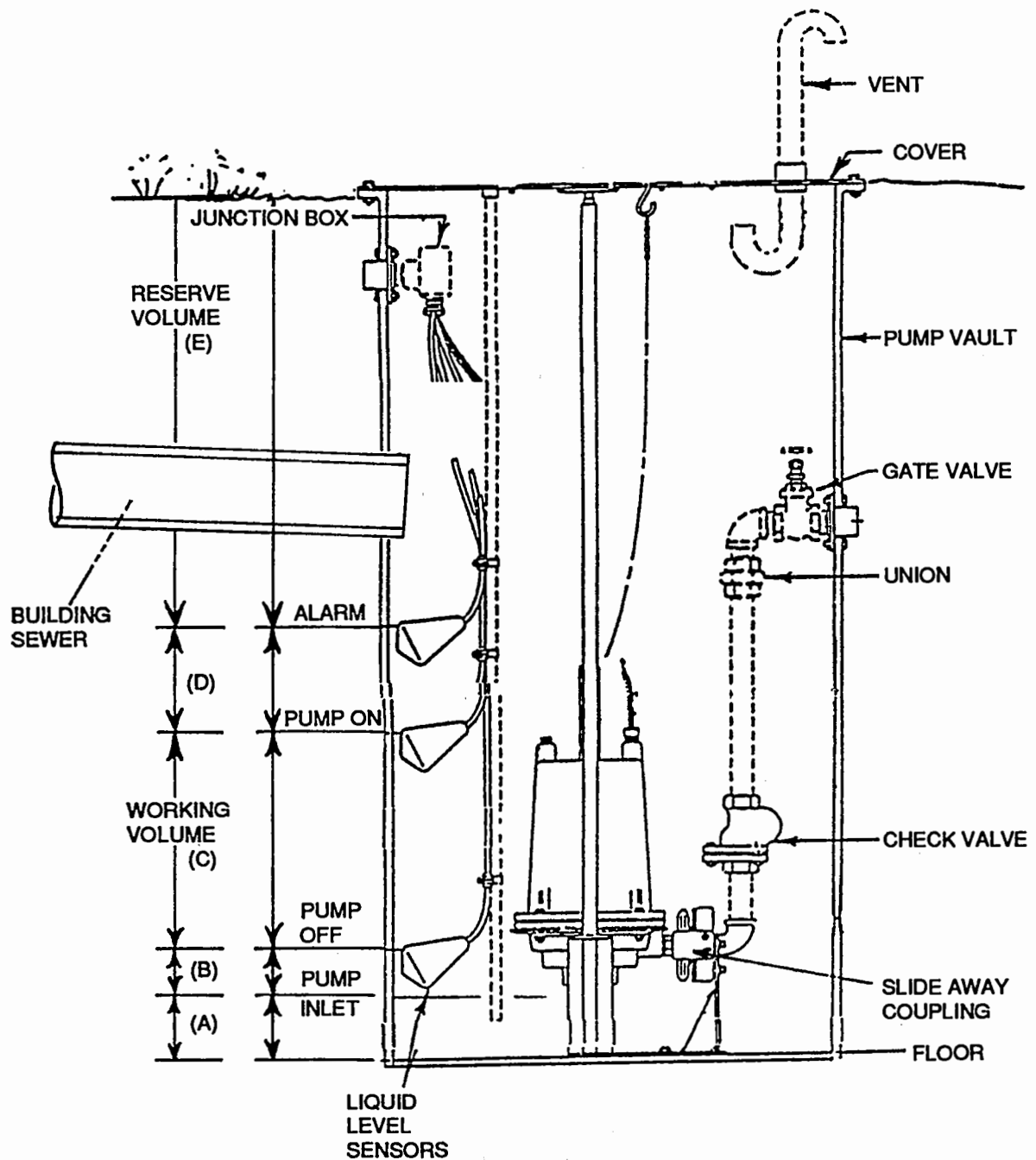
Direct burial (UF) or conduited wiring from the home to the pumping unit is often placed in the same trench with the building sewer, but this practice may require approval of the regulating authorities.

2.4.3.1 Grinder Pump and Solids Handling Pump Vaults

The various manufacturers of pressure sewer equipment provide somewhat different packages, but many generally resemble that shown in Figure 2-13. These vaults are typically made of FRP and vary in diameter from 60 cm to 120 cm (24-48 in), with the larger sizes usually being applied to duplex installations involving two pumps to serve a group of homes. The height may vary from 1.2 m to 2.4 m (4-8 ft).

The pump vault may be divided into zones, with each zone describing a particular purpose. Each manufacturer may have recommended dimensions to fit their own equipment, but to gain an understanding of the functions, an example is given. For ease in mental calculation of volumes held in circular basins, Equation 2-11 is used:

Figure 2-13. Zoning of GP or solids handling pump vault.



$$V = 6 D^2 \text{ (approximate)} \quad \text{Equation 2-11}$$

Where,

V = Volume per foot of depth (gal)
D = Inside diameter of basin (ft)

Referring to Figure 2-13, the pump inlet is seen to be suspended some distance (a) above the floor of the vault. This dimension may typically be about 10 cm (4 in).

The pump inlet is submerged some distance (b) below the lowest operating liquid level in the vault, the pump "off" level. This dimension may be about 2.5 cm (3 in), or a greater distance may be preferred to prevent vortexing. When using grinder pumps this dimension b is kept small so floating grease will not accumulate excessively.

The pump "on" level may be 30 cm (12 in) or so (c) above pump "off." If a 60-cm (2-ft) diameter basin is used, the working volume would be 91 L (24 gal) pumped/cycle (ignoring the volume displaced by the pump, and the wastewater entering the vault during the pumping cycle).

The alarm level is above the pump on level by some amount (d). In this example assume 15 cm (6 in) so the volume held in the basin between on and alarm is 45 L (12 gal), a small allowance.

If a duplex installation is used, the lag pump would turn on at the level shown as alarm in Figure 2-13, and the alarm level would be correspondingly higher.

Once the liquid level rises above the crown of the incoming building sewer, ventilation via the roof vent of the home is interrupted. Some users of GP or SH systems install a small P-trap vent through the cover or upper wall of the vault for continued ventilation under this condition.

Between the alarm level and the top of the basin is the reserve volume (e), if ventilation has been provided. Alternatively, an overflow may be provided to a holding tank or other structure (not shown).

The vault cover may be bolted on or, with some designs, the cover will be lifted up to allow a spillage on the lawn in preference to having backflow into the home in the unlikely event both the pump and check valves fail. If sized large enough, the P-trap vent accomplishes the same thing.

2.4.3.2 Septic Tanks (Interceptor Tanks)

In pressure sewer and small diameter gravity systems the septic tank has often been called an interceptor tank

owing to the differences between septic tanks used in conjunction with drainfields versus tanks used on pressure sewer systems. The interceptor tank is generally an engineered product of higher quality, stronger, and more water tight. Except for the possible incorporation of a pump and its containing vault, an interceptor tank is functionally the same as a septic tank.

A comprehensive study on septic tank sludge and scum accumulation was accomplished in the 1940s by the U.S. Public Health Service.²³ Over 600 references were made to develop information from previous research, and practices were reviewed in 12 countries plus the United States. Over 200 operating tanks also were studied, as well as many full-scale laboratory systems. A regression analysis of their observations resulted in equations relating sludge and scum accumulation with time and are presented here as Equations 2-12 and 2-13:

Sludge accumulation:

$$V = 0.7T + 2.12 \quad \text{Equation 2-12}$$

Scum accumulation:

$$V = 0.45T - 0.12 \quad \text{Equation 2-13}$$

Where,

V = Volume per capita (cu ft)
T = Time in years

Of the total scum accumulation, about 1/3 was reported to lie above the liquid level, and 2/3 below.

Sludge clear space was described as that distance between the top surface of the sludge and the outlet tee. To avoid scour and carryover of solids, a minimum sludge clear space of 15 cm (6 in) was suggested.

Scum clear space, the distance between the bottom of the scum layer and the outlet baffle or tee (or inlet ports in the pump vault) was recommended to be a minimum 7.5 cm (3 in), but pressure sewer experience suggests 15 cm (6 in) to be a better allowance since scum is a particularly problematic material if allowed to enter the system.

When Equations 2-12 and 2-13 are solved for typical single family occupancies and 3,780-L (1,000-gal) interceptor tanks of usual shape, and using 15-cm (6-in) clear spaces for scum and sludge, the pump vault inlet port level appears best placed at about one-third of the lowest liquid level in the tank.

An audit of septage accumulation was made on the Glide, Oregon STEP system by the Douglas County Department of Public Works. Sludge and scum levels were measured in 400 tanks which had been in service for 8-years. In one analysis of that study, measurements in 186, 3,780-L (1,000-gal) STEP tanks serving single family residences were selected for evaluation. Results are shown in Table 2-4.

From the Glide study and other observations, the following guidelines were proposed for estimating average sludge and scum accumulation at single family residences, with the caveat that accumulations vary greatly from home to home:

1. Annual combined sludge plus scum accumulation: 33 gal/home.
2. Scum comprises about 1/3 of the combined volume of sludge plus scum.
3. About 1/3 of the scum lies above the water (effluent) level.
4. Pump vault inlet ports should normally be located at about 1/3 of the depth below the 'pump off' level.

It has been described that sludge and scum accumulations vary so much as to make accurate forecasts futile.²⁴ Observations on hundreds of interceptor tanks reinforce his position. However, no better general placement of the outlet ports has been dictated than that given above.

Zoning of the interceptor tank for scum and sludge accumulation and location of the ports in the pump vault are shown in Figure 2-14.

When the pump vault is an integral part of the tank, the liquid level in the entire interceptor tank rises and falls in response to incoming flows and in response to pumping. Although liquid level control settings may vary, typical settings for single home application in 3,780-L (1,000-gal) tanks are 7.5 cm (3 in) between pump off and on, and 7.5 cm (3 in) between on and high water alarm. Most 3,780-L (1,000-gal) interceptor tanks contain about 30 L/cm (20 gal/in) depth, so the 7.5-cm (3-in) settings correspond to about 230 L (60 gal). Figure 2-15 depicts these liquid levels.

The various dimensions may differ as dictated by the individual design engineer. One typical design for a single family residence, using a 3,780-L (1,000-gal) tank and the guidelines for sludge and scum accumulation noted above is given in Table 2-5. (Note that septic tanks normally hold 10 percent more than their rated volume, so a 3,780-L (1,000-gal) tank would contain 4,160 L (1,100 gal) filled).

Table 2-4. Sludge and Scum Accumulation at Glide, Oregon (186 1,000-gal tanks)

	Time (yr)	Occupants (No.)	Sludge (gal)	Scum (gal)	Total (gal)
Mean	8.2	2.75	195	92	289
S. Dev.	0.7	1.18	98	60	114
Min.	7.2	1	20	0	60
Max.	9.1	6	530	300	650

This type of table is used to locate the positions of liquid level sensors and pump vault ports, but is not a reliable indicator of the amount of sludge and scum to be accumulated at the time septage removal is necessary. This is because accumulations vary so greatly from home to home. Scum and sludge accumulations at facilities other than single family homes vary considerably. For example, restaurants produce considerable grease; while laundromats produce considerable heavy sludge, but little scum.

2.4.3.3 Multiple-Compartment Tanks

The use of baffled, or multiple compartment septic tanks has often been considered. Objectives have been to reduce the concentration of suspended solids in the effluent, and to limit the consequence of digestion upset. Some have speculated that if septage is not removed as scheduled, flow into the first cell of a two compartment tank may be plugged with sludge or scum before low quality effluent is discharged from the second cell, but this speculation has proven unreliable.

Baffling is sometimes thought to achieve improvement in performance by providing longer detention time, better dispersion, reduced short circuiting, keeping sludge and scum away from the outlet, and reduction of turbulence. But opinion differs as to whether the performance of two smaller tanks (the product of providing baffles) is superior to that of one large tank.

Studies have been made on the performance of single- and multiple-compartment tanks by the U.S. Public Health Service,²³ Winneberger,²⁴ Baumann and Babbitt,²⁵ and Jones.¹¹ These studies have generally concluded that single compartment tanks are economical, practical, and perform well, but that baffling is advantageous to performance. The degree of improved effluent quality has been described as ranging from "microscopic" to "statistically significant."

Performance varies considerably depending on how compartmentation is accomplished. Two types of compartmented tanks are shown in Figures 2-16 and 2-17. In the former figure, a hole or window is provided in

Figure 2-14. Zoning of a STEP system interceptor tank showing scum and sludge accumulation.

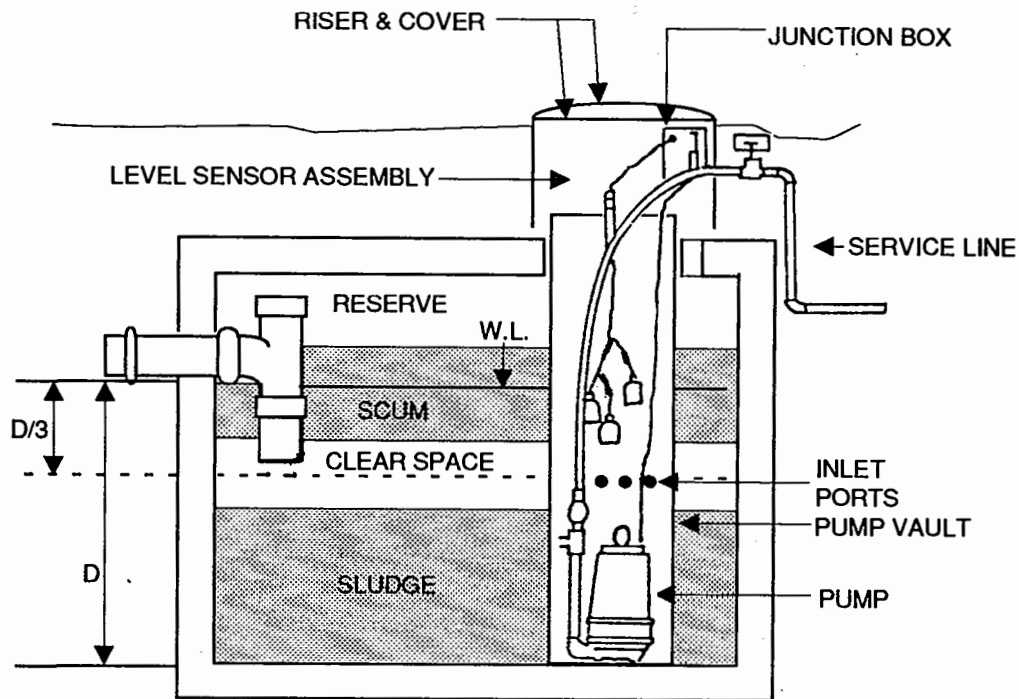


Figure 2-15. Zoning of a STEP system interceptor tank showing liquid levels at pump off, on, and high level alarm.

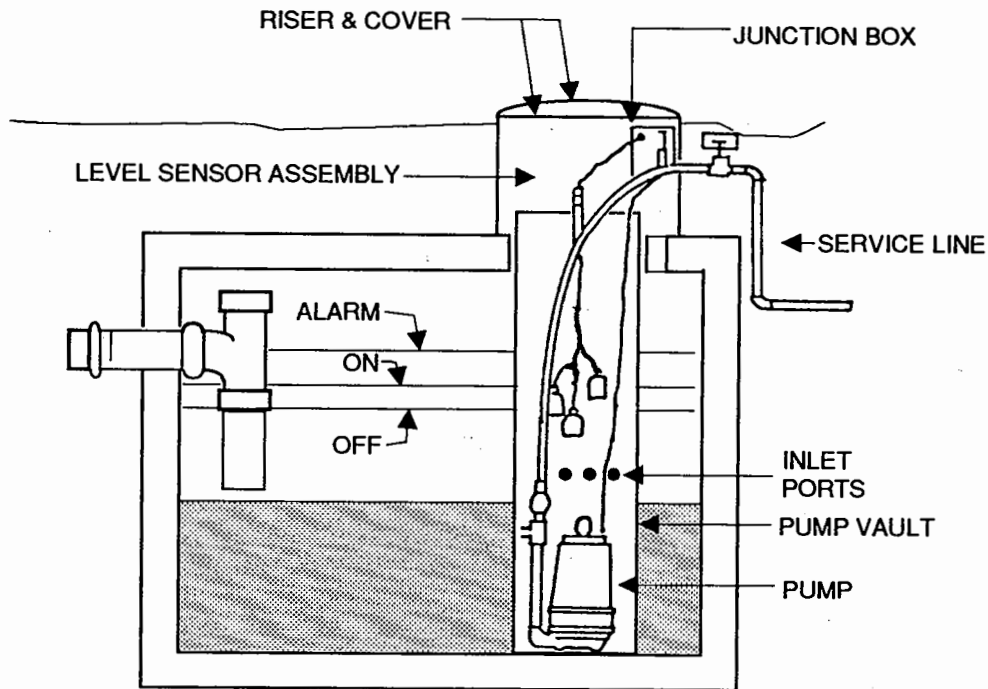


Figure 2-16. Two-compartment interceptor tank with hole in baffle wall where clear space expected.

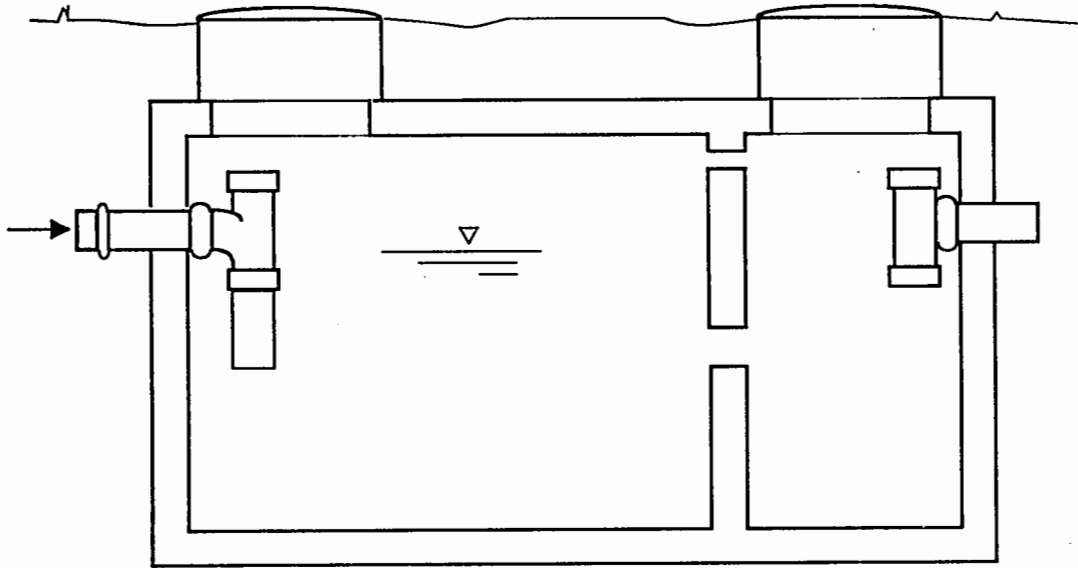


Figure 2-17. Two-compartment interceptor tank using combination tee and 1/4 bend.

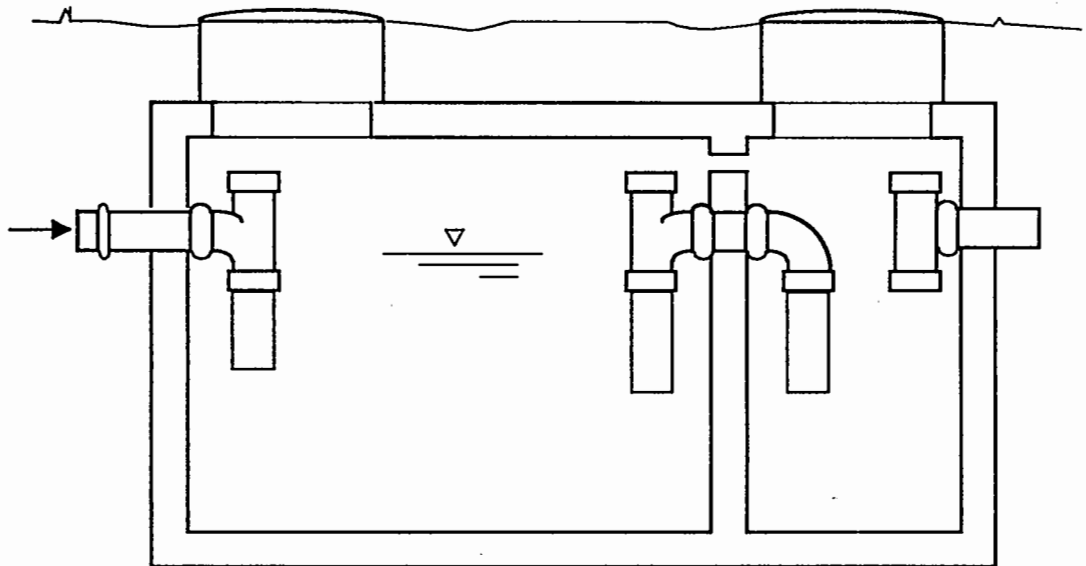


Table 2-5. Typical Zoning Design For a 1,000-gal Interceptor Tank Serving a Single-Family Residence

Parameter	Volume (gal)
Sludge	370
Sludge clear space (6-in)	120
Scum clear space (6-in)	120
Submerged scum	120
Floating scum	60
On-off pump cycle (3-in)	60
On-alarm (3-in)	60
Reserve space*	190
Total	1,100

* Reserve is 720 L (190 gal) above the alarm level when there is 230 L (60 gal) of floating scum, or 950 L (250 gal) when there is no floating scum.

the baffle wall separating the two cells, placed in the center of where the first compartment clear space is expected to be. The latter figure shows a combination tee and 1/4 bend with the invert placed at the liquid level of the first cell, and the inlet located in the clear space of the first cell. Generally, the latter design has been credited as providing the better performance.

If an internal pump vault is placed in the second cell of the tank, as shown in Figure 2-16, the liquid level will rise and fall throughout the full length of the tank in response to pumping, as shown in Figure 2-15.

However, if an internal pump vault is placed in the second cell of the tank shown as Figure 2-17, the liquid level fluctuates only in the second cell. If the second cell is small and if the usual zoning volumes are used between pump off, pump on, and high level alarm (normally about 230 L [60 gal] each), the liquid level fluctuations may be considerable. This causes the liquid level within the second cell to be quite low at pump off level, and subjects the tank to a more unbalanced structural loading due to the soil backfill. This has been of most concern when flexible, plastic septic tanks, or concrete tanks of marginal strength are used.

Baffle walls must be made strong enough to withstand the liquid level being at operating height on one side of the wall, but with the other cell being empty. This has been difficult to accomplish with some plastic tank designs.

Experience with thousands of single-cell septic tanks used on STEP systems has shown a single riser to be sufficient. If multiple cells are used, each cell must be fitted with a riser to provide access for septage removal.

To further evaluate multiple-compartment tanks, the purpose of the tank as used in a STEP system should be reviewed. If discharge is to a municipal treatment works, the purpose is generally to capture the grit, grease, and stringy material that would present a problem to pumping, foul the liquid level sensors, and possibly cause obstructions in the piping system.

Single-cell tanks have been used extensively and perform satisfactorily for this purpose. Pump clogging occurs in only about one percent of the installations annually. Clogging of mains is nonexistent. It seems little benefit would be derived by the use of multiple-compartment septic tanks.

If, however, discharge is made to a soil absorption field or other similar facility where the maximum reduction of suspended solids may be critical, properly designed multiple compartment tanks will perform better functionally.

The need for quality, structurally adequate, infiltration-free tankage is usually regarded as more apparent than the need for compartmentation. However, research on tank shape, inlet and outlet fittings, gas baffle deflectors, and other design factors is encouraged.

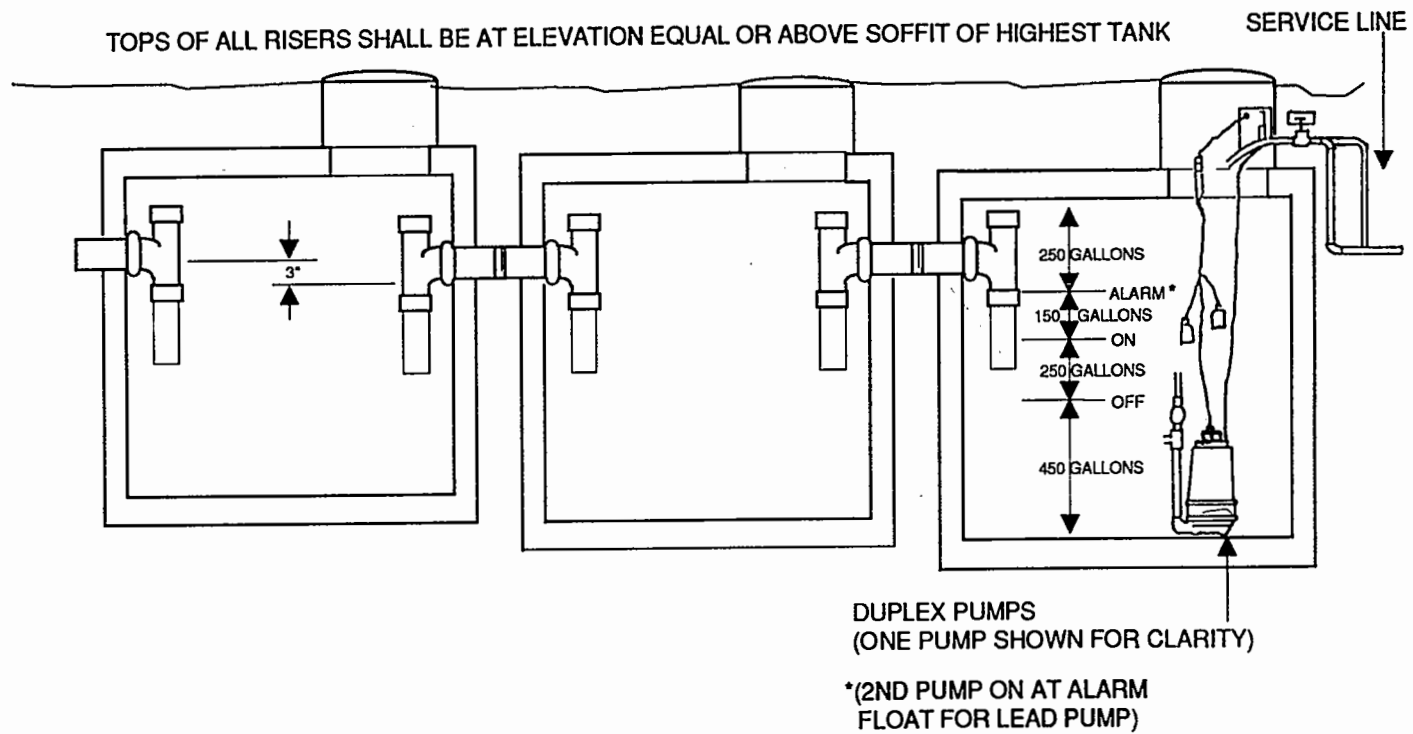
2.4.3.4 Tanks Serving Multiple Homes

Most projects standardize on 3,780-L (1,000-gal) tanks to serve any size home, and are used to serve up to 3 homes. The benefits of standardization outweigh the benefits of variable tank sizing. However, the frequency of septage pumping increases, but not proportionately, with the number of people served.

When MEDU installations are made, such as to serve a restaurant, apartment complex, mobile home court, or other facility having flows greater than that expected from about 3 EDUs, larger tankage is needed. The use of precast tanks placed in series has been successful. Multiple tanks in parallel have experienced problems in dividing flows evenly. In some cases single large precast tanks have been used. In a few cases, large tanks have been cast in place, but this practice is often the least desirable option due to site disruption.

Figure 2-18 shows a MEDU installation using precast tanks placed in series. Two pumps are placed in the final tank. To make use of reserve space within the tanks without breaching the lowest tank riser, all risers should extend at least to the elevation of the soffit of the highest tank. It is often impractical to provide as much reserve space in the tanks as would be desired, in which case emergency overflow to an existing or new drainfield is sometimes provided.

Figure 2-18. Multiple-unit interceptor tank and pump assembly.



To insure ventilation between tanks, even if the liquid level in any tank is higher than the crown of the inlet or outlet fittings, a small pipe "jumper" may be placed to join risers.

Sizing relies in part on the judgment of the engineer, with regard to flows and to character of the wastewater. Expectations of sludge and scum accumulation are guided by experience with the types of facilities being served. Sizing of MEDU grinder pump vaults follows conventional sewerage pumping practice.

One method used for septic tank sizing is provided by Equation 2-14:²⁶

$$V = 0.75Q + 1,125 \quad \text{Equation 2-14}$$

Where,

V = Volume of septic tank (gal)
Q = Daily flow (gpd)

Daily flow can be estimated by making comparisons with similar facilities in the area having metered water. Other methods are described in the *Design Manual for Onsite Wastewater Treatment and Disposal Systems*.²⁶

As for septage removal frequency, experience with hundreds of interceptortanks on pressure sewer systems has shown that tanks which meet the above criteria serving typical single-family residences require pumping at about 10-yr intervals. However, septage accumulation varies widely from home to home, and an interval of about 8 yr is often adopted.

The best method is to remove septage when it begins to encroach on the clear space minimums, which requires measurements using devices described best in several publications.^{23,24,27} Septage removal from tanks discharging to soil absorption fields should be more frequent due to the variability of septage accumulation and due to the severe damage caused if solids are discharged to them.

MEDU establishments such as restaurants require septage removal much more frequently. Restaurants discharge large and troublesome volumes of grease and the extremely hot dishwasher water adds to the problem. Excess grease should be removed prior to discharge to the interceptor tank. Methods of accomplishing this are outside the scope of this document, but are presented elsewhere.^{11,23,28}

2.4.4 Pumps/Electrical Service

2.4.4.1 Pumps

a. General

Centrifugal pumps are most commonly used, followed by progressing cavity pumps. Submersible water well pumps having 5 or more stages (impellers) are sometimes used on STEP systems, and pneumatic ejectors have seen limited use in the past, but none are presently being marketed.

For approximate estimations of horsepower required for particular head and flow conditions, the following equation can be used. Equation 2-15 has been derived from the definition of horsepower being 33,000 ft-lb/min, and the weight of water being 8.34 lb/gal:

$$H_p = QH/(3,960E) \quad \text{Equation 2-15}$$

Where,

H_p = Horsepower
Q = Discharge rate (gpm)
H = Head (ft of water)
E = Pump and motor efficiency (%)

Equation 2-15 is used for only the most general purposes since pump selection depends considerably on specific pump characteristics. It is used, however, in conjunction with pump characteristic curves or testing data to determine efficiency.

The ability of a pressure sewer pump to run at shutoff head is a consideration. Shutoff head conditions occur when an isolation valve has been closed, or following a long power outage when many pumps run simultaneously, dominating some of the pumps to shutoff head.

Some pumps have the ability to run dry for extended periods. A dry running condition occurs when the pump has become air bound or when the "off" liquid level sensor malfunctions.

If the liquid level in the pump tank is higher than the hydraulic grade line of the main, siphoning to the main can occur after the pump motor has turned off. This can lower the liquid level in the pump vault to the elevation of the pump intake, allowing air to be drawn into the pump and causing some pumps to become air bound.

In areas where the power supply undergoes extremes of voltage variation or brownouts, motors tolerant of these conditions may be preferred, such as permanently split capacitor (PSC) motors.

b. Centrifugal Pumps

The most common GP or STEP pressure sewer pump is the submersible centrifugal.

The head-discharge curve is typically shaped as shown in Figure 2-19a. When two or more pumps discharge simultaneously into a common header the abscissas are additive, and the resulting curve is as shown in Figure 2-19b. Because in pressure sewer use the pumps are located at different stations and different elevations along the main, the analysis becomes more detailed. This procedure is given by Flanigan and Cudnik.¹³

Since the pump discharges via a service line to a pressure sewer main, headlosses in the service line can be subtracted from the ordinates of the pump H-Q curve to form the effective pump curve at the main, as shown in Figure 2-20.

Centrifugal pumps draw most power at maximum discharge, at the far right of the H-Q curve, and draw the least power at shutoff head. Efficiencies are shown on some published curves, with greatest efficiency usually being about mid point on the curve.

STEP system centrifugal pumps can discharge light solids that may be present in septic tank effluent. Typically the pumps can handle solids ranging from 6-mm to 18-mm (0.25-0.75 in) diameter. Small solids handling pumps, intended for raw wastewater use, can pump solids of about 5-7.5 cm (2-3 in) in diameter. Grinder pump impellers can handle only small solids since the pumping of large solids is not necessary due to the grinding action.

STEP impellers are usually made of bronze or plastic. If a pump having an iron impeller sets in septic wastewater without operating for a while, e.g. when the homeowner is on vacation, the impeller can become bonded to the volute by iron sulfide. Often the motor will not have enough starting torque to break the impeller loose from the iron sulfide, occasioning a service call. Bronze and plastic impellers are generally more resistant to this bonding than iron impellers.

Some grinder pumps use iron impellers, but have fewer occasions of iron sulfide binding than STEP pumps because the GP uses a higher horsepower, higher starting torque motor and the wastewater is less likely to contain sulfide species at the pump vault than a STEP system.

Iron sulfide plates onto the iron casing, especially in STEP systems. In most cases the effect is only cosmetic, but in some cases corrosion and metal loss occurs. The

corrosion depends on the sulfide generating potential of the wastewater (e.g. sulfate in water supply, BOD, and temperature). If the pump is constantly submerged it will normally corrode less than if it is sometimes exposed to the atmosphere.

Most centrifugal, submersible pumps used on pressure sewer systems can operate at shutoff head without damage for extended periods. Some engineers specify that a 3-mm (1/8-in) diameter hole be provided in the pump casing, to leak slightly during shutoff conditions, causing circulation and cooling. Since the holes tend to clog, some engineers favor using orifice bleeder valves for this purpose. These are simple, neoprene valves that have a flapper to partially close the orifice during discharge.

Most submersible pumps can run dry for extended periods without damage. Dry running is often caused by an air bound condition following siphoning. To prevent siphoning, a hole or orifice bleeder valve is sometimes provided to admit air and break the siphon. The hole or valve can also allow the air to escape, preventing air binding even if siphoning occurs. With STEP systems using pump vaults inserted in the interceptor tank, uncontrolled siphoning can cause the pump vault contents to be lowered such that the pump vault can float out of position.

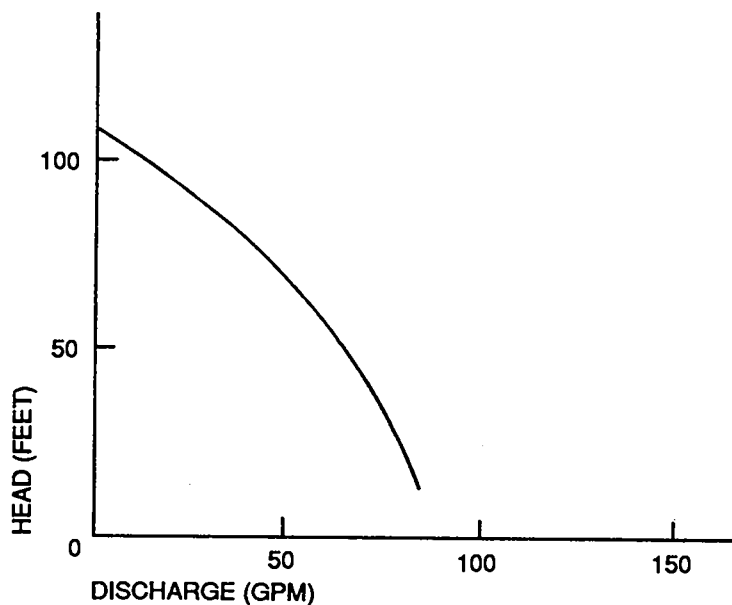
Most high-head centrifugal pressure sewer pumps use 3,450-rpm, 2-pole motors rather than slower running 1,725 rpm, 4-pole motors.

In general, for centrifugal pumps steeper H-Q curves and higher heads are obtained by the impeller being shallow (having less solids handling capacity), having fewer vanes, and having more wrap to the shape of the vanes. Larger diameter impellers are associated with higher heads. There are various impeller designs, such as enclosed, open, and vortex. Each type and design has its own characteristics.

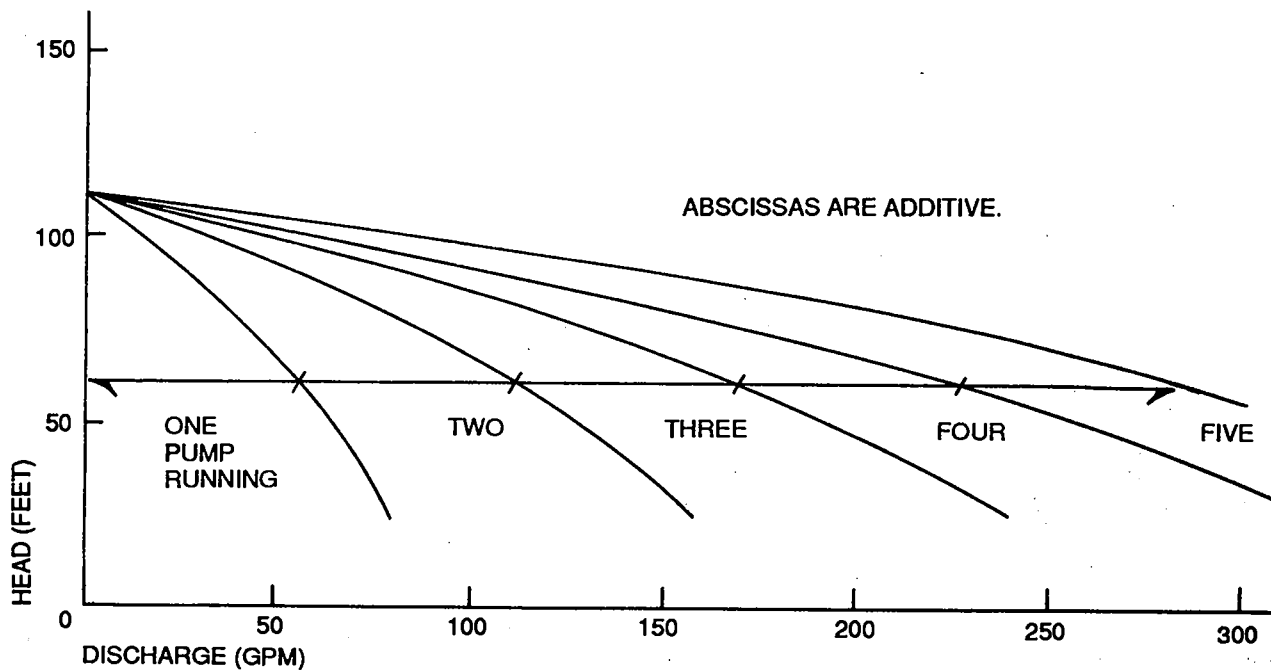
Submersible, multiple stage water well pumps are small and light-weight which make them easier for field personnel to handle. Due to the multiple stages, high running speed, and shallowness of the impellers, high heads are achievable using fractional horsepower motors. Well pumps are damaged if run at shutoff head, so employ the drilled hole or bleeder mentioned previously to leak sufficient flow to lubricate the pump and to keep the motor from excessively overheating.

If run at excessively high heads, a well pump develops a downthrust condition, and if run at excessively high discharge rates, an upthrust condition develops. To limit the latter condition an orifice restriction is sometimes

Figure 2-19. Head-discharge curves for one and multiple centrifugal pumps in parallel.

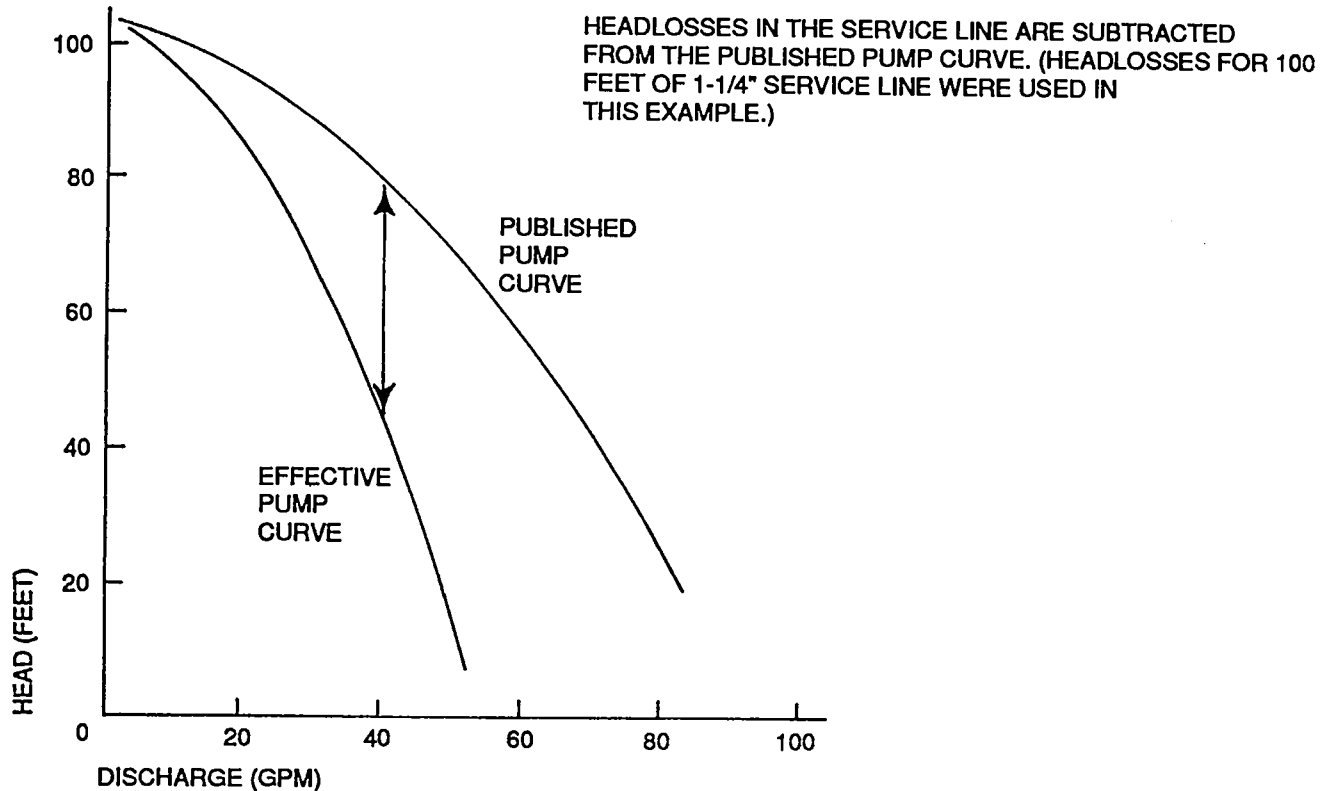


a. Single pump H-Q curve



b. H-Q curves for multiple pumps

Figure 2-20. Effective pump curve.



and consequently preventing the pump from running at too high a discharge rate.

Well pumps must be used in conjunction with screens or filters, since they have no solids handling capability. They must also be installed in a sleeve resembling a well casing, so water flows past the motor to provide cooling.

c. *Progressing Cavity Pumps*

A progressing cavity pump is a semi-positive displacement, screw type-pump consisting of a single helical rotor turning eccentrically in a double helical elastomeric stator having twice the pitch length of the rotor. This forms a series of spiral shaped sealed cavities that progress from suction to discharge. Figure 2-21 shows the rotor and cutaway stator of a progressing-cavity pump.

Most progressing-cavity pumps used on pressure sewer systems have the pumping elements submerged, but dry well installations are sometimes used. The progressing-cavity pump self-primers reliably.

A typical head-discharge curve is shown as Figure 2-22. The H-Q curve is steep, discharging a predictable flow rate. The mid range discharge rate is generally adopted as the pump flow rate, irrespective of the slight change caused by head variation. When numerous progressing-cavity pumps discharge simultaneously into a common header (pumping in parallel), the resulting flow is taken as the adopted discharge rate for one pump times the number of pumps running. This is in contrast to centrifugal pump analysis where the composite pump curve is plotted, and the discharge rate is taken to be the intersection of the composite curve and the system curve.

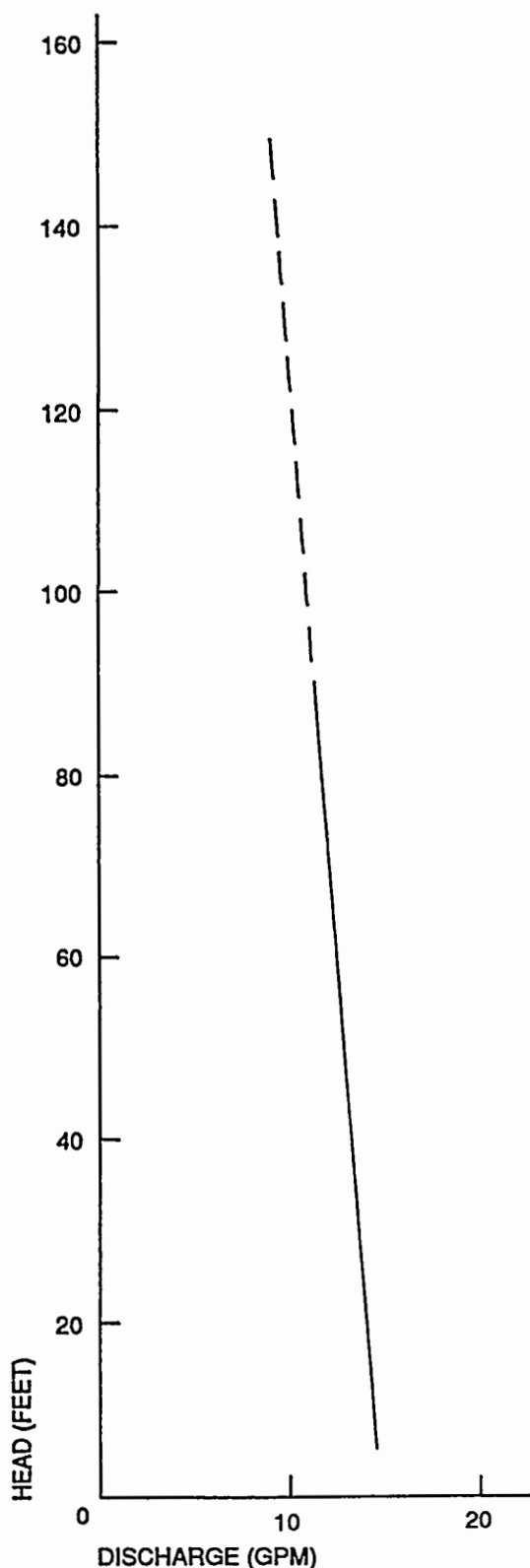
The power draw of a progressing-cavity pump increases with increasing discharge pressure.

Progressing-cavity pumps do not have a natural shutoff head but instead continue increasing pressure within the capacity of the motor and the ability of the components to withstand the pressure. If run against a closed valve, amperage draw increases and the thermal overload eventually trips out, shutting off the motor. After cooling, the thermal overload automatically resets and the pump

Figure 2-21. Rotor and cutaway stator of progressing cavity-type pump. (Courtesy of Environment/One Corp.).



Figure 2-22. Typical progressing-cavity pump H-Q curve.



tries again to discharge. If the valve is still closed, the thermal overload again heats and trips out, and the process repeats. The thermal overloads used are capable of withstanding this duty.²

If the closed valve was located right at the pump discharge, the stator would likely be destroyed by running at excessively high pressure. However, in pressure sewer applications some air is normally present in the piping system to cushion the effect, so a closed mainline isolation valve may present a less severe condition.¹²

Some installations use a pump-mounted pressure relief valve to avoid overpressure conditions, some rely on the protection provided by the motor thermal overload, and others sense the discharge pressure and turn off power to the pump motor until the high pressure condition has been corrected.

The stator will be destroyed if a progressing-cavity pump is run dry, and if the dry running continues, the rotor and other components will be damaged. However, if the rotor and stator are wet enough for lubrication they can be run without damage.

Progressing-cavity pumps do not become air bound, but anti-siphoning devices are recommended to be used with them to prevent air release into the pressure sewer and to keep the rotor and stator lubricated.

Four-pole motors, running at 1,725 rpm are used.

2.4.4.2 Electrical service

Most grinder pumps and solids handling pumps, which require more starting torque than effluent pumps, use capacitor start-capacitor run (CSCR) motors, and some use capacitor start-induction run (CSIR) motors. Centrifugal effluent pumps use CSIR or permanently split capacitor (PSC) motors, and some fractional horsepower effluent pumps use shaded pole (SP) motors. Nearly all motors have automatic reset thermal overload protection built in.

Power consumption is normally low; often less than \$1.00/month. Power use can be estimated by Equation 2-16, or more correctly by Equation 2-17:

$$P = 745 H_p T \text{ (approximate)} \quad \text{Equation 2-16}$$

$$P = T I E F \quad \text{Equation 2-17}$$

Where,

P = Power consumption (watt-hours)
 H_p = Horsepower

T = Running time (hours)
I = Amperage
E = Voltage
F = Power factor (percent)

As points of reference, typical power factors are about 50 percent for CSIR motors, and higher for PSC motors. CSIR motors will generally draw more amperage than PSC motors.

Malfunctions of the liquid level sensors are a major cause of service calls. Accordingly, special attention should be given to specifying good sensors and applying them properly.

Mercury float switches have been the most commonly used liquid level sensors. One float is required for pump off, one for pump on, and one for high level alarm. If redundant off is desired, an additional switch is used. Duplex installations add one more switch for lag pump on.

Most mercury float switches are pilot devices that control the motor start contactor (relay) in a control panel, but some are motor rated. Some variations of mercury float switches provide a differential so that one float can control both pump on and off. Motor rated, differential switches are sometimes used on economically motivated installations.

Grinder pump and solids handling pump systems encounter rags and grease in the raw wastewater that interfere with the movement of mercury switches. Larger size floats have generally been more reliable.

Some STEP pump vaults are so small that the mercury switches have little room to operate. Also, when the pump vault is internal in the septic tank the differential between floats is small (typically about 7.5 cm [3 in]). The small space and small differential require that the mercury switches be given a short tether. The short tether and the likelihood of the switches coming in contact with pumping equipment in the vault often cause these installations to be unreliable.

Displacer-type liquid level sensors have seen limited use. Displacers are floats that move vertically in the pump vault, thus conserving space and presenting fewer opportunities for being obstructed. Most displacers are built to provide a differential between pump on and pump off. Some are pilot devices, while others are motor-rated.

Bubbler type liquid level sensors have also been used. These consist of a small compressor which purges air down a sensing tube in the wet well. The pressure in the

sensing tube increases as the liquid level in the wet well rises. Pressure switches in the control panel sense the pressure to turn the pump on or off, or to activate alarms.

Bubblers are more common than mercury switches on pressure sewer installations in Europe. In the U.S. their use is usually limited to more expensive installations, or they are used where the liquid level sensors must be "explosion proof"-rated. To achieve that standard, mercury switches use intrinsically safe relays which are expensive, complicate the control panel, and have had a history of being troublesome.

Environment-One uses a trapped air system, similar to the bubbler but without the compressor.

Numerous other level sensing methods have seen limited use, such as diaphragm switches, reed switches, probes, transducers, and ultrasonics.

The electrical control panel is usually mounted on the outside wall of the home, but is sometimes placed on a pedestal near the pumping unit.

Features of the control panel vary greatly depending on the choices of the designer. Figure 2-23 shows typical, simple control panel circuitry using mercury float switches. This controller depicts a 120-volt panel not requiring a panel mounted capacitor, and works as follows:

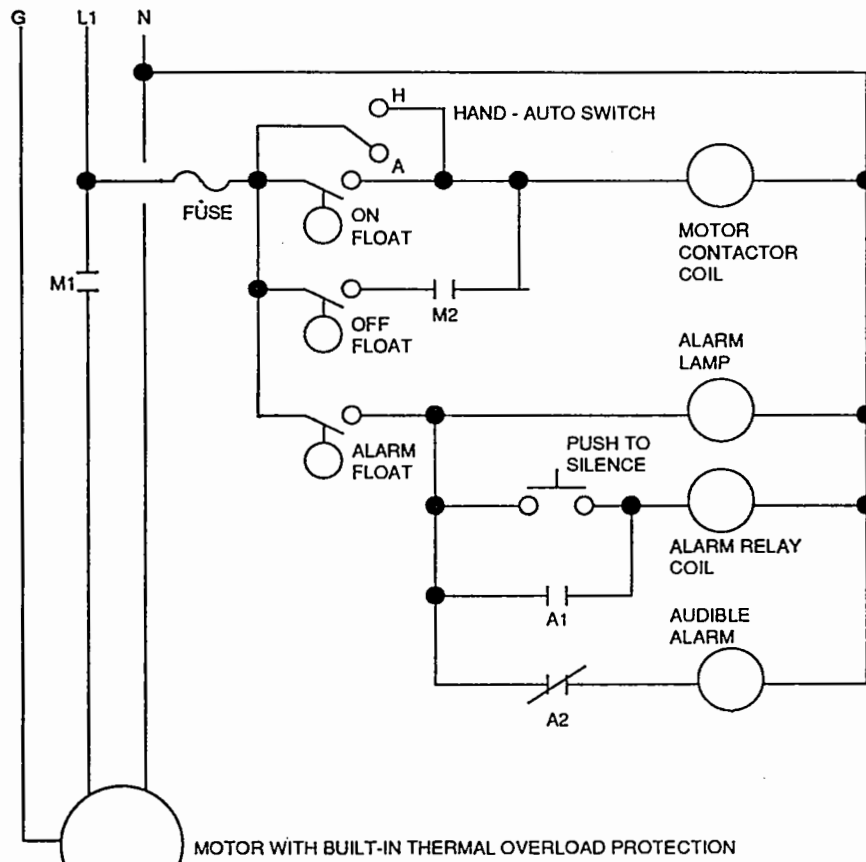
Assume the hand-auto switch is in the auto position, in which case that circuit is open. In the hand mode, the switch powers the motor contactor coil. Off is often provided by the fuse or circuit breaker being openable.

As the liquid level in the wet well rises, the off float is closed and eventually the rising water closes the on float. Power then passes through the closed on float switch to the coil of the motor contactor, which electrically closes and holds contacts M1 and M2. M1 being closed, power is provided to the motor.

The pump motor is now running, so the liquid level in the wet well is receding. As the liquid level in the wet well recedes, the on float opens but the motor contactor coil remains energized via the still closed off float and the closed contact M2. As the liquid level continues to fall, the off float switch opens, discontinuing power to the motor contactor coil and opening contact M1 which stops the motor and opening contact M2 so the motor contactor coil no longer receives power via the off float.

If the liquid level in the wet well rises above the on float and continues rising, it eventually causes the alarm float switch to close. This provides power to the alarm lamp.

Figure 2-23. Circuit diagram of a basic 120-volt control panel.



Power is also applied to the audible alarm via a normally closed contact A2. The alarm may be silenced by pushing a button mounted on the control panel door. This energizes the alarm relay coil, opening contact A2 and closing contact A1. The alarm relay coil remains energized via the now closed contact A1. When the high liquid level condition has been corrected, the alarm float switch opens and the alarm circuitry is automatically restored to the condition shown in the figure.

A simple panel might have the following features:

1. Motor start relay
2. Audible high water alarm
3. High water alarm light
4. Control circuit fuse
5. Audible alarm push button silence
6. Audible alarm automatic reset relay and circuitry
7. Power leads accessible for taking amperage readings
8. Hand-off-auto (HOA) toggle switch
9. Terminal strip

If the pump uses a capacitor start motor, the capacitor may be in the control panel or it may be mounted on the

motor. With a capacitor start - capacitor run motor both capacitors are in the control panel.

Numerous additional features can be added to control panels.

In some cases they have proven to be detrimental owing to the complexity produced. This is particularly the case if the service personnel that maintain them are not accomplished in electrical matters.

Care should be exercised in providing a proper balance of control panel features versus the benefits of simplicity.

Additional features sometimes used in control panels:

1. Elapsed running time meter
2. Event counter
3. Power failure alarm
4. Overload protection in addition to that built in the motor
5. Various switches and status lights
6. Low voltage transformers
7. Seal failure lights

On STEP systems having a mixture of 115- and 230-volt motors, it has been common to provide 230-volt power with neutral to each control panel. In that way, either voltage pump can be run.

A junction box is used at the pumping unit to join the mercury switch wiring and pump wiring to the branch wiring extending from the pumping unit to the control panel. This wiring is either rated for direct burial or is placed in a conduit. Each mercury switch uses two conductors and the pump uses 3 conductors. Accordingly, a typical installation involving a pump and 3 mercury switches requires 9 wires. One leg of each mercury switch can be commoned, so 7 wires extend from the pumping unit to the panel.

Junction boxes have often been a maintenance problem due to leakage and corrosion. Splices made inside them should be made watertight. Corrosion-resistant materials should be used on the junction box. Abundant room for access to the junction box is required for ease of service.

On some installations the pumping unit is placed so near the home that wiring can be run directly from the pumping unit to the control panel without need for a junction box. The conduit must be perfectly sealed to prevent the migration of corrosive and flammable gases to the panel.

The use of simple and easily understood electricals is generally advised. Thought must be given to electrical safety and to the certified electrical qualifications of the workmen. Familiarity with the National Electrical Code is required. Some electricals are listed by testing laboratories, e.g. Underwriters Laboratories, Canadian Standards Association, or Factory Mutual. This provides a measure of protection from electrical shock and from concerns over liability.

Power can be taken from the homeowner's load center (the circuit breaker panel). If the panel has no remaining space, sometimes two wafer breakers can be used in place of one standard sized breaker. Circuit breakers should be clearly marked for identification.

A problem in using the homeowner's load center is that access into the home is usually required which is a practice generally avoided by contractors and engineers. When the load center is used, the homeowner is typically required to provide the branch circuit to a specified location, instead of the work being included in the contract. Sometimes the work is improperly accomplished or not done in the time required.

An alternative to the use of the homeowner's load center is to take power from the meter base. In this case the power is run hot from the meter base to a fused safety switch placed as close to the meter base as possible. Use of this option requires specific approval of the regulatory authorities, such as the state electrical inspector and/or the state fire marshal, and also the approval of the electric utility.

2.4.5 Valves/Cleanouts

2.4.5.1 Mainline Isolation Valves

Isolation valves are used on pressure sewer mains to close a reach of the main for repairs if necessary, and to accommodate pressure testing of limited lengths of main. In some cases plastic valves have been used, generally ball valves, but more commonly bronze gate valves are used in sizes up through 7.5-cm (3-in) diameter, and epoxy coated cast iron valves are used in larger sizes.

Bronze and cast iron are subject to plating with sulfide, but generally have performed well. This assumes the pipeline flows full as opposed to being exposed to air at the crown. If air (gases) were present there, the hydrogen sulfide gas present could be converted to sulfuric acid. If the pipeline flows full, the corrosive acid cannot form.

Standard AWWA gate valves have been used but those using a resilient wedge and closing on a smooth bore have been found to close more tightly.

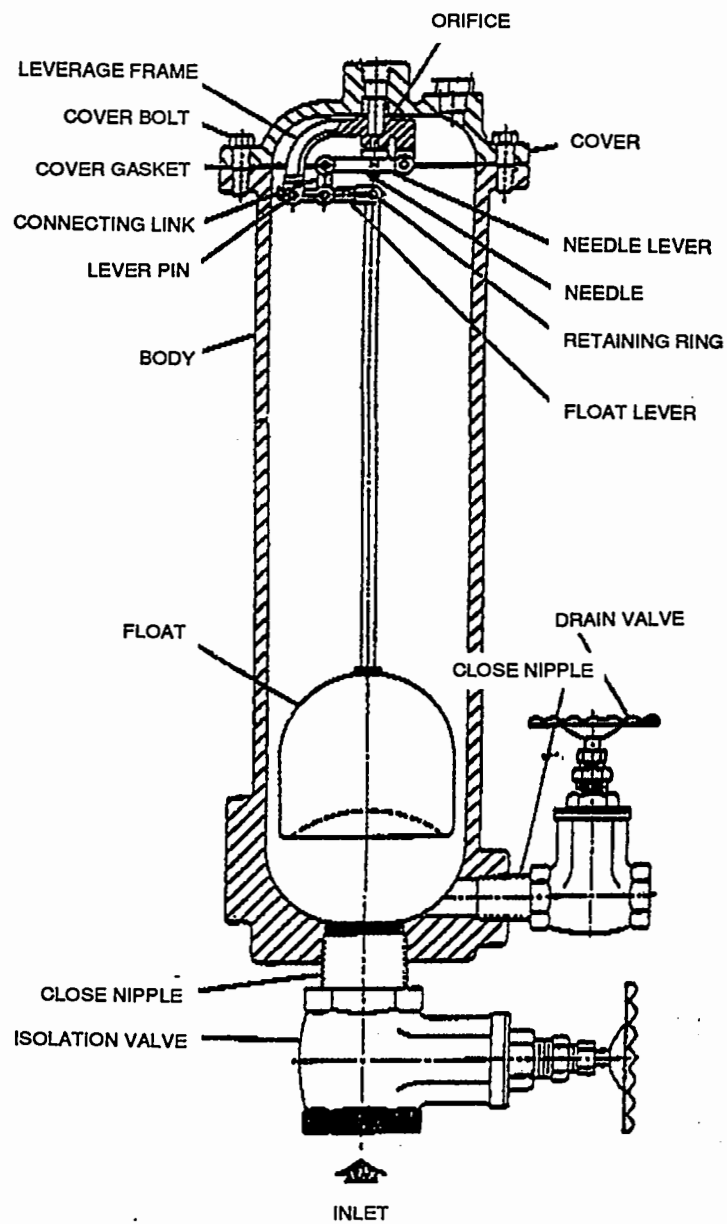
2.4.5.2 Air Release Valves

A common air release valve is shown as Figure 2-24. The valve inlet is connected to the top of the main. If the valve itself is placed to one side of the main, a service line can be used for the connection. The service line connects to the top of the main (where air is accumulated), and slopes continually upward to the valve inlet.

Normally the body of the air release valve is partly full of water (effluent). If it is full enough to buoy up the float, the rubber needle closes the orifice that passes through the top of the valve body. As air (or gas) enters the valve from the main, the trapped air accumulates and the liquid level in the valve body is correspondingly lowered. Finally enough air is trapped that the liquid level is lowered enough that the float is no longer buoyed up. When this happens the needle falls away from the orifice seat and the previously trapped air is expelled out the orifice.

The air release valve can also admit air under vacuum conditions. If the main undergoes a vacuum, as happens when siphoning occurs, the effluent in the valve body is drawn out of the valve and into the main. Since there is

Figure 2-24. Wastewater-type air release valve. (Courtesy APCO Valve and Primer Co.).



no effluent in the valve body to buoy up the float, the rubber needle falls away from the orifice seat. Air can then be drawn into the valve and into the main by the vacuum, through the orifice.

The amount of air that an air release valve can release or admit depends on the orifice size and the pressure differential across the orifice. For perspective, a 8-mm (5/16-in) diameter orifice will pass about 7 L/s (15 cfm) of free air at 6.9 kPa (1 psi), and about 5 L/s (20 cfm) at 69 kPa (10 psi).

Automatic air release valves should be wastewater type. Water system valves have occasionally been used but they usually become inoperative due to a gel-like accumulation. Also, water type valves may be produced from materials not sufficiently corrosion resistant, and they may have unsuitable opening sizes.

A soft durometer needle should be used where pressure is low, which is typical of pressure sewer application. Also, a large orifice size needs to be specified, for example 8-mm (5/16-in) diameter, to accommodate the comparatively large volumes of air in and out of the valve under the low pressures involved. The valve manufacturers should be consulted for guidance.

The valve bodies are cast iron, thoroughly epoxy coated. Working parts should be Type 316 stainless steel or a plastic proven by experience to be suitable.

Air release valves, not vacuum valves or combination air release and vacuum valves, are typically sufficient, but standard hydraulic evaluations would apply.

Because of the possible odor, air release valves are often vented to soil beds for odor absorption. Activated carbon canisters have also been used for treatment of off-gases, but with only limited success. Further data are presented elsewhere.²⁹ When the valves are located distant from dwellings and/or where they are expected to expel little gas they are normally vented to atmosphere, in which case the discharge needs to be vented outside of the valve box or the valve, box and appurtenances must be made of corrosion resistant materials.

Soil beds used for odor absorption generally consist of a perforated pipe bedded in gravel, underlying at least 45 cm (18 in) of loam soil backfill. Drainage should be provided if the soil bed is located in an area of high groundwater. Sizing depends on the volume of gas expected, but usually soil beds are greatly oversized as the extra sizing is low in cost and provides a generous assurance that the bed will perform despite possible adverse conditions.

Where the location of air release facilities be precisely determined, manifolded connections to the main may be made. These manifolds should include a connection several pipe diameters below the point where a hydraulic jump would form.

The geometry and valving should be such that each connection can be flushed clean by maintenance staff.

2.4.5.3 Cleanouts

Where cleanouts are used on the mains they usually are pipe cleaning pig launching stations. These are placed at pipeline terminations and where pipe diameters change. Mostly they are used to insure that the pipelines are clean of construction debris following pipeline installation. This removes the speculation of debris-caused blockages in the event that hydraulic anomalies occur.

The cleanouts typically extend to ground surface and may constitute summits that accumulate air (gas). Manual air releases are usually fitted to them.

2.4.5.4 Service Line Valves

Most of the valves and appurtenances available were conceived and designed for purposes other than pressure sewer use. They may work well on this application, or they may not. Advice is to proceed cautiously, and if at all possible, to see that the product has been used successfully on previous installations with the same application.

Corporation stops are often used at the main, fastened to the service saddle. Being difficult to replace, a quality product is desired. They are bronze, and should be full port opening.

Bronze gate valves have been used as isolation valves. These tend to perform well but do not seal drip tight. Unless high quality valves are used the handles corrode when exposed to soils and moisture, and they corrode badly if exposed to the wastewater atmosphere.

Plastic ball valves have been successfully used. These close tightly and because of the 1/4 turn of the handle, it is easy to see at a glance if the ball valve is open or closed. Union type valves are preferred, but if buried there is no access for adjusting the union. Perhaps surprisingly, some plastics become brittle due to exposure to hydrogen sulfide. Other plastics are not strong enough to withstand external forces, such as differential settlement. The proper material should be specified, such as PVC. Most manufacturers offer tables showing the corrosion resistance of their materials.

Two check valves are often used on services, with one being located at the pumping unit and the other being buried at some designated point along the service line, such as at the street right of way line or near the main. Service lines are quite subject to damage by subsequent excavations. The purpose of having two check valves is to prevent a spill in event of damage to the service line, and as redundant protection against backflow.

Bronze swing check valves have been successfully used, but do not close drip tight. Resilient seats improve the closing characteristics, but such valves are equipped with rotating disks that have a bolt protruding through the disk. The bolt tends to gather stringy material. A clear waterway is preferred.

Wye-pattern swing checks are preferred over tee-pattern valves when installed horizontally (due to the gravity component provided) but can be used in either the horizontal or vertical mounting position.

PVC swing checks using neoprene flappers have performed well. These tend to have large, clear waterways and open and close easily without becoming stuck by sulfides. However, some brands are cheaply made and quality control varies.

Many ball check valves, especially spring operated ones, have protruding parts that catch stringy material. Other designs have clear openings and are suitable.

Proven experience with the valve is desired. This can usually be provided when the valve is part of a package provided by an experienced pressure sewer products manufacturer.

2.4.5.5 Building Sewer Appurtenances

Cleanouts are used on building sewers, located near the home or at the point of demarcation between homeowner maintenance and district maintenance. Typical cleanouts are shown in Chapter 3.

Check valves termed "backwater valves" are made to be installed on building sewers, but are rarely used. These are swing check valves with the working parts being removable from the top of the valve, and are available in 7.5-, 10-, and 15-cm (3-, 4-, 6-in) diameter.

2.4.6 Miscellaneous Appurtenances

2.4.6.1 Septic tank effluent screens

While septic tanks are effective at the removal of troublesome solids, they are not 100 percent effective. Some solids are discharged in the effluent. Some effluent pumps have limited ability to handle these occasional

solids, making necessary the use of effluent screens or filters, especially at particular installations where maintenance history shows that solids carryover is common. Water well pumps have no solids handling ability so must always be used with a screen. If discharge is made to an on-site disposal system having distribution laterals with small orifices, effluent screening is sometimes suggested to reduce the possibility of orifice clogging.

Basket strainers were fitted to the discharge of a number of septic tanks used on STEP systems in the early 1970s in Florida,²⁴ and later in Oregon. These were observed over a period of time and showed that solids carryover varied greatly from home to home. Strainers at most installations were found to be nearly free of solids after months of use while those at certain other homes were full and overflowing.

The principal reason for the differences in solids carryover seems to be the practices of the user with respect to disposal of troublesome items. Some solids are prone to carryover as they attain a neutral buoyancy, and are not removed by sedimentation or flotation. Other solids are susceptible to being gas-lifted from the sludge layer and entrained in the tank effluent.

The proximity of the scum or sludge layer to the septic tank outlet is a major factor relating to solids carryover. Scum and sludge accumulation can vary considerably. While the clear space between the top of the sludge and the bottom of the scum layer may be within an expected range, either scum or sludge may constitute a large fraction of the total volume such that one of the two can encroach unpredictably on the outlet.

Another common reason for solids carryover has been that the "pump off" liquid level sensor has been set too near the level of the inlet ports, allowing submerged scum to be drawn into the pump vault. Also common is siphoning that can occur through the pump and discharge piping if the hydraulic grade line of the main is below the liquid level in the septic tank. This lowers the scum layer sufficiently that scum discharges from the tank as effluent.

In cases where scum is carried over, pumps and screens (if used) can be clogged.

To describe the volume and composition of carried over solids, guidance can be taken from the Manila, California STEP system. All flow from this system serving 350 homes is discharged to a main pumping station, fitted with basket strainers having about 6-mm (1/4-in) diameter holes. Annually, about 1,640 cm³ (100 cu in) of solids/home are captured by the strainers. The solids are comprised of cigarette filters, hair, prophylactics, tiny

grease balls, clumps of detergent, common earthworms, plastic sandwich wrap, and lint. Some carryover of scum is suspected at this project for the reasons outlined above.

The recognition that some solids pass through septic tanks and the use of effluent screens is not new. Winneberger showed that 6-mm (1/4-in) mesh screens were recommended by the U.S. Public Health Service in 1920.²⁴

Screened pump intakes have been tried, mostly without success. The poor performance has been due to the small screen area, the resulting high velocity through the screens which tends to hold solids on the screens. Their horizontal position permits trapping of floatable material. Also, since the floor of the pump vault is only a few inches below the screened pump intake, solids that fall away from the screen come to rest only a short distance from the screen and are resuspended each time the pump runs, and captured again by the screen. Vertical screens have been more self cleaning.

Effluent screens fall into two basic categories: 1) those that are a part of the septic tank outlet device, and 2) screened pump vaults, located within the septic tank.

Basket strainers are simple devices of the former category, hung on the septic tank outlet, and shown in Figure 2-25. These capture the solids so they can be easily seen for identification and to quantify the volume of carryover. Basket strainers have mostly been used for research rather than for pump protection, since they are not self-cleaning. Manual emptying of basket strainers is periodically required.

A multi-tray filter shown in Figure 2-26 is a patented device that replaces the septic tank outlet tee. It uses stacked plates, separated by a gap of about 1.5 mm (1/16 in) between each plate, and housed within an open-bottomed plastic case. Some solids slough off the filter and fall to the bottom of the septic tank. The plates may be lifted out of the case as a unit and rinsed off to remove solids that may accumulate between the plates.

Slotted PVC well screens have been fitted to septic tank outlet tees as shown in Figure 2-27. The screen can be cleaned with a round swab or brush placed inside the well screen.

The simplest type of screened pump vault is one where mesh is placed over the vault inlet ports, as shown in Figure 2-28. About 6-mm (1/4-in) plastic mesh is usually used. Because of the small screen area, blinding of this type of screen is usually experienced after a year or so,

requiring routine cleaning of the mesh which is attempted by hosing the screen from the inside of the vault. Often hair, lint, and other fibrous or stringy material becomes tangled in the mesh and the vault has to be removed from the septic tank for manual cleaning.

The screened vault, a patented method, is shown in Figure 2-29. A large, basket shaped plastic screen of 1.5 mm (1/16 in) mesh fits inside the pump vault but is slightly smaller in diameter, providing an annular space between the vault and the basket. After removing the pump and liquid level controls, the basket can be lifted out for cleaning.

A slotted pump vault is shown in Figure 2-30. A variation of this design not shown is for the vault inlet to be mesh instead of slotted. The slotted vault is made of PVC well screen, usually 30-40 cm (12-16 in) in diameter (depending on the size of the pump and appurtenances). If discharge is to a municipal treatment works, the location of the screen or slots is less critical. Some digested sludge may be pumped in this case, which is to be avoided if discharge is to a drainfield or other facility more sensitive to effluent quality.

In overview of the various designs, proponents of screens that are part of the septic tank outlet tee usually favor the external pump vault arrangement, which better allows factory packaging of pump components. They also prefer that flow through the screen be governed by the natural flow rate through the septic tank rather than coinciding with pumping rates, as with internal vault designs.

Proponents of screened pump vaults internal to the septic tank favor the economy of the internal vault and the integrated packaging of the septic tank and pump vault.

With most screen designs, if the liquid level in the septic tank rises sufficiently, as can happen during a long power outage, the screen can be bypassed from above, carrying scum inside the screen. If the screened vault becomes blinded, the pump vault can be floated out of position due to the higher liquid level outside the vault.

Slotted screens are believed to be more resistant to clogging than mesh screens due to the one-way bridging action provided by the long slot as opposed to the two-way bridging action of the mesh. However, the mesh better insures that long, stringy solids are captured.

The use of screens is vitally important when non-solids handling pumps are used. When effluent pumps are used capable of passing 13-mm (1/2-in) or larger solids, only about one percent of the pumps experience clogging per

Figure 2-25. Basket strainer used with external pump vault.

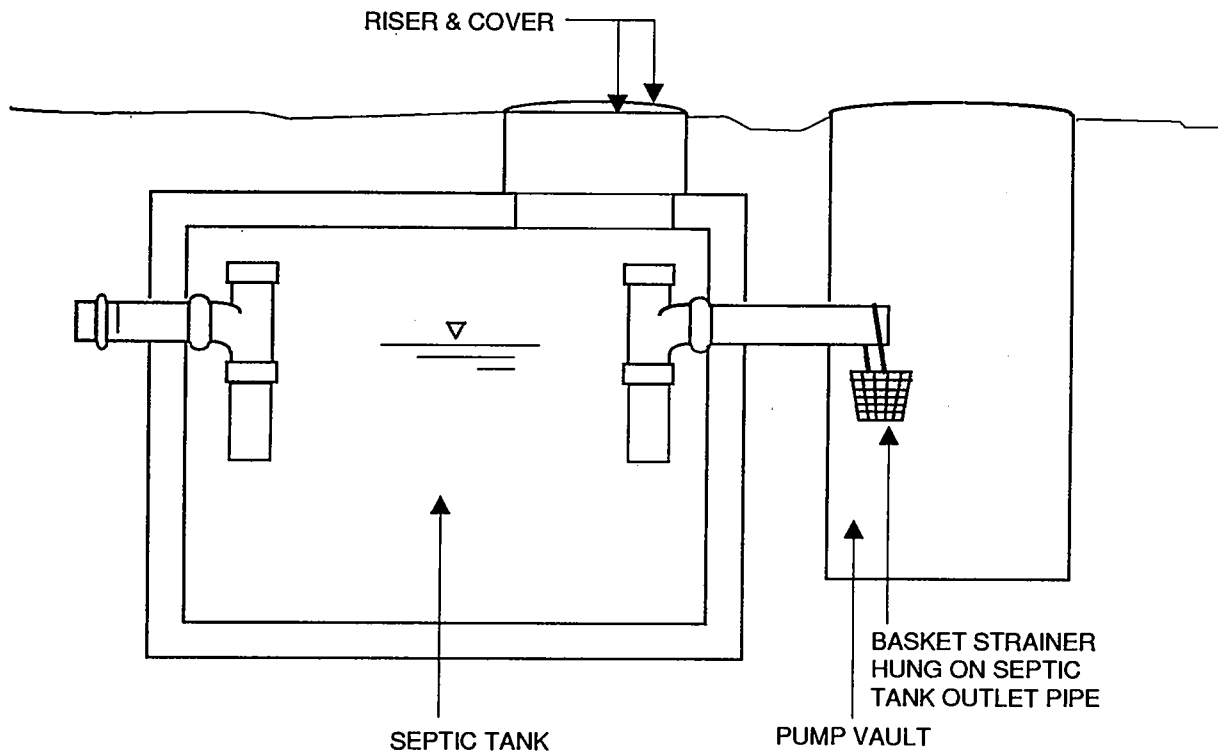


Figure 2-26. Multi-tray filter, used with external pump vault.

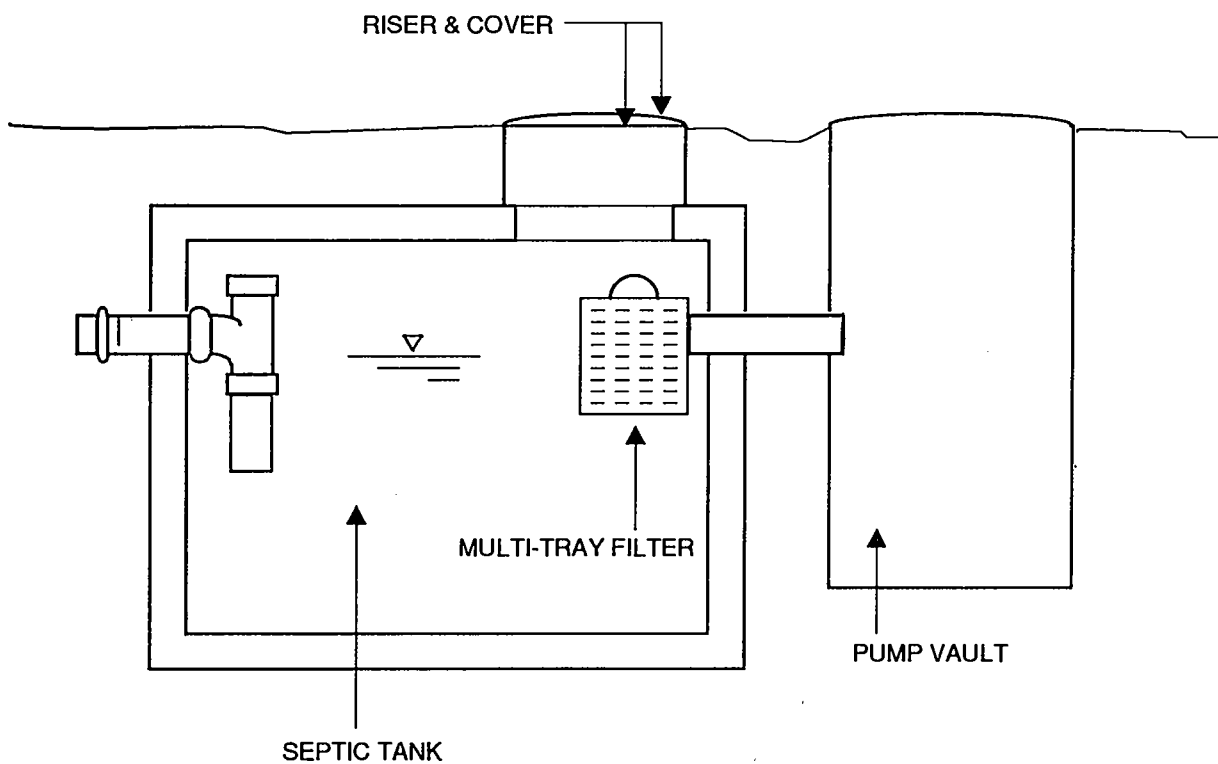


Figure 2-27. Outlet tee fitted with well screen.

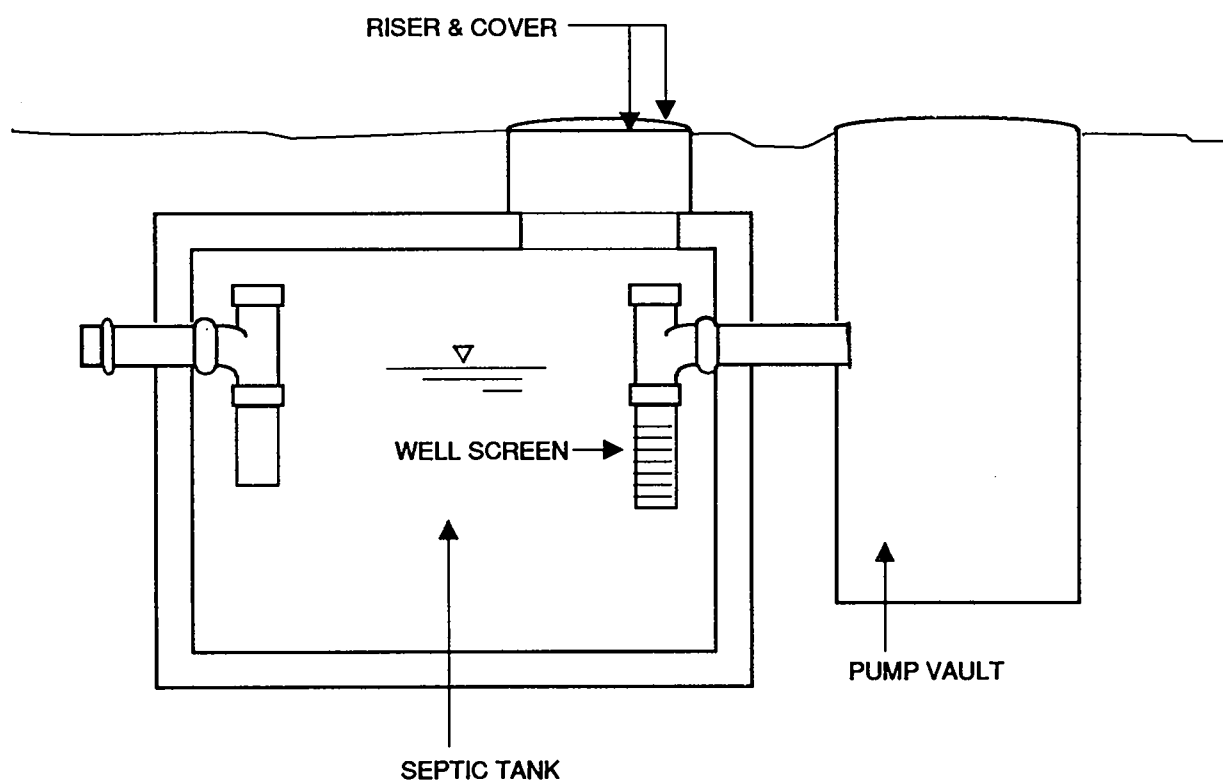


Figure 2-28. Mesh placed over inlet ports of internal pump vault.

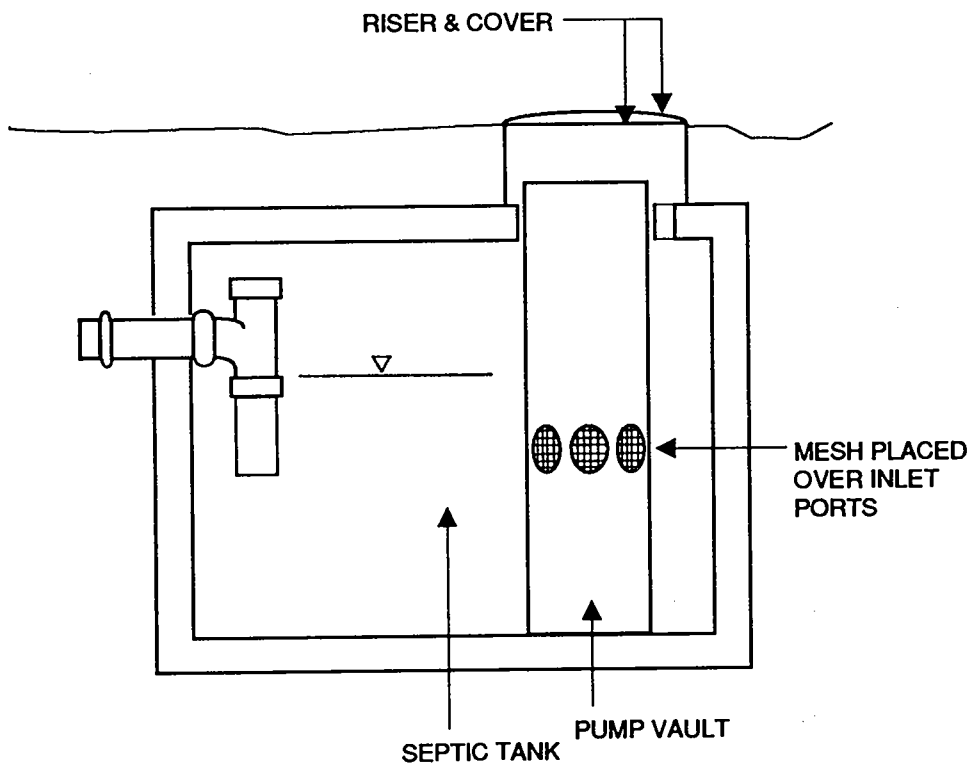


Figure 2-29. Fully-screened internal pump vault. (Courtesy Orenco Systems, Inc.)

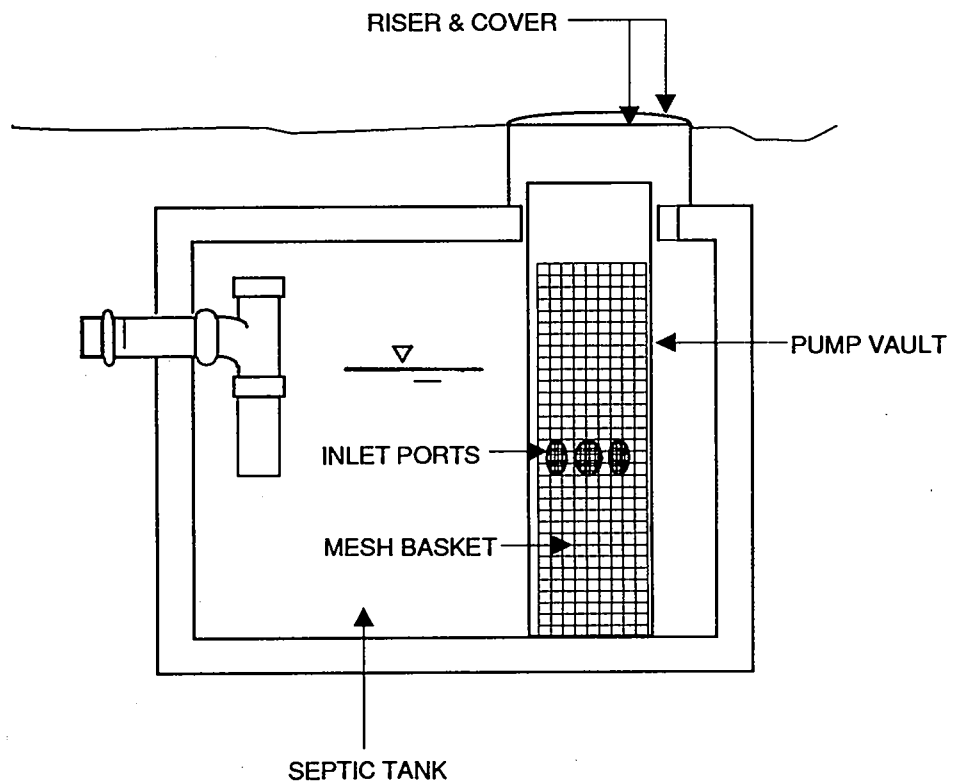
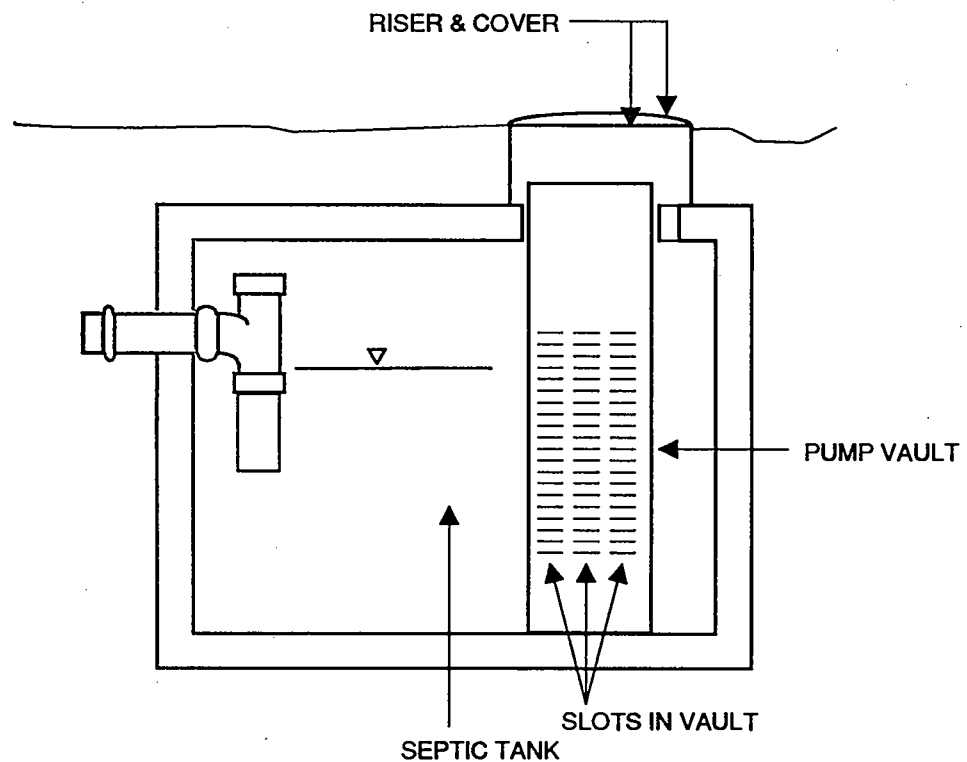


Figure 2-30. Slotted pump vault.



year. Accordingly, most installations using effluent pumps do not use screens.

2.4.7 Odors and Corrosion

Grinder pump and solids handling pump basins are odorous only to the extent the fresh, raw wastewater is odorous. When the wastewater is retained in the basin for some time it becomes septic and begins producing hydrogen sulfide gas.

On occasions when odor control is required at grinder pump installations, enzymes have been added, either by the homeowner or the maintenance district. The enzymes can also be beneficial in reducing grease accumulation in the pump vault, but are expensive when required for any length of time.

With STEP systems the tank effluent is always septic, and potentially odorous and corrosive. Some of the H_2S can escape from the septic tank, however, and some may be captured by the floating scum layer. The BOD of the effluent is lower than that of raw or ground wastewater. Since sulfide production is generally proportional to BOD, the STEP system effluent has a reduced potential for total H_2S production.

A septic wastewater atmosphere is characterized as being odorous, corrosive, and toxic. The rotten egg odor of H_2S is repulsive and detectable in concentrations as low as 3 ppb. H_2S is itself corrosive but is also reactive with *thiobacillus* bacteria present on the appurtenances and walls of the pressure sewer vault above the water line to form sulfuric acid, H_2SO_4 . In sufficient concentrations H_2S causes acute poisoning, paralyzing the respiratory center. Methane is also produced by septic wastewater, which is asphyxiating, as is the carbon dioxide and nitrogen present in wastewater gas. When sufficiently ventilated the atmosphere in the pump vault is usually at a safe level for brief exposure.

For odor control, basin covers are typically gasketed or made such that escaping gases are vented into the soil, or ventilation is provided by the roof vent of the home. While H_2S is heavier than air, it is presumed drafted away with the greater volume of air and lighter gases present. So long as turbulence is minimized in the basin to limit the amount of H_2S liberated, odors are rarely reported via roof ventilation. In most cases where problems have been investigated improper house venting has been a major contributor.

Proper materials must be selected for resistance to corrosion. Most packages assembled by manufacturers of pressure sewer components comply reasonably with this requirement. Particularly well-suited materials include

Type 316 and Type 304 stainless steel, PVC, polyethylene, ABS, and FRP.

Because of the toxic and asphyxiating atmospheric conditions possible in the vaults, designs should be made where exposure of the service personnel to these gases is unnecessary and difficult. More than brief exposure is to be avoided.

Where grinder pumps or solids handling pumps discharge a short distance, as in a typical service line to a receiving gravity sewer, the residence time in the pipeline is usually short enough for the wastewater to be relatively fresh or even stale, but not so septic as to present a problem of odors or corrosion at the receiving sewer. When they pump to a pressure sewer system where the wastewater is retained in the pipeline for more than about 30 minutes, hydrogen sulfide begins to be produced. With increased retention time the effluent becomes totally septic, with all the attendant concerns.

The septic aspect of the wastewater in the mains presents no particular problem as the PVC pipelines are unaffected. Isolation valves should be made corrosion resistant, as should air release valves. Air releases should vent to an odor control facility, such as a soil absorption bed if much gas is expected to be expelled or if the air release is near habitation.

There have been cases where pressure sewer-collected septic effluent has been discharged to gravity sewer mains without causing nuisance or corrosion. In these cases the pressure sewer flows were small, the receiving sewer flows were large and aerobic, and flows were introduced as quiescently as possible to avoid driving off H_2S . More commonly, however, the discharge is odorous, corrosive, and, in extreme cases, can cause the atmosphere within the receiving sewer to become hazardous.

Concrete sewers are attacked by H_2S . PVC and vitrified clay pipes are inert. The usual situation is that the receiving concrete manhole corrodes more rapidly than any other sewer component due to turbulence during transition.

When discharging a pressure sewer to a receiving conventional sewer, a reach of the latter should be chosen which has a substantial quantity of flow. Some jurisdictions have used a 5:1 ($Q_{\text{receiving}}/Q_{\text{pressure sewer}}$) flow ratio, however such generic rules are not equally applicable for all situations. In cases where pretreatment for sulfide must be provided, aeration is a favored method for converting the sulfide to thiosulfate, but requires a substantial reaction time. Chemicals have been used,

such as chlorine, a strong oxidizing agent and bactericide, hydrogen peroxide which is a source of oxygen, and ferrous sulfate which can either act as a catalyst for oxidation of sulfides or precipitate them. All of these chemicals require mixing, and some require substantial reaction times while others react instantly.

Much information is available on the characteristics and pretreatment of septic wastewaters.²⁹ Unfortunately, information has historically been ignored or poorly understood by the parties involved in design.

Where septic pressure sewer-collected effluent is discharged directly to a municipal treatment facility, odors have not been a problem if the discharge is submerged and diffused, and if the receiving basin is large, well mixed, and aerobic.

2.5 Construction Considerations

2.5.1 Line Changes

Because of the flexibility of small diameter PVC piping and because the pressurized flow regime is not very sensitive to horizontal alignment, minor field changes in alignment usually pose no particular problem and are often made by the construction manager. Major changes should be evaluated and approved by the design engineer prior to implementation. Changes in alignment should be well documented and shown on as-constructed plans.

2.5.2 Grade Control

Profiles are shown on the plans, but in most cases the pressure sewer main is shown to be at a constant depth below ground surface, such as 75 cm (30 in). The profile is necessary for the proper evaluation of air release station use and placement. At culvert crossings, or for separation from water mains or other utilities, the pressure sewer profile may vary from the standard depth. The configuration at these locations must be specified by the designer for air release valve considerations, and by contractors so that the project is properly bidable.

As with horizontal alignment, minor changes in vertical alignment may be made in the field, but major changes should be evaluated in advance by the design engineer. The as-constructed plans should reflect the installed profile.

2.5.3 Service Connections

Grinder pump vaults and septic tanks should be located in an area of stable soil, accessible for construction, but not subject to vehicular traffic. Some GP and SH installations are made in basements.

Some designs locate the vault within a few feet of the home, so wiring can pass directly from the vault to the control panel without need for an electrical junction box in the pump vault. The building sewer is short, reducing maintenance needs and reducing the possibility of receiving infiltration from poorly made pipe joints.

Other designs use long building sewers and place the pumping unit next to the side property line and near the street. This design is uncommon but is used in certain areas, especially where ground slopes are flat and building lots are mounded, thereby providing sufficient downward slope away from the home. The pumping unit is most easily accessed with this design. Where adjacent homes have the pumping units adjoining the same property line, the construction easement from each homeowner is narrower than would otherwise be required.

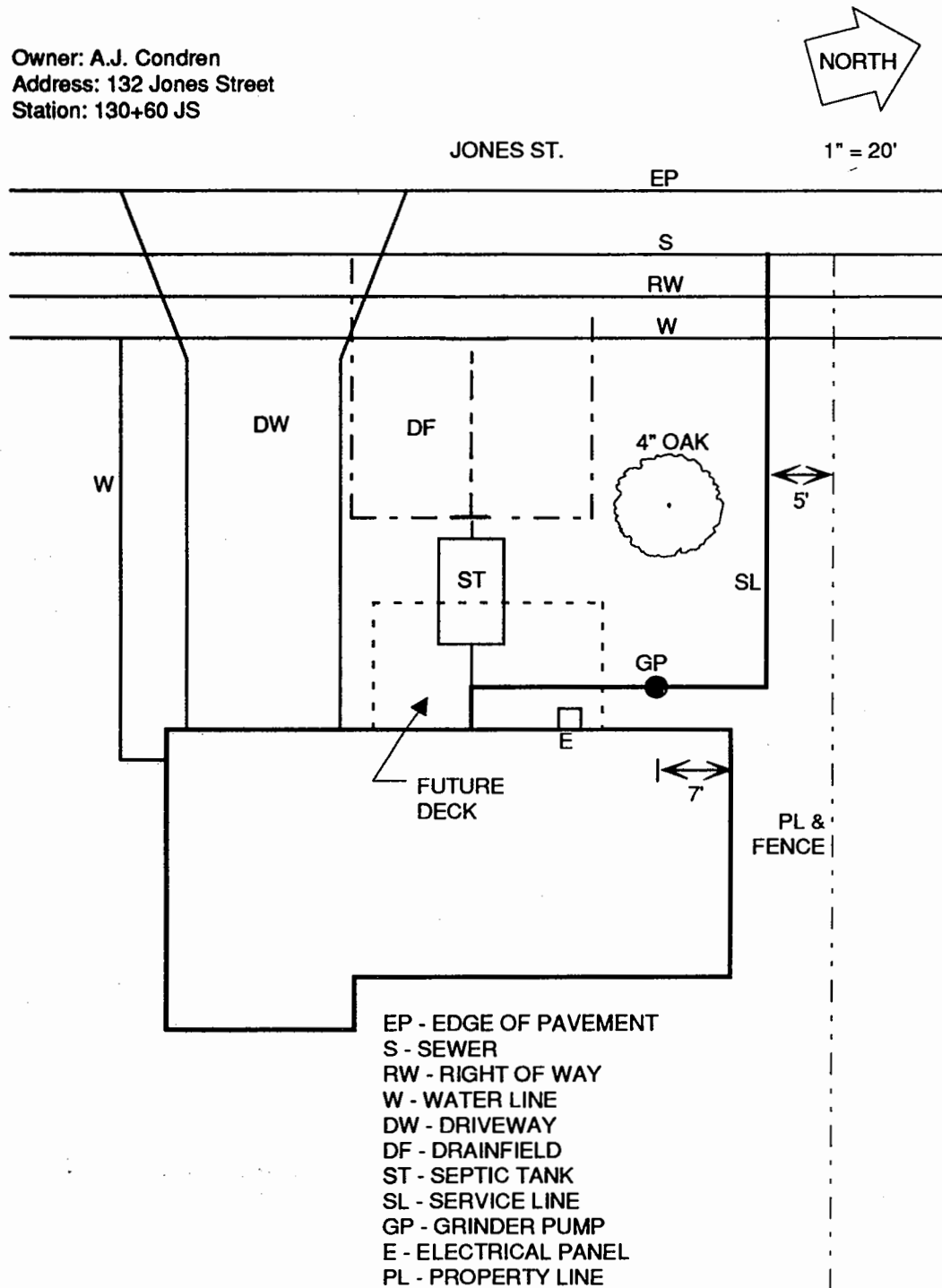
When serving existing homes the pumping unit is usually located near to the existing septic tank, which terminates the existing building sewer. Being close to the existing septic tank, excavation material for the new tank can be conveniently placed as backfill inside the hole left by the old tank, crushed in place. Usually, old septic tanks are abandoned by being crushed in place or backfilled with sand or gravel. Occasionally the old tank is removed. The new tank may occupy the same location as the old tank. On the rare occasions when existing tanks are considered useable, they must be extensively tested for leaks and illegal inflow sources. These procedures are usually considered too expensive, and contribute to the usual 100 percent replacement approach.

When serving existing homes, planning tank and service line locations must be done with the homeowner's involvement. It is common for the appropriate site for the tank to conflict with the homeowner's wishes to build a driveway, deck, garage, or additional bedroom. The homeowner may know the locations of such features as water wells or buried utilities, which are to be avoided. The family pet burial ground can be a sacred area to be avoided at all costs.

Whenever possible, lot facility plans should be drawn when serving existing homes. These larger scale plans show sensitive areas, and show the locations of the planned improvements. They also list such information as the homeowner's name, phone number, contact person (if the owner is non-resident), whether the resident works nights (day sleeper), if the dog bites, and numerous other points of valuable information. A simple lot facility plan is shown as Figure 2-31. The additional information, usually on the reverse side of the lot facility plan, is:

Figure 2-31. Example lot facility plan.

Owner: A.J. Condren
Address: 132 Jones Street
Station: 130+60 JS



Owner: A.J. Condren
Address: PO Box 1190, Fairbanks, AK 99543
Station: 130+60 JS
Phone: (503)345-3001
Contact person: Joe Baily (renter - resident)
Phone: home 543-4640, work 543-5569
Locations of GP & SL approved by owner? Yes
Easement signed and recorded? Yes

Special notes:

1. Renter (Joe Baily) has been designated to make local decisions on behalf of the owner.
2. Baily is not available Saturdays.
3. Do not trench near roots of 4" Oak tree.
4. Mount electrical control panel 1' higher than normal to account for access from future deck.
5. Replace building sewer to the house foundation. (Existing building sewer has root intrusions and is known to be broken.)

Lot facility plans should be prepared in advance of construction, so the time consuming contacts can be completed. Also, having lot facility plans at the time of construction bidding enables the contractor to better estimate costs and, later, to schedule work.

As locations for the tanks, service lines and electrical service are decided in the field, and agreed to by the involved parties, conspicuous lath may be placed. These mark the agreed location for file photos and remind the homeowner of their locations. Owing to long delays prior to construction the markings may require replacement before construction to jog homeowners regarding these locations. It is common for the homeowner to phone the district a few days later to say they have realized (reminded by the lath) that the routes are unacceptable for whatever reason. While the changes may be costly annoyances, they are preferable to making errors and subsequent changes after the installation has begun, and provide an opportunity for better public relations.

The contractor, sometimes together with the construction manager, should contact the homeowner or resident again a few days in advance of construction. This helps minimize inconvenience, better coordinates the work, and is generally required public relations. The authority must designate a coordinator to ensure minimal disruptions to the homeowners.

Videotapes of the property before and after construction eliminate many disagreements about property damage during construction.

2.5.4 Equipment Substitutions

It sometimes happens that the contractor awarded the job will place orders for equipment that does not comply with the specifications, and not notify the engineer or owner of this. The substitution may not be discovered until the equipment arrives, usually after a considerable time has passed and the construction season is growing short. Claims are made that the equipment is equal to that specified. The client and engineer are sometimes pressured into accepting what they believe is substandard equipment.

To avoid this situation some system owners have opted to purchase key equipment separately, and to furnish the equipment to the contractor. This not only insures that the specified equipment will be used but may have an added benefit of lower cost. However, since the contractor is not in control of that equipment supply there may be concerns for delay if the equipment does not arrive on schedule. The contractor may also take the position that proper operation is beyond the contractor's control. This can be partially avoided if contractors are aware of the owner's plans prior to bidding.

In some cases where the construction contractor provides the equipment, a list of the particular equipment is required to be furnished as a part of the bid, or formal submittals are required. In other cases, only preapproved equipment is allowed, with the list being acknowledged in writing by the contractor. The construction manager is furnished with copies of equipment orders.

Where substitutions are allowed, the securing of samples is advised. If the equipment substituted is a component part of a larger assembly, a prototype of the assembly should be required for examination and testing. This provision should be a part of the contract specifications.

Not all substitutions are detrimental. In some cases the suppliers offer substitutions based on substantial experience, and their suggestions should be heeded.

2.5.5 Testing

Mains should be hydrostatically pressure-tested following established procedures, such as those of the American Water Works Association. Test pressures should be at or near the working stress rating for the pipe materials. Properly accomplished installations can easily pass these tests. If the installation is flawed, that should be known during construction rather than later during operation when the mains are filled with wastewater. The mains may be subject to pressures considerably higher than design during pipeline cleaning operations.

When custom (non-commercial) pumping units are used, prototypes should be built for examination and testing.

Experience has shown that many septic tanks used on STEP systems leak, allowing infiltration. Some plastic tanks deform badly due to backfill loads. Septic tanks should be thoroughly tested and/or be otherwise proven. Concrete tanks are often tested by filling with water to the soffit of the tank and observing seeping and water levels over a period of time. Fiberglass and polyethylene septic tanks may also be hydrostatically tested, and may be further tested by imposing a vacuum in the tank to simulate backfill loading pressures.

2.5.6 Scheduling/Warranties

Depending on the method and timing of construction, some components can be installed very early during construction, and some very late. There have been some cases where the 1-year equipment warranty period had expired for some of the installations before the facility had initiated operation and the pump had ever been used. The contract documents need to be explicit in stating precisely when the warranty period starts.

2.6 O&M Considerations

2.6.1 O&M Manual

Many pressure sewer systems operate without an O&M manual. Other systems have O&M manuals that resemble design manuals. Neither practice has proven satisfactory. The O&M manual should primarily be a reference document, intended for the regular use of the service personnel.

Major manufacturers of pressure sewer equipment have manuals or catalogs available for the components or packages supplied by them. Some of the information is generally suitable for insertion into the overall manual. For example, air release valve manufacturers can provide cutaway drawings that are beneficial to understanding how the valve works, and details listing and identifying the various parts used. Some septic tank manufacturers have complete O&M manuals describing, for example, how and when septage should be removed.

A "system analysis plan" is particularly useful. This plan capsulates the project on one or two sheets, showing infrastructure pipe routes and sizes, valve locations, profiles, nodes of the accumulated number of EDUs contributing to each reach, and static and dynamic hydraulic grade lines.

Septic sewer gases are expected at STEP septic tanks, at relatively inactive GP vaults, and points where pressure sewers discharge. The proper practices of pressure

sewer maintenance are usually such that the gases are not hazardous due to dilution with ambient air, but service personnel need to be aware of the potential hazards of these gases. For example, hydrogen sulfide is known to deaden a person's ability to smell it after brief exposure. This may cause the person to wrongly think the gas has drifted away. Many deaths have been attributed to exposure to septic sewer gases.

Service personnel should be advised of procedures and precautions regarding exposure. Designs should be such that no exposure is required, or at the most, only brief and limited exposure to a diluted atmosphere.

Extensive electricals are used at each pumping unit, typically including an electrical control panel, mercury float switches, and electrical junction boxes. Service personnel are exposed to the possibility of electrical burn or shock in their maintenance duties. They may be standing on wet ground while servicing electricals, and working under adverse conditions such as darkness, rain or snow. Electrical safety should be included in the O&M manual. Designs should limit exposure of O&M personnel to live electrical systems.

Sanitation practices should also be covered in the design manual as with any project involving contact with wastewater.

Simple, straightforward designs are more easily understood and better maintained. Maintenance functions and management programs should be fully considered during the design phase.

2.6.2 Staffing Requirements

Staffing requirements are dependent on the type of pressure sewer involved, the features provided, and the quality of the system. For example, some systems use heavy pumps that require two people to lift them from the vault, while others use light-weight pumps easily lifted by one person.

Some designs have a large reserve volume available in the tank for storage after the high level alarm sounds, or an overflow to a standby drainfield. These are "fail soft" provisions that allow the service personnel to better schedule their activities, while not significantly inconveniencing the user. In contrast, some systems use small basins that hold only a few gallons beyond the alarm level. These systems need to be attended as soon as an alarm condition is known, sometimes late at night or on holidays or weekends.

Quality designed and constructed systems, and those systems receiving regular preventive maintenance

generally experience fewer service calls in response to alarms.

Service calls likely to require exposure to dangerous conditions, e.g., live electrical or sewer gas exposure, should be attended by at least two people for safety purposes.

Nearly all systems have defects that are not discovered during construction. If the correction of these defects is assigned to the maintenance forces, excessive maintenance can result. A preferable alternative is to identify the defects, and to correct them as a capital improvement.

Recognizing all of the variables involved that cause some systems to be more maintenance intensive than others, no general rule can be made regarding staffing needs. However, systems that are well designed, well built, and properly maintained may experience a mean time between service calls (MTBSC) of about 4-years, loosely meaning that 1/4 of the pumping units will be serviced in a year.

The personnel-hours spent per service call depends on whether two personnel are required or one, and the nature of service typical of the particular system. The mean times range from 20 minutes per service call to about 3 hours.

A minimum of two personnel are required to be trained and available. On some systems one person can attend to the service calls, but a fully trained and experienced backup is needed for times when the lead person is unavailable. The two people do not necessarily have to be full time employees, but at least one person has to be available on call.

In the most general sense, two full time employees have usually been found sufficient to maintain a well-designed system of about 1,000 pumping units.

2.6.3 Operator Training

Typically, the malfunctions of most service calls are electrically related. The service personnel should be trained accordingly and should have the appropriate credentials.

Familiarity and a basic knowledge of plumbing practices, particularly as applied to pumping, is required. Personnel should be advised on practices regarding exposure to septic/sewer gases. Public relations are important. Service personnel should be able to represent the sewer district diplomatically. Training in this subject area may be advised.

2.6.4 Spare Parts Inventory

The number of spare parts required is related to the particular system being operated and maintained.

In general, sufficient pipeline fittings and special tools should be on hand to quickly repair any rupture that may occur in the piping system. Anticipation of need during non-working hours should be made, when parts would not be available from outside sources.

All working parts of the pumping units, for example the pump itself, liquid level sensors, check valves, and control panels should be on hand in sufficient quantity to quickly restore operation in event of malfunction. The need for inventory can be refined by experience with the particular system, with consideration given for particular parts that cannot be obtained quickly. In general, an inventory of 5 percent of the number of pumps in operation is sufficient.

Many pressure sewer systems are intended for growth within the system, and for piping extensions to be made. These systems usually have enough parts and equipment on hand to satisfy maintenance needs.

2.6.5 As-Built Drawings/Maps

The prevention of damage to pressure sewer mains and service laterals caused by subsequent excavations should be a high priority.

Warning signs have been posted on some projects, periodically placed along the route to notify or remind excavators of the presence of the pipeline. Toning cable is installed adjacent to the pipeline on some systems, which can be induced with a tone and located using standard utility-locator devices. Identification tape buried with the pipelines further warn excavators. And reliable as-built drawings are beneficial, especially to those agencies planning future excavations.

As-constructed lot facility plans, showing locations of the pumping unit, electrical service, service line and building sewer are equally helpful. These are of particular benefit when new service personnel are engaged who are unfamiliar with the locations of key site features.

2.6.6 Maintenance

2.6.6.1 Normal

Service calls made in response to phone calls by the home residents constitute most maintenance activities.

The amount and type of maintenance required varies widely between projects, depending on the equipment

Table 2-6. Distribution of Causes for Call-Out Maintenance On Selected Grinder Pump Pressure Sewer Projects

Category	Percent of Occurrences
Electrically related	25 - 40
Pump related	20 - 25
Miscellaneous	20 - 30
Pump vault related	5 - 15
Piping related	5 - 15

used, quality of installation, and other natural and human factors.

a. Grinder Pump Maintenance

To describe maintenance functions generally, Table 2-6 was prepared based on the experiences of two major projects, one using centrifugal pumps and the other using progressing cavity pumps. Each project kept detailed daily records of service calls. A tedious examination of the maintenance records was made, augmented by detailed personal examinations of the projects and visits with the maintenance staff.

Causes for maintenance were divided as follows:

Electrically related: Where mercury float switches were used, about 50 percent of the service calls related to their malfunction. Grease accumulation was the principal cause of the float switches not operating properly. The typical correction was removal of the grease, adding enzymes to the pump vault, and providing extra enzymes to the home resident along with the request that they dispose of cooking grease elsewhere. Other descriptions of malfunctions included the float switches being obstructed, loose, cracked, stiff cords restricting movement of the float, and simply "not working".

Where pressure switches were used in lieu of float switches, about 20 percent of the electrically caused service calls related to them. Adjustment or replacement of the switch was usually accomplished.

Problems with electrical control panels were highly diverse, ranging from inoperative components to loose wiring, and problems with the intrusion of ants or other insects. Control panel problems constituted 25-55 percent of the electrically related causes for service calls.

Fuses were blown or circuit breakers were tripped or turned off in 7-18 percent of the electrically related service calls. The reporting was not clear as to whether

the breakers were tripped out due to an overload or ground fault, or turned off by the homeowner.

Problems with splices contained in electrical junction boxes can be a major cause of maintenance, especially if the splices in the junction boxes are not water tight. Junction boxes typically leak, despite claims to the contrary.

In about 3 percent of the electrical problem cases, the homeowner's power supply was at fault.

Other electrical problems too diverse to categorize represent perhaps 5 percent of these service calls.

Pump related: Pumps were often removed and replaced on one project, and seldom removed on the other. On the project where replacement was more common, it was usually due to the pump drawing excessive amperage, indicating that something was jammed in the grinder mechanism. Troublesome materials found in grinders were mentioned in the reports as being washrags, sanitary napkins, underwear, kitty litter, handkerchiefs, and similar items.

Miscellaneous: One system reported overflowing wastewater onto the yard or backups in the home on 60 percent of the miscellaneous service calls. This was to be expected as the pump vaults were small. The other system investigated used emergency overflows to holding tanks, so experienced rare cases where surfacing or piping backups occurred.

Odor problems were reported on one of the systems. Usually the field personnel attributed this to lack of use, causing the vault contents to be septic. Where vents were used in the vault covers, they were checked to see if water was in them preventing the transmission of gases to atmosphere.

Pumps or service lines were sometimes found to be airborne. Check valves were reported to be leaking slightly in only 2 percent of the miscellaneous service calls.

A large fraction of the miscellaneous service calls were too diverse in nature to categorize.

Pump vault related: One project used pump vaults and piping within the vaults that had been designed and produced by a local supplier, rather than that available from the pump manufacturer. Over half of their pump vault related service calls were related to changing this inadequate piping system.

The intrusion of water into the pump vaults was noted on both projects. In some cases the water entrance was due to roof drain discharging in proximity to the pump vault, or due to careless irrigation practices. In many instances the pump vault was placed too low, so water could puddle around and over the vault cover.

Other pump vault related service calls were diverse, ranging from damage inadvertently caused by the home resident to faulty installation during construction.

Piping related: Piping related causes for service calls were similar for both projects. About 50 percent of the calls were for clogged or broken building sewers (usually a maintenance responsibility of the homeowner). Forty percent of the calls related to damaged service lines, and the remainder were diverse.

b. STEP System Maintenance

Two major STEP projects were selected for detailed evaluation, both having kept extensive daily records of service calls. Both systems used submersible centrifugal effluent pumps. Table 2-7 indicates causes for call-out maintenance.

Causes for maintenance were divided as follows:

Electrically related: Both systems used mercury float switches, and both systems also used displacer switches on early installations. The mercury float switches have been the cause of numerous maintenance calls, but less than the displacers. Some of the displacers remain in service on one project and have been particularly maintenance intense due to imperfect design, but not due to problems inherent with the concept. Well over half of all electrically related service calls are attributed to adjustment or failures of the liquid level sensors. The remaining reasons for electrical malfunctions are spread among problems with junction boxes (used on one of the two projects), electrical control panels, and tripped or thrown breakers.

Pump related: One project used low cost pumps, relying on the philosophy that they are relatively easy and inexpensive to replace, while the other project used more expensive pumps. Both approaches have been reasonably successful. The low cost pumps are removed whenever there appears to be a pump related problem. They are taken to the shop for evaluation, and in the majority of cases they are found to be clogged with a cigarette filter or prophylactic. Some of these clogging problems are attributed to an unannounced change made in the design of the pump which made it less able to pass solids than the original design which was evaluated and selected. The clogging object is removed in the shop,

Table 2-7. Distribution of Causes for Call-Out Maintenance on Selected STEP Pressure Sewer Projects

Category	Percent of Occurrences
Electrically related	40 - 60
Pump related	10 - 30
Miscellaneous	20 - 40
Tank related	1 - 5
Piping related	5 - 10

and the pump is placed back in service during a subsequent service call.

The project using more expensive pumps encounters clogging on only a trivial number of pumps; about 1 percent of the installations. The need to remove these pumps from the basins is rare.

Miscellaneous: Air bound service lines are a common occurrence on one system, and air bound mains are reported on the other. This is one of the most common sources of maintenance calls.

One system's staff attributes the problem to reaches of the main having so few homes presently served that peak flows are of such short duration that air accumulations are not purged from the main. The other system has reaches experiencing the two-phase flow of air and water. Improved venting practices have successfully corrected problem areas, but have not been applied to the project as a whole.

Tank related: Few tank related service calls occur, but this is because high quality tankage was used on both projects. Tankage problems have been so extreme on some other projects using poor quality tanks that little attempt was made to deal with the problems by maintenance forces. Instead, replacement was undertaken as a capital improvement.

Overflows infrequently occur because of the large reserve volume provided in the septic tank.

Piping related: Clogged building sewers represent half of these service calls, even though maintenance of the building sewer is the responsibility of the home owner. Damaged service lines represent the other half of the service calls.

2.6.6.2 Preventive

Pipeline locating by sewer staff may be frequently needed by utility companies or others planning excavations in the area. Mainline isolation valves should be exercised annually. Air release stations should be checked for

proper operation, the frequency being best established by experience with the particular system. If pretreatment devices are used, they need to be attended regularly.

There is little preventive maintenance practical to accomplish at most pumping units. The pumps and ancillary components are not routinely removed from the vaults.

On routine maintenance visits the pumps and controllers are run through their cycles to see that all aspects are in working order. Voltage and amperage readings are taken. High amperage indicates that something is restricting the movement of the rotor, usually a clogged impeller or grinder. Motor starter contacts are sometimes cleaned, especially if the area experiences problems with insect intrusion.

The first year or two after installation, earthwork settlement is common around the pump vaults and may need to be corrected. Often the tank settles, causing the top of the vault to be below ground surface where inflow could enter. The tanks then require a water-tight extension to be retrofitted.

Mostly, routine maintenance consists of visual inspection. Grinder pump vaults (particularly with float switches) are washed down to reduce grease buildup. Where enzymes are popular, they may be added. STEP pump vaults accumulate less grease, so there is less need to clean them. The sludge and scum accumulation in the STEP tank should be monitored during these visits.

2.6.6.3 Emergency

Even though they may be infrequent, mainline ruptures are possible. Repair materials and equipment should be reasonably accessible for such needs.

When pump vaults are used that have small reserve volumes between the high level alarm setpoint and the top of the basin, response time must be prompt or an overflow or backup in the home will occur. Either way, the user is inconvenienced. In many cases, maintenance forces respond to such calls whenever the call is received, even during late night or early morning hours.

During extended power outages pump basins may be filled and overflowing or backing up in the home. However, water use and corresponding wastewater flows are greatly reduced during power outages. An emergency overflow or the provision of adequate reserve space is a "fail soft" provision. Portable standby generators and gasoline-powered pumps have been provided in a few cases, but rarely if ever used.

2.6.7 Record Keeping

The O&M manual should contain forms for this purpose. A record should be kept of routine maintenance, along with a summary list of corrective action to be taken. A data base should be prepared to document call-out maintenance. With a data base, a printout of previous maintenance for any particular address can be prepared for the service person attending a call. This is especially beneficial to new employees, to alert them as to probable causes of the malfunction. Repeat calls to particular addresses for repetitive problems are common. These are clearly shown by data base reporting.

2.6.8 Troubleshooting

About all the field personnel usually know about the performance of a pressure sewer main is that it is adequate.

As growth occurs an increased frequency of high level alarms at the individual pumping units is usually due to the mains having reached capacity or having developed a problem with air-caused headloss.

A preferable method to measure the performance of the mains is to take readings at pressure monitoring stations located at key locations along the route of the main. These are taken periodically, and compared with previous readings that correspond to times when lower populations were being served, periods of especially high or low infiltration, periods when air accumulations in the mains may be expected, and other critical times. In that way the hydraulic performance of the system is measured and documented. Air binding conditions can be identified, located, and corrected. Knowledge of the capacity and other characteristics of the system is continually refined.

During service calls for the pumping units, the service personnel usually attempt to troubleshoot the problem and correct it in the field. A typical scenario is as follows:

First, they confirm that power is being supplied to the control panel and observe the liquid level in the tank to confirm that a high water condition exists. If no reserve volume remains available to receive flow, they may pump the basin down some by running the pump manually (if it will run), or by using a mobile pump.

Then, they may turn the power off so they can work more safely with the malfunctioning installation. Guided by their experience with pumping units on the project, or a history of performance of the particular pumping unit being serviced, they first address the most likely causes of the problem. A common first check is of the mercury float switches, often obstructed by grease or otherwise being out of position.

They will run the pump on the manual switch setting in the electrical control panel, and take amperage readings. A high-amperage reading usually indicates a jammed impeller. A low amperage reading usually indicates an air-bound pump.

By this process the cause of the malfunction is identified and corrected in the field. Not infrequently, a repair is made that is believed to have been the cause of the malfunction, only to receive another call for service the next day. In some cases components are taken to the shop for further evaluation.

2.7 System Costs

2.7.1 Construction

2.7.1.1 General

A wide variety of factors cause construction costs to vary considerably from project to project.

Topographical matters, such as the steepness or flatness of an area can impact costs. The proximity and number of culvert or buried utility crossings can greatly influence the cost of pipeline installations. Geological issues such as rock excavation, fragile soils, or high groundwater conditions are major considerations in preparing cost estimates.

Prices also vary with geographical setting, typically being higher in northern metropolitan areas, for example, than in the rural south.

The attitude of the public to be served is important. Consider, for example, the reluctance a contractor would have to enter private property for installation of pressure sewer on-lot facilities if the property owners were opposed to the project. Unit bid prices may reflect the attitudes of the public, particularly with area contractors.

The burial depth of pipelines, compaction requirements, restoration required, degree of field inspection, and traffic control are other examples of causes for cost variance. Due to economy of scale, large projects usually experience lower unit prices, but this may be tied to the bidding climate and the availability of contracting companies large enough to bid the job.

Familiarity with pressure sewer installation plays an important role. It has been common for the first projects built in an area to experience higher unit prices than subsequent projects due to uncertainties of the contractor. For this reason some engineers have arranged for interested contractors to make a few installations on a

time and materials compensation basis prior to the time of bidding. This allows the contractors to sharpen their understanding of the project requirements, and to refine estimates. It also better acquaints the contractors with the engineers, demonstrates installations to the client and the public, and frequently results in final design revisions.

Funding and regulatory requirements play a part in project cost estimating to the extent that the regulations may be a help or hindrance to the contractor, the client, and the engineer.

Because of the many variables, accurate cost estimating guidelines are beyond the scope of this manual, but some generalities are given.

2.7.1.2 Piping systems

Piping systems are best estimated using guidance from water system projects built in the same area, if similar materials and specifications are used. The best situation is one where the water line project was designed and construction managed by the same engineering firm producing the sewer cost estimate. In this way, project similarities and differences can be factored into the comparison from intimate familiarity. If the estimating engineers are not familiar with the project they are obtaining guidance from, they should become familiar with the specifications for that project to rationalize differences between the projects. In some cases, the Associated General Contractors (AGC) can provide helpful insight.

The prices for piping materials can usually be obtained through local suppliers. PVC is generally priced by the pound. At present (mid 1991), in large quantities, a cost of \$1.30/kg (\$0.60/lb) can be used, but this may fluctuate considerably. PVC weighs about 1,425 kg/m³ (89 lb/cu ft).

In the absence of better information, Table 2-8 provides estimating data for planning purposes only. This table was prepared by reviewing bid tabulations from numerous projects throughout the United States. Some projects were known to have been built so cheaply that long term performance was questionable. Other projects had unusually stringent specifications or other features that resulted in particularly high costs. Both the high cost and low cost bid tabulations were discarded, leaving mid range averages to produce this table.

Pipe prices include furnishing and installing the pipe, excavation, bedding, backfilling, compaction, pressure testing, cleanup, and related requirements. Not included

Table 2-8. Average Installed Unit Costs (mid-1991) for Pressure Sewer Mains and Appurtenances

Item	Unit Cost (\$)
2-in Mains	7.50/LF
3-in Mains	8.00/LF
4-in Mains	9.00/LF
6-in Mains	11.00/LF
8-in Mains	14.00/LF
Extra for mains in A.C. pavement	5.00/LF
2-in Isolation valves	250/each
3-in Isolation valves	275/each
4-in Isolation valves	350/each
6-in Isolation valves	400/each
8-in Isolation valves	575/each
Automatic air release stations	1,500/each

are allowances for such items as rock excavation, engineering, and administration.

2.7.1.3 Grinder Pump Services

As shown in Table 2-9, a typical list price for a 2-hp pump is presently about \$1,200. The list price for a simplex grinder pump package is about \$4,100. This example package includes the following. (The package would differ if a progressing cavity type pump were supplied, e.g. the pump would likely be rated at 1 horsepower, and liquid levels would be sensed using a trapped air system. However, costs should be similar.)

- Pump - 2 hp
- Pump vault - 30-in diameter x 8-ft deep
- Pump vault cover
- Slide-away rail assembly
- Piping within vault, with gate valve and check valve
- Electrical junction box with cord grips
- Mercury float liquid level sensors
- Electrical control panel, including:
- NEMA 3R enclosure
 - Circuit breaker
 - Capacitors
 - Motor start contactor
 - Hand-off - auto switch
 - Audible and visual alarm
 - Audible alarm silence with auto reset

When provided in quantity, prices are considerably reduced. Typical volume prices are about \$600 for the pump alone, and \$1,400 for the pump package using a 60-cm (24-in) diameter pump vault, or \$1,800 for a pump package using a 75-cm (30-in) vault.

Some dealers specialize in providing GP packages at low prices, a typical price being about \$1,300. However,

Table 2-9. Average Unit Costs (mid-1991) for Grinder Pump Services and Appurtenances

Item	Unit Cost (\$)
2-hp centrifugal grinder pump	
- List price	1,200/each
- Quantity price	600/each
Simplex GP package	
- List price with 30-in vault	4,100/each
- Quantity price with 30-in vault	1,800/each
- Installation	500 - 1,500/each
4-in building sewer	16/LF
1.25-in service line	6/LF
Abandon septic tank	400/each

many of the components are not provided by the pump manufacturer, but are instead purchased by the dealer from a variety of sources. The dealer often assembles some of the parts. The assembly may or may not have been field-tested and refined.

A low-cost, dealer-provided package usually differs from the factory package in several ways. The pump vault is typically smaller, usually 60-cm (24-in) diameter x 1.5-m (5 ft) deep, and is made of thin wall FRP. Hose is used for the discharge piping instead of hard piping, or galvanized metal piping may be used. No slide away, quick-disconnect coupling is provided. The pump rests on feet screwed into the bottom of the pump instead of being suspended as most factory packages are made. No electrical junction box is provided, i.e., wiring is routed directly from the pump vault to the control panel without splicing. The electrical control panel is often made simpler and with lower cost components. A visual alarm is provided instead of audible and visual, which also eliminates the need for audible alarm automatic reset circuitry.

Some dealer-provided packages may be quite good, but the least expensive packages usually compromise quality, pump vault size, and some other features.

In some cases, sewer districts acquire the various parts and pieces, and assemble the packages themselves, including manufacture of the electrical control panel. A savings of about \$200/package has been reported by several districts following that practice, with variable results.

Installation costs of GP services vary considerably depending on the standards being met, the degree of restoration required, whether existing or new homes are being served, and a host of other factors.

The lowest cost installations are made by sewer district personnel serving new homes prior to landscaping being done. In these instances, costs as low as \$400 have been reported. Contractors' bid prices are usually higher and typically are \$500-1,500.

From the above, the total furnished and installed cost of simplex GP services ranges from \$1,800 to over \$4,000, not including building sewer replacement, abandonment of the old septic tank (if applicable), and service line installation.

When serving existing homes, the building sewer is often replaced to limit I/I. For economic reasons GP vaults are sometimes placed only a few feet from the home which limits the amount of building sewer required and the length of wiring needed.

"Abandonment" of the old septic tank is usually required by the authorities, which means removing and properly disposing of the septage, then either filling the septic tank with sand or crushing it in place and backfilling the hole.

2.7.1.4 STEP Services

Prices of effluent pumps vary according to the quality provided. For examples of the varying qualities, some pumps use ball bearings while others use sleeve bearings. Some use Type 316 stainless steel fasteners while others may use a type of stainless steel that is not corrosion-resistant to the STEP effluent. Motor types vary, as do impellers and seals. Some STEP pumps are built for the specific purpose while others are inexpensive sump pumps, used as pressure sewer pumps whether suited or not.

Pump prices also vary according to the head they produce, and consequently vary with the horsepower of the motor required.

The list price for a typical low-head effluent pump of good quality is about \$300, while a higher head, high quality pump has a list price of about \$800. A factory-provided package, using a pump vault external to the septic tank, has a list price of about \$2,500-3,000 depending on the pump supplied. This example package includes the following:

- Pump - 1/3 to 2 hp
- Pump vault - 24-in diameter x 6-ft deep
- Pump vault cover
- Slide-away rail assembly
- Piping within vault, with gate valve and check valve
- Electrical junction box with cord grips
- Mercury float liquid level sensors
- Electrical control panel, including:

- NEMA 3R enclosure
- Circuit breaker
- Motor start contactor
- Hand-off - auto switch
- Audible and visual alarm
- Audible alarm silence with auto reset

The STEP pump vault is smaller than a GP vault because reserve volume is provided in the septic tank.

When provided in quantity, prices are considerably reduced.

STEP packages use a discharge hose assembly more commonly than the slide-away rail assembly and hard piping listed above. Also, they are often provided by a pump dealer rather than the factory. The pump dealer may provide the package as a specialty sideline, or may custom assemble them according to the design and specifications provided by the engineer. The latter service can also be provided by the factory, especially if a quantity order is involved.

A typical price for a dealer-provided STEP package using a pump vault external to the septic tank may vary from \$700 to \$1,500 depending on the particular pump supplied, the quantity ordered, and other variables. Packages made to be inserted into the septic tank, as contrasted against the external vault design, are generally about \$200 less expensive.

A new water-tight septic tank is often required due to infiltration expected to enter the existing septic tank. Water-tight septic tanks vary in cost according to the quality provided, and according to the materials used. Concrete tanks are usually less expensive than well constructed and engineered FRP or polyethylene tanks, but are heavy and more difficult to install in confined spaces. Prices for quality tanks of either material generally are \$600-1,000.

Installation costs vary depending on whether new or existing homes are served, the degree of restoration required, if new or existing septic tanks are used, the size of the project, and a host of other factors. Mid range installation costs for retrofitting existing septic tanks have been about \$600-1,200, and when installation of a new tank is required, costs are about \$1,000-1,500. These costs do not include replacement of building sewers, service line installation, connection to the main, abandonment of the old septic tank, or restoration.

Average, generalized prices for STEP equipment and installations are shown in Table 2-10. Price extremes

Table 2-10. Average Unit Costs (mid-1991) for STEP Services and Appurtenances

Item	Unit Cost (\$)
Effluent pump list price	300 - 800/each
Effluent pump quantity price	200 - 500/each
Simplex factory package list price	2,500 - 3,000/each
Quantity package price w/external vault	700 - 1,500/each
Quantity package price w/internal vault	600 - 1,200/each
New septic tank	600 - 1,000/each
Installation (retrofit of existing tank)	600 - 1,200/each
Installation (with new septic tank)	1,000 - 1,500/each
4-in building sewer	14 - 18/LF
1.25-in service line	4 - 8 /LF
Abandon septic tank	300 - 500/each

extend far beyond the ranges given here, but are not indicative of general prices for typical well-built projects.

2.7.2 Operation and Maintenance

The operation and maintenance cost for pressure sewers varies greatly, depending on system size and quality. In some instances pipelines have been laid with lax specifications and little inspection. The subsequent maintenance required and lower level of reliability probably offsets the initial cost savings.

The maintainability of the on-lot facilities plays an important part in determining the cost of long term maintenance. For example, some systems are difficult to maintain in that removal of the pump, liquid level controls, and electricals are difficult and unpleasant tasks. In such cases, when a service call is occasioned the service personnel tend to only patch the problem with the result that the number of service calls received increases over time. Preferred for long-term economy are designs where the working parts are easily tested, repaired, and if possible, shop or factory reconditioned.

Many systems have inadequate cost accounting systems, making O&M cost analyses difficult to accomplish or misleading. Also, systems vary widely as to type. Some are grinder pump systems while others are STEP systems. Some systems have their own treatment facilities to operate and maintain, while others discharge to nearby facilities in other jurisdictions. In some cases maintenance is provided by contractors, and in other instances maintenance is provided by the controlling agency's staff who may have part time duties other than maintenance of the pressure sewer.

As a result, a detailed analysis of particular project circumstances is required to forecast O&M cost.³⁰ With that caveat, O&M costs are reported here for one system.

The Glide, Oregon pressure sewer involves about 20 miles of main. A total of 680 EDUs are served by 420 STEP installations, 12 GP units, and 10 variable grade gravity sewer connections. The setting is primarily residential but several schools are served, several restaurants, mobile home parks, and similar installations. The system has been in service since the late 1970s (over 10-years).

Glide is a quality system that was built to demanding standards, and closely inspected. All main installations were specially bedded and backfilled, and pressure-tested. Heavy-duty pumps were used.

Two full-time field personnel maintain the system. While both attend the collection system, one of the personnel focuses primarily on O&M of the treatment facilities (oxidation ditches and mixed media filtration), while the other persons primary obligation is with the collection system.

A detailed cost accounting system is in place. Typical O&M costs incurred are shown in Table 2-11.

Labor costs reported in Table 2-11 include approximately 50 percent fringe benefits, including FICA, retirement, sick leave, and vacation.

No facility amortization or equipment rental is included, nor is customer billing and accounting.

Given the 680 EDUs served, and the total O&M annual cost of \$142,200, or \$17.43/month/EDU. Excluding O&M for the wastewater treatment plant, and the WWTP prorated share of the overhead, remaining overhead and O&M of the pressure sewer is \$4.77/month/EDU.

2.7.3 User Charges and Assessments

When conventional sewers are used, the front-end construction cost is often high. In comparison, pressure sewers generally have a lower initial cost. When the pressure sewer main has been installed and treatment facilities are on line, service to the nearby properties is available. The higher cost item of the on-lot facilities (pump, etc.) is deferred until service is needed or until the property is built upon. Subsequent users finance the capital cost of their own on-lot facilities as opposed to that being a district obligation.

This encourages innovation and sometimes departure from traditional methods of assessment. The high initial cost of conventional sewers may financially require assessment to be applied to all fronting properties, whereas pressure sewer mains may affordably bypass properties not intended to be served.

Table 2-11. O&M Cost Accounting Records for the Glide, Oregon Pressure Sewer System (\$1,000)

Item	Overhead	WWTP	Collection	Services	Total
Labor	28.6	56.7	2.3	16.3	103.9
Materials	2.1	24.3	0.6	11.3	38.3
Total	30.7	81.0	2.9	27.6	142.2
%	22	57	2	19	100

Average costs for 1988 and 1989.

An "Association" approach to financing is possible, as opposed to the "District" approach. An association, as described here, obtains revenues from user and connection charges but has no taxation authority.

Pipelines may be sized to serve those properties desiring service (plus some allowance), as opposed to the conventional sewer - district practice of sizing sewers to serve an entire area at 100 percent anticipated development.

As a guideline for future projects, probably little can be learned from the service and connection charges made in communities now served by pressure sewers. This is because the economics vary so widely. Some projects have received substantial grant funding while others received none. Some projects can be constructed economically while others will be expensive. Reasons for the cost variances include the availability of existing treatment facilities, rock excavation, size of project, and other parameters described throughout this manual.

In a review of 5 projects, monthly service charge rates were set to compensate O&M expenses for the services, collection system, treatment, and for management. Monthly rates were \$12-20. Connection charges pay for on-lot facility materials. Sometimes installation charges are included, and in other cases they are paid separately by the homeowner.

Also included in the connection charge fee is a prorata share of the piping system infrastructure and treatment facilities. Connection charges were about \$2,000-4,000.

Additional information regarding the time value of money associated with the use of pressure sewers is contained in a book by Thrasher.⁹ Deferred costs of subsequent pump installations and O&M costs equate to a lower present worth.

2.8 System Management Considerations

2.8.1 Homeowner Responsibilities

During the planning and design phase property owners should become informed about the project and once properly informed, become involved. This is true of all sewer projects, and not unique to alternative collection systems. However, with these systems it has been particularly common for communities to react prior to becoming accurately informed. Either the use of pressure sewers is falsely glamorized or unduly criticized. Early public dissemination of accurate information is a critical role of the utility and the engineer.

Prior to construction, the property owners may be asked for any knowledge they may have of the location of the existing septic tank, drainfield, buried utilities, or property lines. The property owner may also have some role in the placement/location of the on-lot facilities. In locating these, thought should be given to property alteration plans, such as the widening of a driveway or the addition of a patio or deck.

Disruption to the community will be less for installation of pressure sewer mains than for conventional sewers, but disruption for installation of the services can be greater.

Throughout the planning-design-construction process, cooperation of all parties including homeowners results in a more easily accomplished project and lower costs.

Use of the system should comply with requirements of the user ordinance. Typical requirements include that the homeowner should not drive or build over the tank, and should protect the facilities from damage. Discharge of flammables, acids, excessive amounts of grease, sanitary napkins, or other non-wastewater items is discouraged. This requirement differs little from user ordinance requirements for conventional sewers. Proper use of the system results in lower user charges and improved reliability.

2.8.2 Sewer Utility Responsibilities

The utility should take seriously the need for early and accurate public address. On some larger community projects, opinion leaders of the community representing diverse geographical areas and varied cultural backgrounds have been sought. These people are invited to be special advisors to the utility, and in turn receive advance, more detailed information than is possible to disseminate at large public meetings. The personal contact they have with their neighbors can transfer information more meaningfully than is possible otherwise.

While maintenance and operation of a pressure sewer may not be more difficult than that of a conventional sewer, the technology is less well known. The utility should have the flexibility and talent required to adapt to unfamiliar practices. A degree of long-term commitment is required. The regulatory agency may want assurance of the utility's capabilities, to encourage their use of alternative sewers.

Tactful public relations are important, as they are with any utility function. Personnel in contact with the public become the utility's ambassadors. Selection of personnel should be made accordingly, and special training and ongoing support may be advised.

Detailed daily records should be kept of maintenance functions, and a summary report should be made annually. This report should quantify the maintenance requirements and make recommendations for project improvements. Involvement of the maintenance forces is required. Continuing involvement of the design engineer will close the loop between planning, design, construction, operation and maintenance, and will result in improved future designs.

The utility should be capable of responding to whatever routine or emergency needs may be presented.

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When an NTIS number is cited in a reference, that reference is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

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CHAPTER 3

Vacuum Sewer Systems

3.1 Introduction

The use and acceptance of alternative wastewater collection systems have expanded greatly in the last 20 years. One of these alternatives, vacuum sewers, has been used in Europe for over 100 years. However, it has been only in the last 25 years or so that vacuum transport has been utilized in the United States.

In this period of time, significant improvements have been made in system components. In addition, experience with operating systems has led to advancements in design, construction, and operational techniques. These factors have all contributed to vacuum sewer systems being a reliable, cost-effective alternative for wastewater conveyance.¹

Vacuum sewerage is a mechanized system of wastewater transport. Unlike gravity flow, it uses differential air pressure to move the wastewater. It requires a central source of power to run vacuum pumps which maintain vacuum on the collection system (Figure 3-1). 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 the collecting sump. The resulting differential pressure between atmosphere and vacuum becomes the driving force that propels the wastewater towards the vacuum station.

A vacuum system is very similar to a water distribution system, only the flow is in reverse (Figure 3-2).² This relationship would be complete if the vacuum valve was manually opened, like a water faucet. With proper design, construction, and operation a vacuum system can be made to approach a water system in terms of reliability.

The choice of collection system type is usually made by the consulting engineer during the planning stages of a wastewater facilities project. This choice is the result of a cost-effectiveness analysis. Where the terrain is

applicable to a gravity system, the vacuum system many times is not even considered. While gravity may be cost effective in these situations, many small factors considered collectively may result in a vacuum system being the proper choice. Vacuum sewers should be considered where one or more of the following conditions exist:

- Unstable soil
- Flat terrain
- Rolling land with many small elevation changes
- High water table
- Restricted construction conditions
- Rock
- Urban development in rural areas

The advantage of such systems may include substantial reductions in water use, material costs, excavation costs, and treatment expenses. In short, there is a potential for overall cost effectiveness. Specifically, the following advantages are evident:

- Small pipe sizes, usually 7.5-, 10-, 15-, and 20-cm (3, 4, 6, 8-in) are used.
- No manholes are necessary.
- Field changes can easily be made as unforeseen underground obstacles can be avoided by going over, under, or around them.
- Installation at shallow depths eliminates the need for wide, deep trenches reducing excavation costs and environmental impact.
- High scouring velocities are attained, reducing the risk of blockages and keeping wastewater aerated and mixed.
- Unique features of the system eliminate exposing maintenance personnel to the risk of H₂S gas.
- The system will not allow major leaks to go unnoticed, resulting in a very environmentally sound situation.
- Only one source of power, at the vacuum station, is required.
- The elimination of infiltration permits a reduction of size and cost of the treatment plant.

Figure 3-1. Typical layout - vacuum sewer system. (Courtesy AIRVAC)

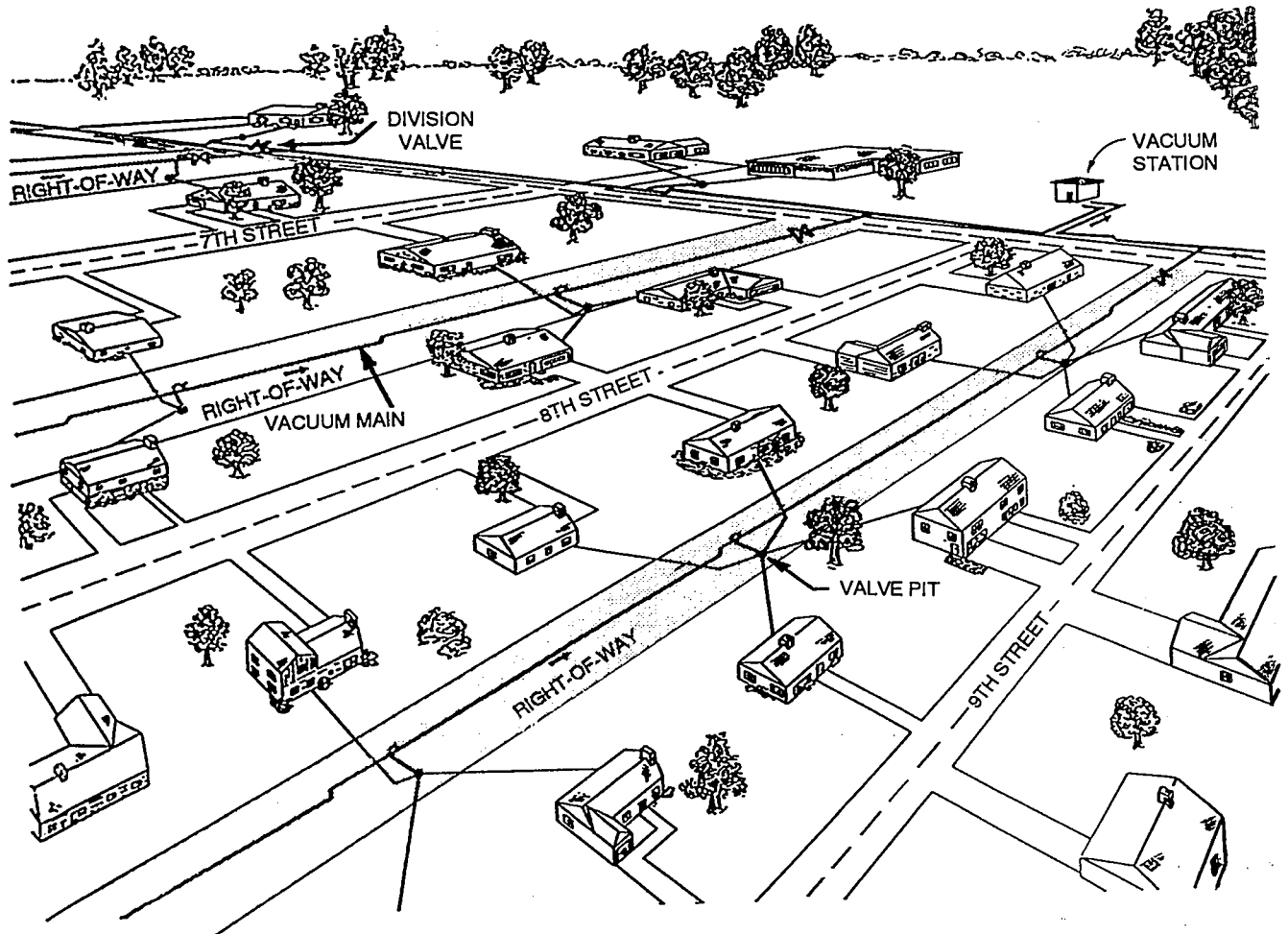
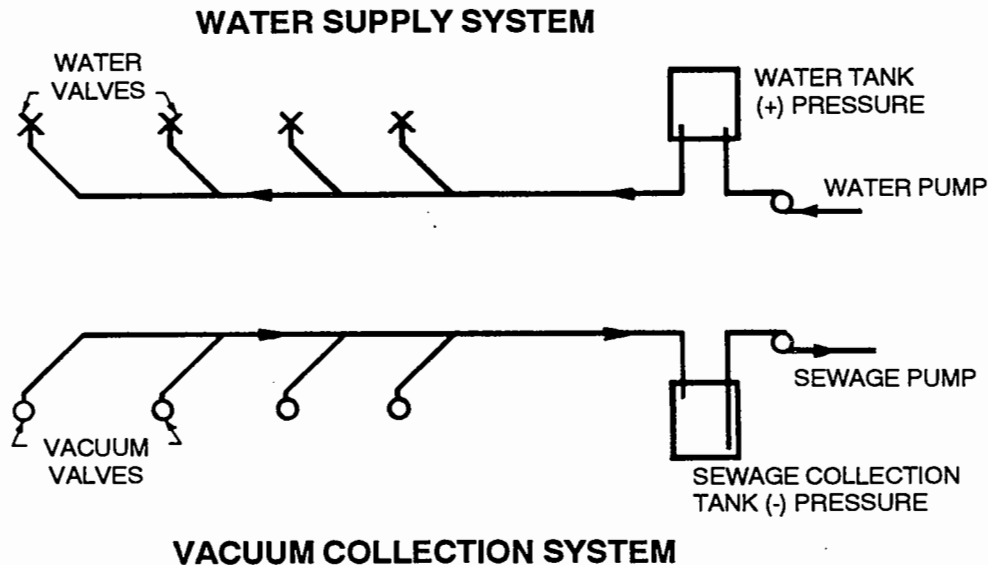


Figure 3-2. Water sewer/vacuum system similarities. (Courtesy AIRVAC)



The history of vacuum sewer technology is discussed in Chapter 1. The differences in overall system philosophy, design concepts, system components, and marketing approaches of four manufacturers are discussed. Each of these companies have made significant contributions to the vacuum sewer industry. Presently, almost all systems in operation in the United States are AIRVAC systems. For this reason, the remainder of this Chapter focuses on that approach. This in no way represents any endorsement of that system, but merely reflects the present state of the art in vacuum sewerage. In fact, at least one competitor has recently entered the U.S market. That manufacturer, Iseki, uses an approach similar to AIRVAC.

3.2 System Plan and Elevation View

Figure 3-3 shows a plan and profile view of a typical vacuum sewer line. Figure 3-4 shows a plan and profile view of a typical valve pit.

3.3 Description of System Components

A vacuum sewer system consists of three major components: the service, the collection mains, and the vacuum station.

3.3.1 Services

The services in a vacuum system consist of the following components:

- Vacuum valve
- Auxiliary vents
- Valve pit/sump, or
- Buffer tanks

The vacuum valve provides the interface between the vacuum in the collection piping and the atmospheric air in the building sewer. System vacuum in the collection piping is maintained when the valve is closed. With the valve opened, system vacuum evacuates the contents of the sump. The valve is entirely pneumatic by design, and has a 7.5-cm (3-in) opening size. Some states have made this a minimum size requirement, as this matches the throat diameter of the standard toilet.

Valve pits and sumps are needed to accept the wastes from the house. These may consist of one setting with two separate chambers. In these cases, the upper chamber houses the vacuum valve and the bottom chamber is the sump into which the building sewer is connected. These two chambers are sealed from each other. The combination valve pit/sump is made of

Figure 3-3. Profile view of typical vacuum sewer line.

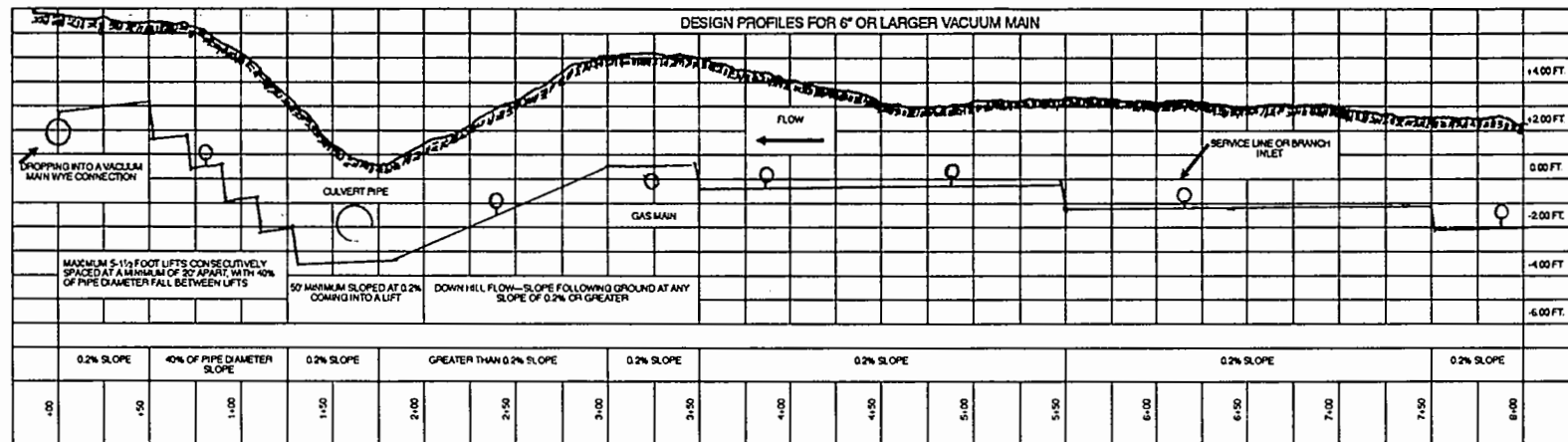
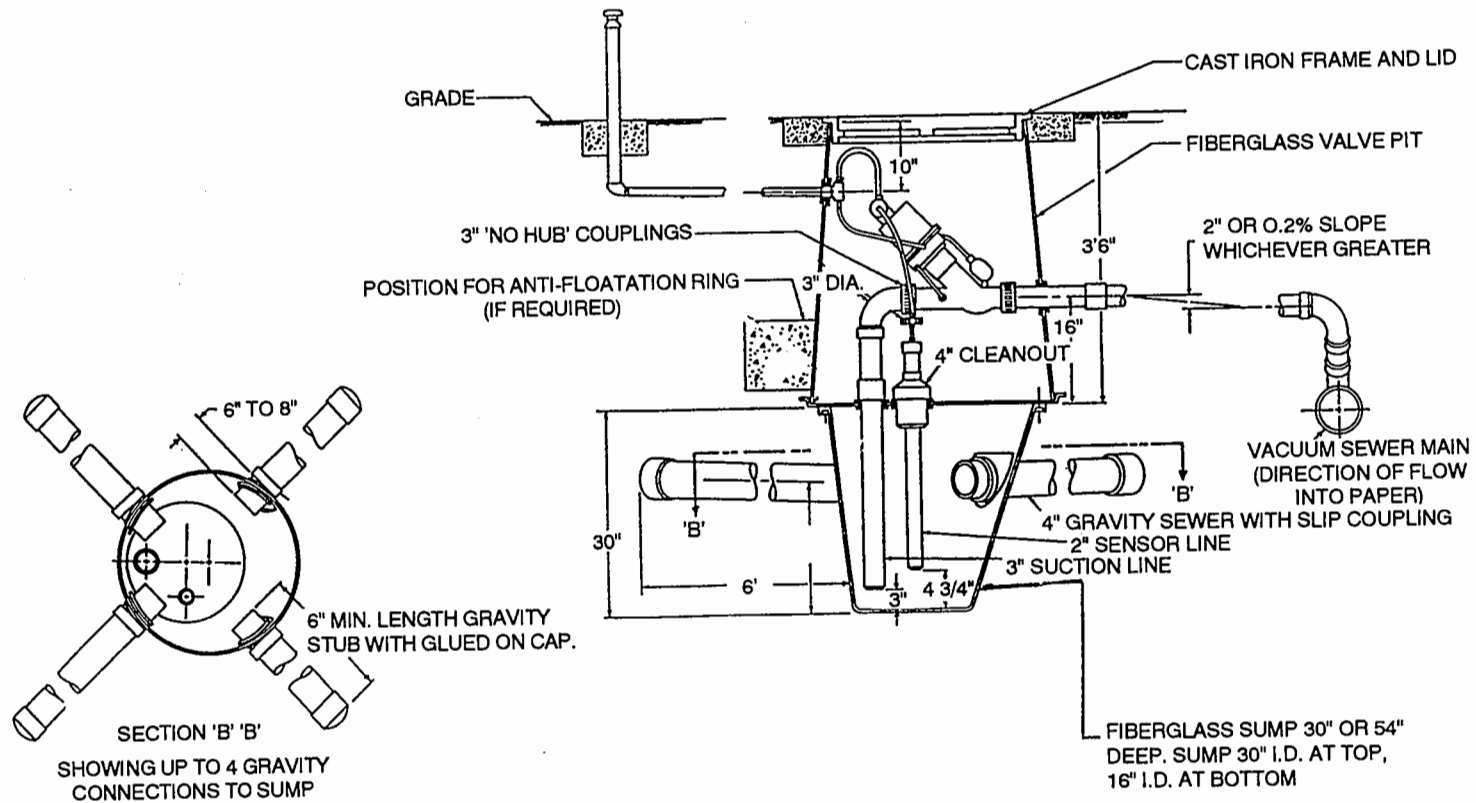


Figure 3-4. Plan and profile view - typical valve pit.



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fiberglass, and is able to withstand traffic loads. For deeper settings, the fiberglass pit/sump arrangement may be replaced by a concrete manhole section in which the vacuum valve is mounted. In this arrangement, only one chamber exists. Buffer tanks are used for large customers or when a pressure/vacuum or gravity/vacuum interface is desired, as would be the case with a hybrid system.

A 10-cm (4-in) auxiliary vent is installed on the homeowner's service lateral, downstream of all of the house traps (Figure 3-5). This vent is necessary to provide the volume of air that will follow the wastewater into the main. This also circumvents the problem of inadequate house venting which had resulted in trap evacuation in early installations.¹ Some operating entities require the vent to be located near a permanent structure for aesthetic and protection reasons. In climates where temperatures fall below freezing, this vent must be located a minimum of 6 m (20 ft) from the valve pit. In this manner, the heat from the wastewater acts to warm the freezing atmospheric air thus reducing the possibility of freezing of some of the valve components.

3.3.2 Collection Mains

The collection piping network consists of the following components:

- Pipe
- Fitting
- Lifts
- Division valves

The piping network is connected to the individual valve pits and the collection tank. Schedule 40, SDR 21 and SDR 26 PVC pipe have been used, with SDR 21 being the most appropriate and most common. Both solvent-welded and gasketed have been used. Experience has shown that there are fewer problems with the gasketed type pipe. Where gasketed pipe is used, the gaskets must be certified for use under vacuum conditions. HDPE pipe has also been used in Europe. Typical sizes include 7.5-, 10-, 15-, and 20-cm (3, 4, 6, 8-in) pipe.

PVC pressure fittings are needed for directional change as well as for the crossover connections from the service line to the main line. These fittings may be solvent-welded or gasketed. Again, the recent trend is to avoid solvent-welded fittings where possible.

Lifts or vertical profile changes are used for uphill liquid transport. These lifts are generally made in a sawtooth fashion. A single lift consists of two 45-degree fittings connected with a short length of pipe (Figure 3-6).

Since vacuum sewers are exposed to repeated energy inputs, pipe movement is possible if proper installation practices are not followed. Early systems used concrete thrust blocks at each fitting. More recent systems have been installed without concrete thrust blocking. The theory behind this is that the pressure is inward rather than outward as would be the case in a positive pressure situation. However, a more important concern is that each fitting is a point of possible joint failure. Failure of the fitting may occur because of trench settlement rather than thrust. For this reason, care must be exercised in the backfill and compaction operations. Granular backfill material covering the fitting, coupled with mechanical compaction, is a must if thrust blocking is to be eliminated. If thrust blocking is used, a thin plastic membrane should cover the pipe prior to the concrete pour.

Division valves are used for isolation purposes during troubleshooting. Both plug and resilient-wedge gate valves have been used. Recent systems have included gauge taps installed just downstream of the division valve. This tap makes it possible for one person to troubleshoot without having to check vacuum at the station. This greatly reduces emergency maintenance expenses, both from a time and manpower standpoint. Therefore, this tap is recommended.

Different pipe location identification methods have been used. These include magnetic trace tape in the top of the trench, metal toning wires above the pipe, and color coding of the pipe itself.

3.3.3 Vacuum Station

Vacuum stations function as transfer facilities between a central collection point for all vacuum sewer lines and a pressurized line leading directly or indirectly to a treatment facility.¹ The following components are included in the vacuum station (Figure 3-7).

- Vacuum pumps
- Wastewater pumps
- Generator
- Collection tank
- Reservoir tank
- Controls
- Motor control center
- Chart recorder
- Fault monitoring system

Vacuum pumps are needed to produce the vacuum necessary for liquid transport. The operational history of vacuum sewers indicates that the optimum operating range is 40-50 cm (16-20 in) Hg. The pumps, however, should have the capability of providing up to 63 cm (25 in) Hg as this level is sometimes needed in the troubleshooting

Figure 3-5. Auxiliary vent location.

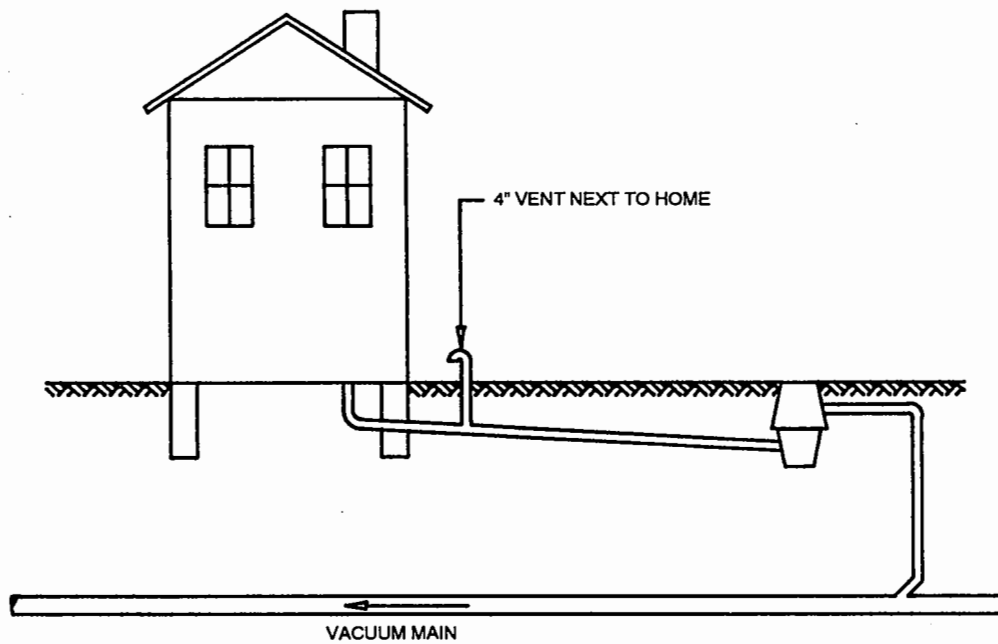


Figure 3-6. Lift detail.

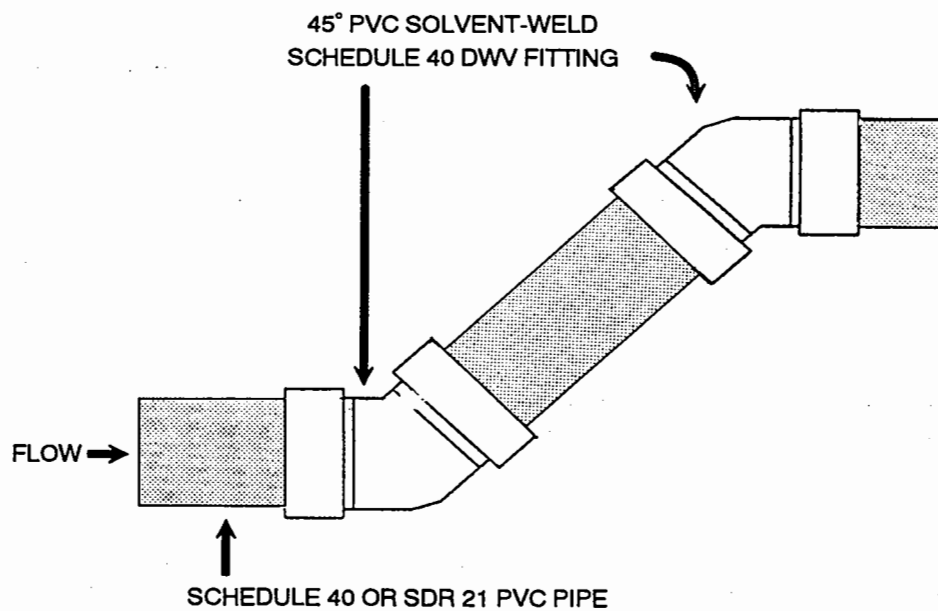
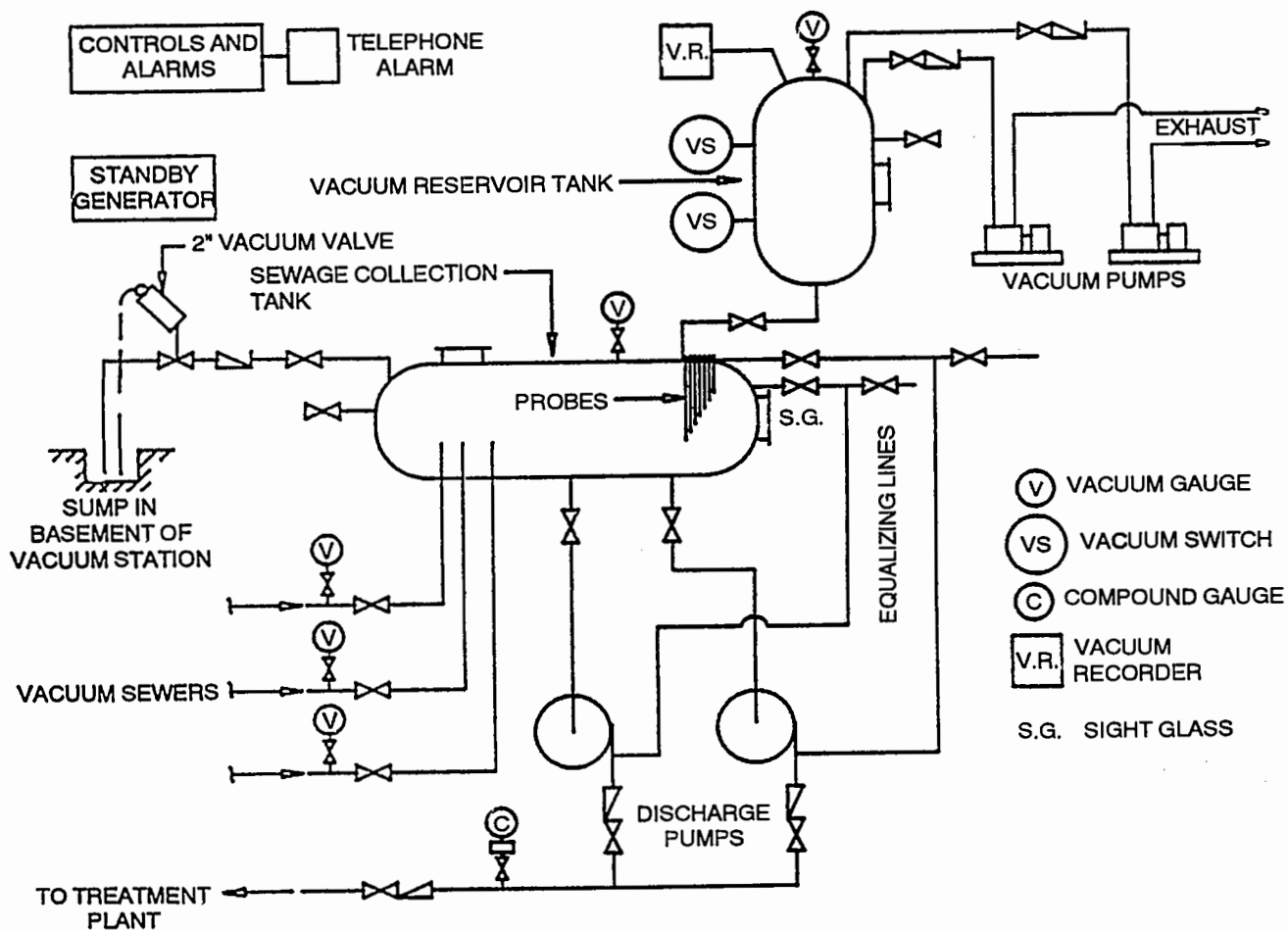


Figure 3-7. Line diagram of a typical vacuum station (Courtesy AIRVAC)



process. Redundancy is a minimum requirement with each pump capable of providing 100 percent of the required air flow (cfm).

Vacuum pumps may be either the liquid-ring or sliding-vane type. A liquid-ring vacuum pump utilizes a service liquid as a sealing medium between an offset impeller and the pump casing. As the impeller spins, the service liquid is forced against the pump outer casing by centrifugal force, and air is compressed and forced out of the discharge pipe by the eccentric liquid action. The vacuum is created as more air is drawn in to be compressed. When liquid-ring pumps are used, oil is recommended as the seal liquid. Since the service liquid continually circulates when the pump is in operation, a service liquid tank must be provided. The tanks are vented with an outlet to the outside. Since the service liquid carries a significant quantity of heat away from the pump, a heat exchanger is required.

Sliding-vane vacuum pumps may also be used. For these types of pumps an air filter is required. This filter is located on the inlet line between the reservoir tank and the vacuum pump so as to remove particulate material which might cause excessive impeller wear if it were to enter the pump volute. The use of sliding-vane vacuum pumps has increased recently. The reason for this is the lower power consumption required for a given pump capacity. On the negative side, there have been problems reported with the vulnerability of these pumps should liquid be carried into them. In this situation, the pumps must be taken out of service to remove the liquid; the result is a shortened service life. By contrast the liquid-ring pump can usually withstand an accident of this type with very little damage. Design precautions, such as an electrically controlled plug valve between the collection tank and the reservoir tank, can be added to the piping system in order to protect sliding-vane pumps.

Wastewater pumps are required to transfer the liquid that is pulled into the collection tank by the vacuum pumps to its ultimate point of disposal. Dry pit pumps have been used extensively, although submersible wastewater pumps located on guide rails within the collection tank may be used as an alternative. The most frequently used pump has been the non-clog type. Redundancy is required, with each pump capable of providing 100 percent of the design capacity. The level controls are set for a minimum of 2 minutes pump running time to prevent excessive pump starting and related, increased wear. The pumps should have shutoff valves on both the suction and discharge piping to allow for removal during maintenance without affecting the vacuum level.

Check valves are used on each pump discharge line and on a common manifold after the discharge lines are joined to it. Equalizing lines, consisting of small diameter clear PVC pipe connecting the pump discharge to the collection tank, are usually required.² The purpose of these lines is to remove air from the pump and to equalize the vacuum across the impeller. In addition, they will prevent the loss of prime should a check valve leak. Since this setup will result in a small part of the discharge flow being recirculated to the collection tank, a decreased net pump capacity results.

In some recent designs, equalizing lines have been eliminated by using horizontal wastewater pumps with a continuously flooded suction. This is accomplished through the use of a ball check valve on the pump suction piping between the collection tank and the wastewater pumps. Prior to using this concept, the designer should carefully weigh whether the pumping cost savings are significant enough to risk the possibility of failure of the ball-check and the problems that could result.

Wastewater pumps are typically located at an elevation significantly below the collection tank to minimize the net positive suction head (NPSH) requirement. In conjunction with NPSH requirements, pump heads are increased by 7 m (23 ft) to account for tank vacuum. Both vertical and horizontal pumps can be used.

Materials of construction for pumps include cast iron with stainless steel shafts, while aluminum, bronze, and brass should be avoided. Fiber packing is not recommended. Double mechanical seals which are adaptable to vacuum service should be used.²

A standby generator is a must. It ensures the continuing operation of the system in the event of a power outage. Standard generators that have been used in other wastewater applications are available from a variety of manufacturers.

The wastewater is stored in the collection tank until a sufficient volume accumulates, at which point the tank is evacuated. It is a sealed, vacuum-tight vessel made of either fiberglass or steel. Fiberglass tanks are generally more expensive, but do not require the periodic maintenance (painting) of a steel tank. Painting may be required every 5-6 years. Vacuum, produced by the vacuum pumps, is transferred to the collection system through the top part of this tank. The part of the tank below the invert of the incoming collection lines acts as the wet well. A bolted hatch provides access to the tank should it be necessary.

Most collection tanks are located at a low elevation relative to most of the components of the vacuum station. This minimizes the lift required for the wastewater to enter the collection tank, since wastewater must enter at or near the top of the tank to ensure that vacuum can be restored upstream. Many times this results in a deep basement required in the vacuum station.

A vacuum reservoir tank is located between the vacuum pumps and the collection tank. It has three functions: 1) to reduce carryover of moisture into the vacuum pumps; 2) to act as an emergency reservoir; and 3) to reduce the frequency of vacuum pump starts.³ Like the collection tank, it can be made of either fiberglass or steel.

The vacuum pumps are controlled by vacuum switches located on the reservoir tank. Usual operating level is 40-50 cm (16-20 in) Hg with a low level alarm of 35 cm (14-in) Hg. The wastewater pumps are controlled by a probe(s) located inside of the collection tank. One method includes using seven probes, one for each of the six set points of the pumping cycle and one as a ground. Another method relies on a single probe that is capable of monitoring all of the set points. These probes are the capacitance-inductive type. They require a transmitter/transducer to send a 4-20 mA signal to the control panel.

The motor control center houses all of the motor starters, overloads, control circuitry, and the hours run meter for each vacuum and wastewater pump. The vacuum chart recorder, collection tank level control relays, and a telephone dialer are also normally located within the motor control center.

Vacuum gauges are used on all incoming lines as well as on both the collection tank and the reservoir tank. Their purpose is to allow the operator to monitor the system. These gauges are very important in the troubleshooting procedures. Chart recorders for both the vacuum and sewer pumps are needed so that system characteristics can be established and monitored. Like gauges, these recorders are vital in the troubleshooting process.

A fault monitoring system is needed to alert the operator of any irregularities, such as a low vacuum level. These systems actuate an automatic telephone dialer. There are a number of manufacturers that have this type of equipment.

For small systems a skid-mounted station is available.³ This unit contains all the components of a typical vacuum station and must be installed inside a protective structure.

3.4 System Design Considerations

3.4.1 Hydraulics

The discussion of Section 2.4.1 is equally appropriate for vacuum sewers. AIRVAC 7.5-cm (3-in) valves have a capacity of 2 L/s (30 gpm) when connected to a 15-cm (6-in) or larger main, assuming the necessary vacuum, 13 cm (5 in Hg), is available at the valve site.² To achieve this capacity with the normal 38-L (10-gal) discharge cycle with an average valve-open time setting of 6 seconds, a vacuum valve would be required to open and close 3 times/minute, with a "rest" of only about 15 seconds between cycles. This may not present a problem to a valve that is relatively close to the vacuum station connected to a 15-cm (6-in) main. A different situation exists for a valve at the far end of the system that is connected to a 10-cm (4-in) main. Vacuum response (the ability of the vacuum main to quickly recover to the same level of vacuum that existed prior to the cycle) is of absolute importance in vacuum sewer design. Vacuum response is a function of line length, pipe diameter, number of connections, and the amount of lift in the system.

Should a situation exist that is cause for concern, the designer should consider using a buffer tank to attenuate peak flows. In this case, the idea is not for the valve to keep up with incoming flow, but rather to use tank reserve volume to prevent backups until the valve is capable of emptying the tank.

Design flows are maximum flow rates expected to occur once or twice a day, and are used to size the vacuum sewer mains as well as the various vacuum station components. Instantaneous flow rates in excess of design flows can occur under certain situations. Chapter 2 describes various studies of flow versus equivalent dwelling units (EDUs). The equation for estimating design flow based on the number of homes to be served is as follows:

$$Q = AN + B$$

where:

- Q = Design flow (gpm)
- A = A coefficient selected by the engineer, typically 0.5
- N = Number of EDUs
- B = A factor selected by the engineer, typically 20

In the usual form, the equation is $Q = 0.5N + 20$, but may be varied to account for anticipated high water use, to

allow for a greater safety factor, and to allow for some infiltration and inflow (I/I).

The term "self cleaning velocity" refers to the flow velocity required to convey solids along with the water carrier. To maintain an unobstructed pipeline, the velocity should be sufficient to transport grit that may be present in the wastewater, prevent grease plating on the crown of the pipe, and scour (resuspend) previously settled matter. This velocity is generally 60-90 cm/s (2-3 fps).

Tangential liquid velocities in the typical vacuum sewer are 4.6-5.5 m/s (15-18 fps), obviously well above the minimum required for self cleaning. A common claim from the manufacturers of vacuum sewer components is that there has never been a blockage reported in a vacuum system. Whether true or not, the high transport velocities suggest that the probability of blockages occurring are remote.

An understanding of the vacuum transport process is needed by the system designer. With the saw-tooth profile, and as long as no vacuum valves are operating, no wastewater transport takes place. All wastewater remaining in the sewers will lie in the low spots. Since the wastewater will not seal the bore of the pipe in these static conditions, little vacuum loss is experienced throughout the system when low or no flow is occurring.

When a sufficient volume of wastewater accumulates in the sump, the vacuum valve cycles. The differential pressure that exists between the sewer main and atmosphere forces the sump contents into the main. While accelerating, the wastewater is rapidly transformed into foam and soon occupies only part of the pipe cross section so that the momentum transfer from the air to water takes place largely through the action of shear stresses. The magnitude of the propulsive forces starts to decline noticeably when the vacuum valve closes, but remains important as the air continues to expand within the pipe. Eventually friction and gravity bring the wastewater to rest at a low spot. Another valve cycle, at any location upstream of the low spot, will cause this wastewater to continue its movement toward the vacuum station.¹

Vacuum systems are designed to operate on two phase (air/liquid) flows with the air being admitted for a time period twice that of the liquid. Open time of the AIRVAC valve is adjustable; hence, various air to liquid ratios are attainable.

Normally, the vacuum pumps are set to operate at 40-50 cm (16-20) in Hg of vacuum. The minimum vacuum of 40

cm (16 in) Hg results in a total available head loss of 5.5 m (18 ft); 1.5 m (5 ft) of this head loss is required to operate the vacuum valve, leaving 4 m (13 ft) available for wastewater transport (Figure 3-8). The summation of friction loss and static lift from any one point on the sewer network to the vacuum station must not exceed 4 m (13 ft). This relationship is expressed by the following equations:

$$V_c = V_s - V_v$$

where:

- V_c = Vacuum available in the collection system for transport, ft
- V_s = Minimum vacuum available at the vacuum station, typically 16 in Hg (which roughly equals 18 ft of water)
- V_v = Vacuum required to operate the vacuum valve, 5 in Hg (which roughly equals 5 ft of water)

With:

$$V_c = \text{Static Loss} + \text{Friction Loss}$$

and the normal values substituted in the above equation, the equation is simplified:

$$\text{Static Loss} + \text{Friction Loss} = 13 \text{ ft of H}_2\text{O}$$

Static losses are those incurred by using lifts, or vertical profile changes. Profile changes are accomplished by using two 45-degree fittings joined by a section of pipe. For efficient use of the energy available, profile changes should be as small as possible. Numerous lifts are recommended over one large lift.² Table 3-1 shows the recommended lift height for various pipe sizes.

Static losses are calculated by subtracting the pipe diameter from the lift height (Figure 3-9):

$$\text{Static Loss} = \text{Lift Height} - \text{Pipe Diameter}$$

Friction loss charts for SDR 21 PVC pipe and a 2:1 air/liquid ratio have been developed by AIRVAC, and are contained in their design manual.² Friction losses are only calculated for sewers that are laid between 0.2 and 2.0 percent fall. Friction losses in falls greater than 2.0 percent are ignored. The hydraulic calculations should be performed including friction loss. A separate calculation can then be made to see how much of the total loss is static versus friction.

Figure 3-8. Vacuum lift capability.

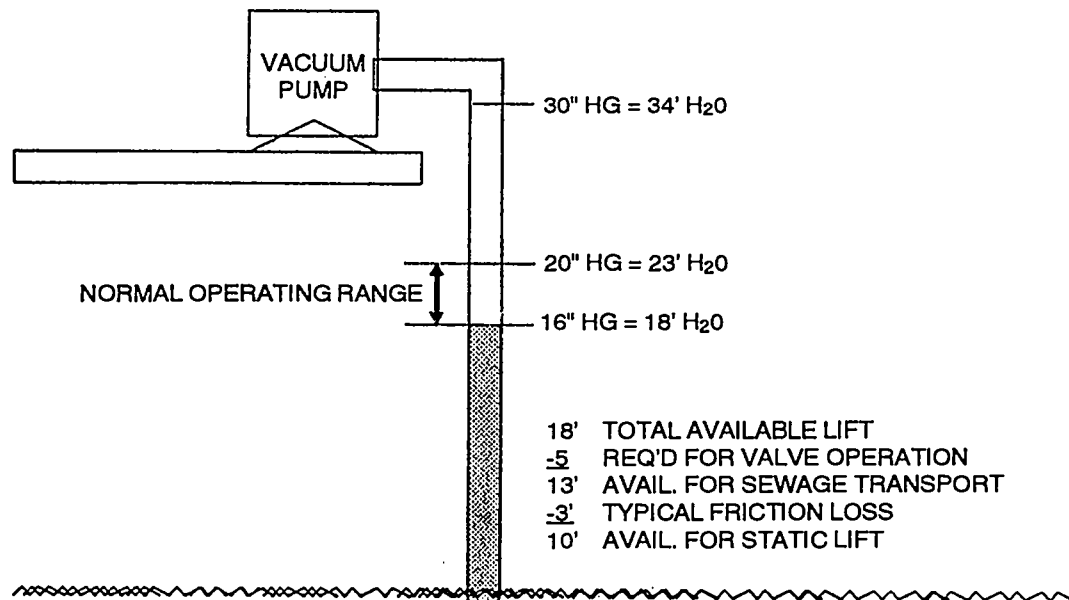
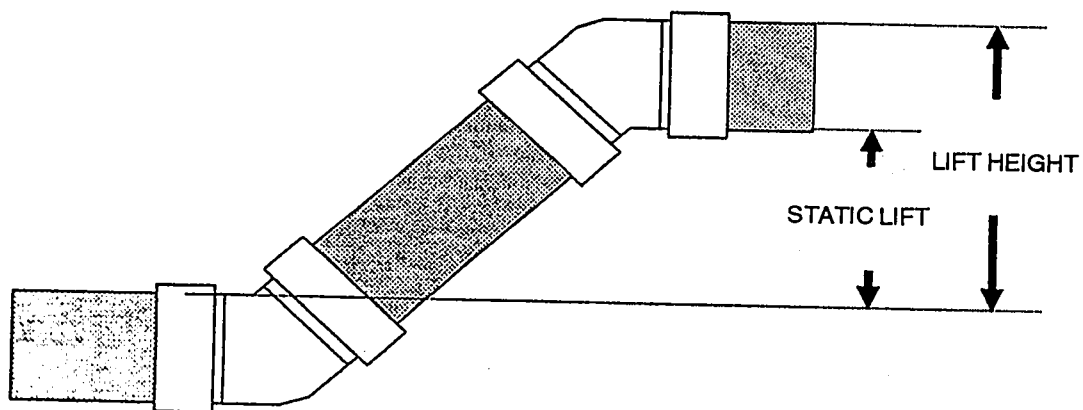


Table 3-1. Recommended Lift Height

Pipe Diameter (in)	Lift Height (ft)
3	1.0
4	1.0
6	1.5
8	1.5
10	2.3

Figure 3-9. Static loss determination.



$$\text{STATIC LIFT} = \text{LIFT HEIGHT} - \text{PIPE DIAMETER}$$

3.4.2 Mains, Service Lines, and Building Sewers

3.4.2.1 Mains

a. Geometry and Sizing

The geometry of a vacuum sewer system is similar to that of a water distribution system. Rather than looped, however, it is normally in a dendriform pattern.

It is desirable to have the vacuum station located as centrally as possible. This lends itself to a system with multi-branches. This is very important, as multiple main branches to the vacuum station give added operating flexibility. For example, with a system having 3 branches serving 300 customers, the worst case scenario is that 100, or one-third, of the customers may be without service while a problem is corrected. By contrast, the worst case scenario assuming a similarly sized system with one branch would have all 300 customers out of service during the same period.

When laying out a vacuum system, the designer should select pipe runs that:

- Minimize lift
- Minimize length
- Equalize flows on each main branch

The length of collection lines are governed by two factors. These are static lift and friction losses. As previously discussed, the summation of these two amounts generally cannot exceed 4 m (13 ft). Due to restraints placed upon each design by topography and wastewater flows, it is impossible to give a definite maximum line length. One operating system has a single main line branch exceeding 4,300 m (14,000 ft) in length.

Vacuum sewer design rules have been developed largely as a result of studying operating systems. Important design parameters are shown in Table 3-2 and 3-3.

Table 3-4 shows at what length the 0.2 percent slope will govern versus the percentage of pipe diameter for the slope between lifts.

AIRVAC has developed a table recommending maximum design flows for each pipe size. Table 3-5 shows these recommendations.¹

Substituting the values of maximum flow (Q) from Table 3-5 into the previously cited simplified equation ($Q = 0.5N + 20$) and solving for N, will give the maximum number of homes served for each line size. Table 3-6 shows these results.

Table 3-2. Main Line Design Parameters

Minimum distance between lifts, ft	20
Minimum distance of 0.2-percent slope prior to a series of lifts, ft	50
Minimum distance between top of lift and any service lateral, ft	6
Minimum slope, percent	0.2

Table 3-3. Guidelines for Determining Line Slopes*

Line Size	Use Largest of:
4" Mains	- 0.2% - Ground slope - 80% of pipe dia. (between lifts only)
6" Mains	- 0.2% - Ground slope - 40% of pipe dia. (between lifts only)

* Assuming minimum cover at top of slope

Table 3-4. Governing Distances for Slopes Between Lifts

Pipe Diameter (in)	Distance	Governing Factor
4	<135 ft	80% of pipe diameter
4	>135 ft	0.2% slope
6 & larger	<100 ft	40% of pipe diameter
6 & larger	>100 ft	0.2% slope

Table 3-5. Maximum Flow for Various Pipe Sizes

Pipe Diameter (in)	Maximum Maximum Flow (gpm)
4	55
6	150
8	305
10	545

Table 3-6. Maximum Number of Homes Served for Various Pipe Sizes

Pipe Diameter (in)	Number of Homes Served
4	70*
6	260
8	570
10	1,050

* The recommended maximum length of any 4-in run is 2,000 ft, which may limit the amount of homes served to a value less than 70.

The values in Table 3-6 should be used for planning purposes or as a starting point for the detailed design. In the latter case, estimated site-specific flow inputs along with the friction tables should be used in the hydraulic calculations. A correctly sized line will yield a relatively small friction loss. If the next larger pipe size significantly reduces friction loss, the line was originally undersized.

Experience has shown that there is little economy in using 7.5-cm (3-in) pipe for mains. For this reason, 10 cm (4 in) is the minimum recommended main size.

b. Routing

In most cases, vacuum sewer mains are located outside of and adjacent to the edge of pavement and approximately parallel to the road or street, which reduces the expenses of pavement repair and traffic control. In areas subject to unusual erosion, the preferred location is often within the paved area. This location is also favored by some municipalities as being an area where subsequent excavation is less likely and more controlled, and therefore a location more protected from damage.

One of the major cost components of a vacuum system is the valve pit. With two or more homes sharing one valve, overall system construction costs can be significantly reduced, resulting in major cost advantage. To do this, however, may require the main line to be located in private property, typically in the back yard. There are two disadvantages to this type of routing. First, it requires permanent easements from one of the property owners, which may be difficult to obtain. Second, experience has shown that multiple house hookups are a source of neighborhood friction unless it is located on public property. The designer should carefully consider the tradeoff of reduced costs to the social issues prior to making the final routing decision.

An advantage to the use of vacuum sewers is that the small diameter PVC pipe used is flexible and can be easily routed around obstacles. The feature allows vacuum sewers to follow a winding path as necessary. The pipe should be bent in as long of a radius as possible, never less than that recommended by the pipe manufacturer. The equation from the Uni-Bell Handbook of PVC Pipe for the minimum radius of bending is presented in Chapter 2. This equation is:

$$R_b/OD = 200$$

where:

R_b = Minimum radius of the bending circle
OD = Outside diameter of the pipe

Vacuum sewers are normally buried with a cover of 90 cm (3 ft). In a few cases, where economy is paramount and subsequent damage is unlikely, they are buried with less cover. The depth of burial in colder climates is usually dictated by frost penetration depths. In the northern United States, they are often placed at 1.2-1.5 m (4-5 ft). Even though line freezing is a concern with most engineers, it usually is not a problem with vacuum mains since retention time in small-diameter lines is relatively short and turbulence is inherent. Long periods of disuse could still lead to freezing conditions however, unless the system were adjusted to ensure relatively complete evacuation of the mains (a technique used for "winterizing" some resort systems).

The separation of vacuum sewers from water supply mains and laterals often requires the vacuum sewer be buried deeper than would be required for other reasons. Horizontal and vertical separation requirements are dictated by State Agencies. These requirements vary from state to state.

Profiles of the mains should always be shown on the plans. Slopes, line sizes and lengths, culvert and utility crossings, inverts, and surface replacements are typically shown on the profiles.

Culvert and utility crossings often dictate numerous variations in the depth of burial of vacuum sewer mains, with many resulting sags and summits in the pipeline profile. Unlike pressure mains, where air accumulates at a summit requiring an air release valve, vacuum sewers are not affected by high points in the profile. The sags, however, may present a problem, as they typically will add lift to the system. In addition, if not designed and constructed properly, a sag may trap wastewater at low flow periods blocking off the low part of the sewer.

To minimize damage to the vacuum sewer main caused by subsequent excavation, route markers are sometimes placed adjacent to the main, warning excavators of its presence. Accurate as-constructed plans are helpful in identifying the pipeline location, and a cable buried with the main can be induced with a tone so the main can be field located using common utility locating equipment.

A warning tape marked "vacuum sewer" is sometimes placed shallowly in the pipeline trench to further notify excavators. When the tape is placed lower in the trench, e.g., adjacent to the pipe, it is called an identification tape. The tape can be metalized so it can be detected with utility locating devices. Most tapes cannot be induced with a tone at a significant depth, so metalized tape should be placed shallowly to be detected. It is also very

or twisted during its placement or the detectable surface area will be reduced.

c. Trench Section

Trenching may be accomplished by using a backhoe, wheel trencher, or chain-type trencher. The choice of equipment is usually dictated by the contractor based on the material to be excavated, depth requirements, topography and available working space.

Imported material termed "pipe zone backfill" is often placed to surround the main if material excavated from the trench is regarded as unsuitable for this purpose. Pipe zone backfill is usually granular, such as pea gravel or coarse sand. Fine sand or soil is generally not as desirable as it bulks, rather than flows, into place under the pipe haunching.

The remaining backfill material required is often specified by the agency controlling the road or street, especially if the mains are located within the pavement.

In some cases a lean cement-sand slurry is used for backfill. This option is particularly attractive when a trencher is used, the mains are located within the pavement, and prompt restoration for traffic control is important.

d. Pipe Materials

PVC thermoplastic pipe is normally used for vacuum sewers in the United States. In some European installations, HDPE and ABS have been successfully used. In certain cases, ductile cast iron pipe (DCIP) has also been used, assuming the joints have been tested and found suitable for vacuum service.

The most common PVC mains are iron pipe size (IPS), 200 psi working pressure rated, standard dimension ratio 21 (Class 200 SDR 21 PVC). Class 160, SDR 26, and Schedule 40 PVC have also been used. From a pressure standpoint, the lower class pipe is acceptable. However, thinner wall pipe is more likely to be damaged during installation. Further, there is little cost difference between SDR 21 and SDR 26 when the excavation, backfill, and surface restoration are considered. For these reasons, Class 200, SDR 21 is recommended.

PVC pipe has a high (3.0×10^{-5} in/in/°F) coefficient of thermal expansion; about 3/8-in length variation/100 ft of pipe/10°F change in temperature. Considerable temperature changes will be experienced during pipeline installation, and some degree of temperature change will occur during operation, with climate and shallow soil temperature changes. To reduce expansion and contraction induced stresses, flexible elastomeric joint

("rubber ring" joint) pipe is preferred. If solvent-welded joint pipe is used, the pipe manufacturers recommendations for installation regarding temperature considerations should be followed. The Uni-Bell Handbook of PVC Pipe also provides guidance as to proper practices.

In the past, solvent-weld fittings were most often used with Drain, Waste, and Vent (DWV) pipe. These fittings are more commonly available than gasketed joint fittings (one major line component, the wye required for each connection to the main, is not made in gasketed PVC). Expansion and contraction, while a concern if the entire system were solvent-welded, are allowed for in the gasketed main-line pipe joints.

Presently, there is a move toward eliminating all solvent-welding. At least one of the major fitting manufacturers is making gasketed wye fittings. Spigot adapters (an adapter fitting that can be solvent welded in a controlled environment into each of the three legs of the wye resulting in three gasketed joints) can also be used.

3.4.2.2 Service Lines

Vacuum sewer service lines run from the vacuum main to the valve pit. Typically these lines are near and parallel to property lines.

It is good practice to boldly field mark the location of the service line with properly identified lath a few days prior to installation. This serves as a reminder to the property owners about the intended location and may cause them to recognize some reason why the location should be changed. It also serves as an advance notice to neighbors if property lines are in doubt.

Most municipalities prefer locating the service line where it will not be driven over. Others, however, prefer locating the service line within the paved driveway. The reasoning is that subsequent excavation and associated damage to the service line is less likely within the paved section.

Service lines should be located distant from potable water lines to reduce the possibility of cross contamination. They should also be distant from other buried utilities, if possible, due to the possibility of damage caused by subsequent excavations for maintenance or repair of those utilities.

All connections to the main, e.g., crossover connections, are made "over the top" (Figure 3-10). This is accomplished using a vertical wye and a long radius elbow. Due to the restraints placed upon the depth of sewers by the connecting sewers entering "over the top," engineers should consider the ground cover required on these

Figure 3-10. Top view of crossover connection.

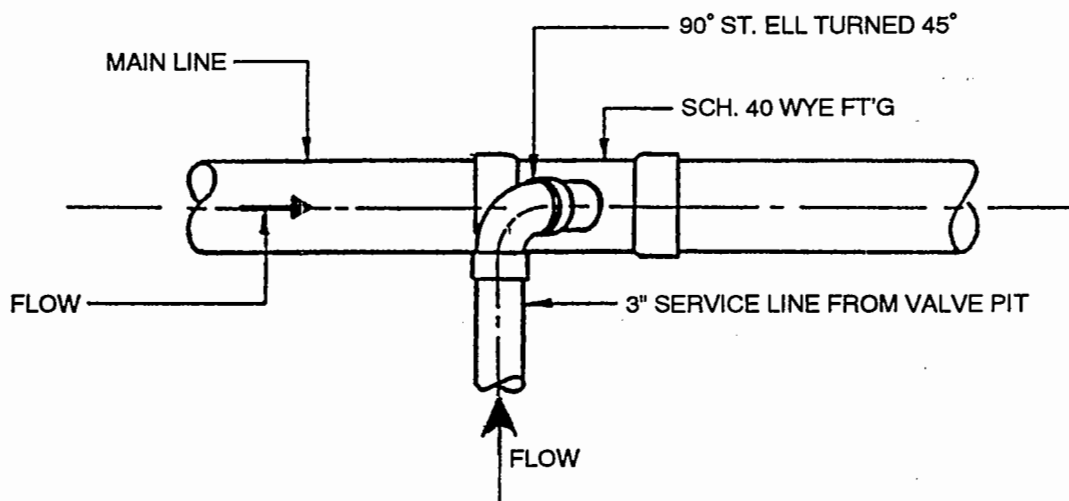


Table 3-7. Service Line Design Parameters

Minimum distance from lift to valve pit, ft	5
Minimum distance from lift to crossover, ft	5
Minimum slope between lifts	2 in or 0.2% (whichever is larger)

connections at the design stage. Table 3-7 gives design parameters when lifts are required in the service line.

Service lines are typically 7.6 cm (3 in) in diameter. An exception to this occurs when a buffer tank is used. Buffer tanks are used for large flows which otherwise result in frequent valve cycles. To maintain good vacuum response at the buffer tank, a 15-cm (6-in) service line is recommended.

As with the vacuum sewer mains, Class 200, SDR 21 PVC pipe typically is used for the service lines. Solvent-welded DWV fittings are used, although rubber ring fittings are becoming more common.

3.4.2.3 Building Sewers

The term building sewer refers to the gravity flow pipe extending from the home to the valve pit setting. In many cases, state or local authorities regulate installations of building sewers. The Uniform Plumbing Code is often referenced.

For residential service, the building sewer should be 10 cm (4 in) and slope continuously downward at a rate of not less than 0.25 in/ft (2-percent grade). Desirably, the valve pit setting should be located near the home so the building sewer is short, with less need for maintenance and less opportunity for infiltration and inflow (I/I). Line size for commercial users will depend on the amount of flow and local code requirements.

Bends should be avoided in building sewers, and a cleanout used for each aggregate change in direction exceeding 57°.

Infiltration via leaking building sewers has been common, as has the connection of roof and yard drains. A quality inspection during homeowner connection is advised to determine if these situations exist. If so, steps should be taken to require their elimination prior to final homeowner connection.

To minimize the risk of damage to the fiberglass valve pit during homeowner connection to the system, a stub-out pipe of sufficient length, typically 1.8 m (6 ft), from the valve pit is recommended. The orientation of the valve pit as it relates to the house and the wye connection is dependent on the number of connections to the pit (Figure 3-11).

If the home piping network does not have a cleanout within it, one should be placed outside and close to the home. Some agencies prefer having a cleanout at the dividing line where agency maintenance begins (i.e., the end of the 1.8-m [6-ft] stub-out pipe).

3.4.3 Valve Pit Settings

3.4.3.1 General

a. Fiberglass Settings

The premanufactured, fiberglass type of valve pit setting is by far the most common. This type of setting is composed of four main parts; the bottom chamber (sump), the top chamber (valve pit), the plate that separates the two chambers (pit bottom), and the lid (Figure 3-12).

Wastes from the home are transmitted to the sump via the building sewer, the inlet entering the sump 45 cm (18 in) above the bottom. Up to four separate building sewers can be connected to one sump, each at 90 degrees to one another. A tapered shape helps facilitate the backfilling procedure.

The sump has a wall thickness of 5 mm (3/16 in) and is designed for appropriate traffic loading with 60 cm (2 ft) of cover.¹ Elastomer connections are used for the entry of the building sewer. Holes for the building sewers are field cut at the position directed by the engineer.

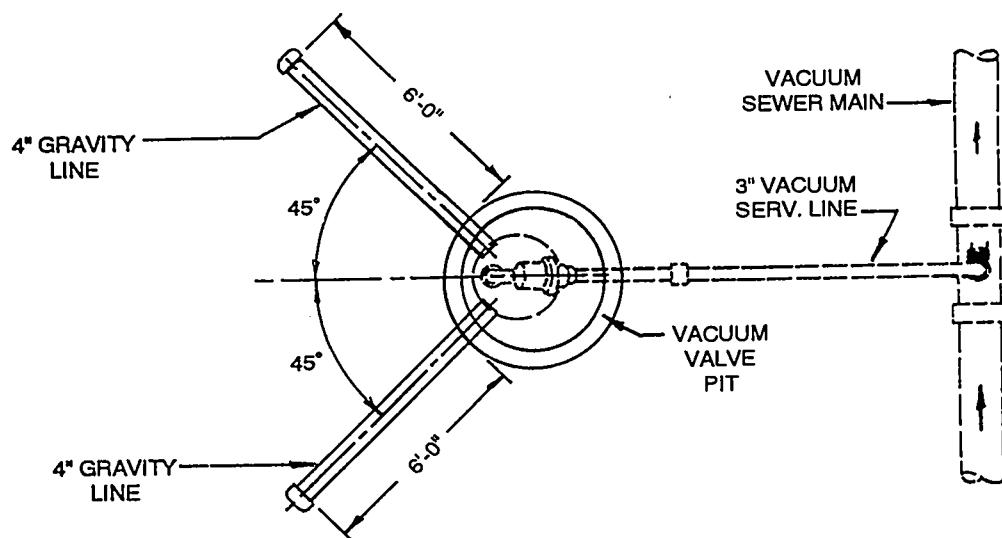
The sumps employed thus far have two different heights: 76 and 135 cm (30 and 54 in). Both are 45 cm (18 in) in diameter at the bottom and 90 cm (36 in) in diameter at the top, with the smaller size having a capacity of 208 L (55 gal) and the larger one 380 L (100 gal).

The valve pits house the vacuum valve and controller. They are usually fabricated with filament-wound fiberglass with a wall thickness of 5 mm (3/16 in) in order to be suitable for appropriate traffic loading.¹ The valve pit is normally 90 cm (36 in) in diameter at the bottom and is conically shaped to allow the fitting of a 60-cm (23.5-in) diameter clear opening cast iron frame and cover at the top. Depths are normally 1 m (42 in). One 7.5-cm (3-in) diameter opening, with an elastomer seal, is pre-cut to accept the 7.5-cm (3-in) vacuum service line.

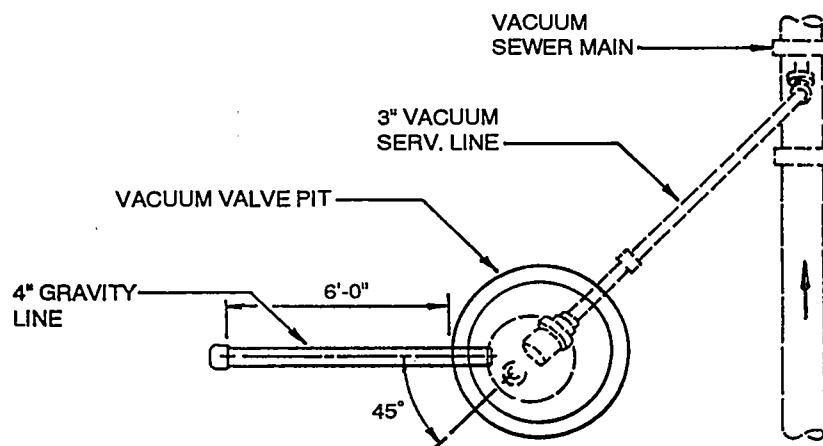
The pit bottom is made of reinforced fiberglass that is 6-mm (1/4-in) thick at the edges and 8-mm (5/16-in) thick in the center. These bottoms have been molded by the resin injection process.¹ Valve pit bottoms are provided with holes pre-cut for the 7.5-mm (3-in) suction line, 10-cm (4-in) cleanout/sensor line and the sump securing bolts. Sealing between the valve pit bottom and the sump is done in the field using a silicone, butyl tape rubber sealant or neoprene O-ring. The pit bottom should have a lip which allows the valve pit to rest on top of it.

Cast iron covers and frames, designed for heavy traffic loading, are typically used. The frame weight is generally 40 kg (90 lb) and the lid weight about 45 kg (100 lb). When

Figure 3-11. Typical configurations for gravity connections.

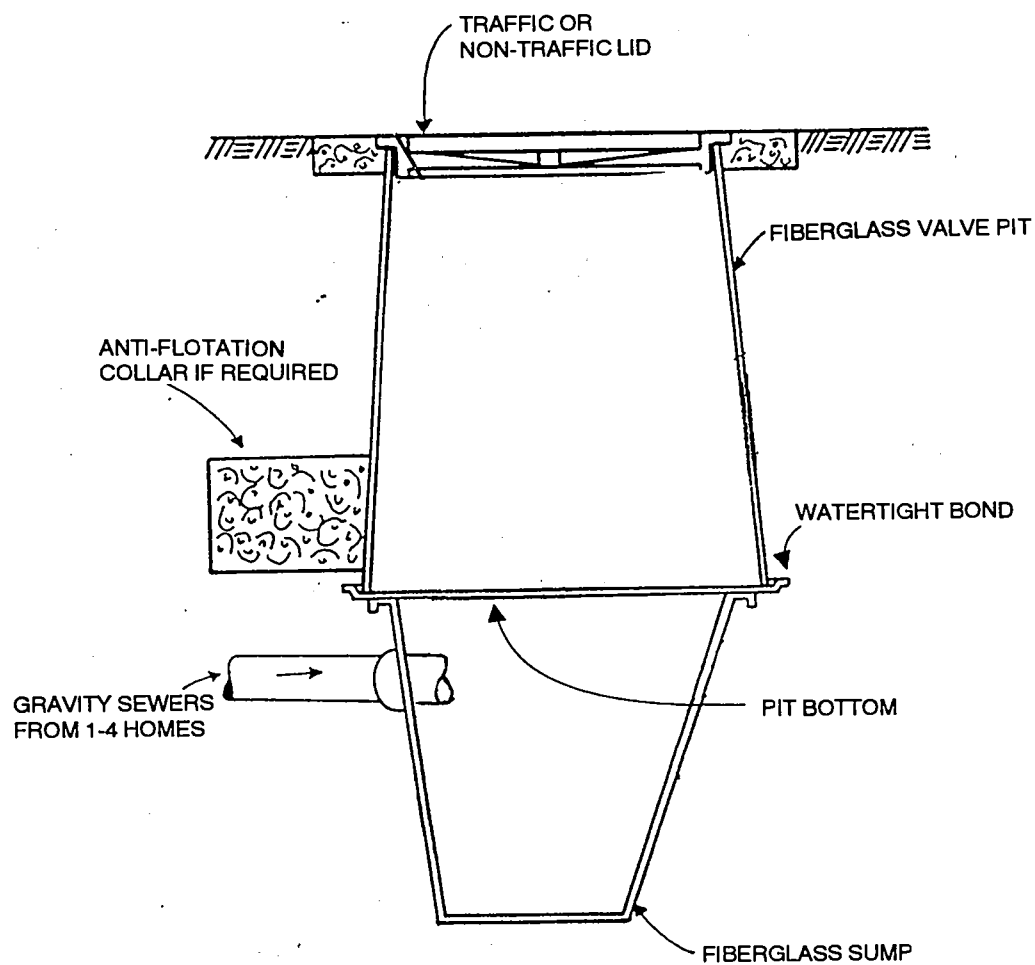


2-HOUSE CONNECTION



SINGLE HOUSE CONNECTION

Figure 3-12. Typical fiberglass valve pit setting.



a lighter lid is desired, such as in non-traffic situations, a lightweight aluminum or cast iron lid may be used. These types of lids do not have frames, but rather are fitted to the valve pit through the use of two J-bolts. These lids should clearly be marked "Non-Traffic."

A shallower arrangement is possible, if so desired (Figure 3-13). This arrangement would be used in areas where high ground water or poor soils exist and depth of the building sewers is very shallow.

b. Concrete Settings

Certain situations call for the use of concrete valve pit settings:

- When the deepest fiberglass setting is not sufficient to accept the building sewer.
- When a large flow is anticipated requiring flow attenuation.
- When an interface between two system types (e.g., pressure and vacuum) is needed.

The deepest possible fiberglass setting is 2.4 m (8 ft). The building sewer depth at the valve pit setting is therefore limited to 2 m (6.5 ft), since the building sewer enters 45 cm (18 in) above the bottom. Should a deeper setting be required, a concrete valve pit setting may be used. The maximum recommended depth for a concrete pit is 3 m (10 ft).

These types of settings are typically constructed of 1.2-m (4-ft) diameter manhole sections, with the bottom section having a pre-poured 45-cm (18-in) diameter sump. It is very important that all joints and connections be watertight to eliminate ground-water infiltration. Equally important is the need for a well-designed pipe support system, since these tanks are open from top to bottom. The support hardware should be of stainless steel and/or plastic.

Earlier in this section hydraulics were discussed, with the general conclusion that 5.5 m (18 ft) of system loss was available; 4 m (13 ft) for the collection piping and 1.5 m (5 ft) for the valve operation. The 1.5 m (5 ft) generally corresponds to the amount of lift required to evacuate the sump contents, assuming the deepest fiberglass valve pit setting is used. Increasing this depth by use of a concrete setting will result in a decreased amount of lift available for the collection system. Depending on the specific location of the deep setting required, the engineer may opt to serve the home by other methods. Should a deep concrete setting still be the choice, the engineer should seek written agreement of the manufacturer regarding any warranties.

c. Buffer Tanks

For large flows that require attenuation, a buffer tank should be used. Buffer tanks are typically used for schools, apartments, nursing homes, and other large users. They are designed with a small operating sump in the lower portion, with additional emergency storage available in the tank.

Like the deep concrete valve pit settings, the buffer tank is typically constructed of 1.2-m (4-ft) diameter manhole sections, with the bottom section having a pre-poured 45-cm (18-in) diameter sump (Figure 3-14). The same water tightness and pipe support concerns apply to the buffer tank.

When an interface between two system types is needed, a dual buffer tank should be used. For example, a hybrid system may be used, with vacuum sewers serving the majority of the service area and pressure sewers serving the low-lying fringes. At some point, a transition will be needed between the pressure flow and vacuum flow.

A dual buffer tank is similar to a buffer tank, with the exception that it is larger to accommodate two vacuum valves (Figure 3-15). These tanks typically utilize 1.5-m (5-ft) diameter manhole sections. Dual buffer tanks may also be used if the single buffer tank does not have the capacity for the large flows. A single buffer tank has a 2-L/s (30-gpm) capacity while a dual buffer tank has a 4-L/s (60-gpm) capacity.

3.4.3.2 Appurtenances

Anti-flotation collars are sometimes used on the fiberglass valve pit settings (See Figure 3-12). Buoyancy calculations should be performed by the designer to see if they are necessary. Past experience has shown that these collars are usually not needed. Should they be used, care must be taken during the valve pit installation as poor bedding and backfill may lead to settlement problems. Settlement of the concrete ring most likely will coincide with damage to the building sewer and/or the pit itself.

3.4.4 Vacuum Valves

3.4.4.1 Valve Arrangements

All vacuum valves except Vac-Q-Tec operate without the use of electricity. The valve is vacuum operated on opening and spring assisted on closing. System vacuum ensures positive valve seating.

The AIRVAC valves have a 7.5-cm (3-in opening), are made of schedule 80 ABS and have stainless steel shafts, delrin bearings and elastomer seals.² The valve is equipped with a rolling diaphragm-type vacuum operator and is capable of overcoming all sealing forces and of

Figure 3-13. Shallow fiberglass valve pit setting. (Courtesy AIRVAC).

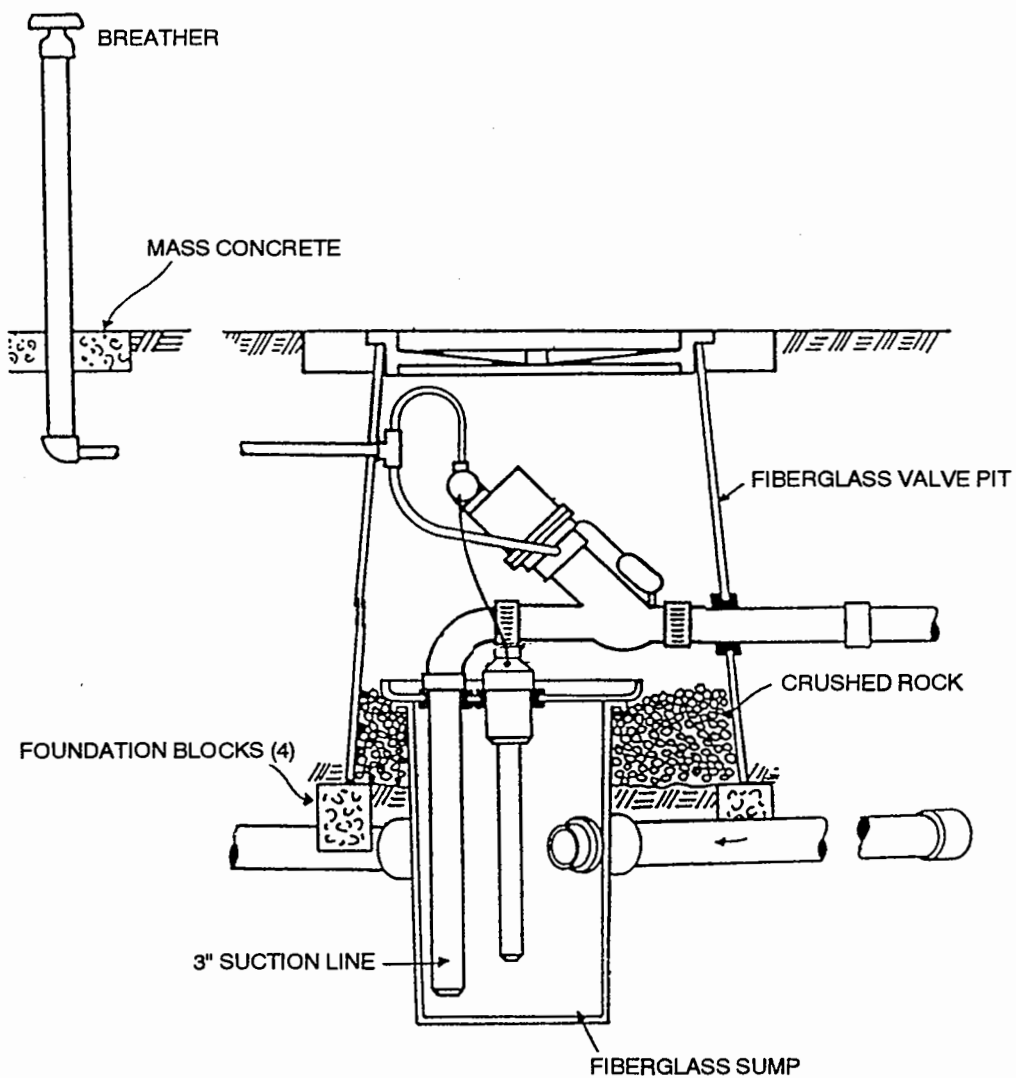


Figure 3-14. Plan and elevation views of typical concrete buffer tank. (Courtesy AIRVAC)

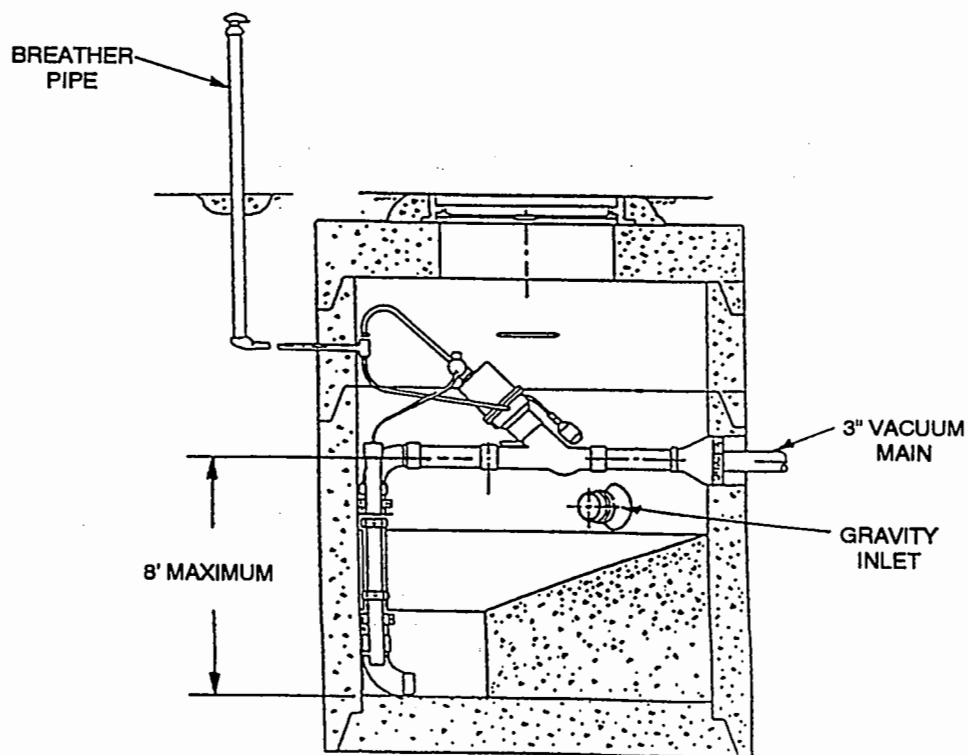
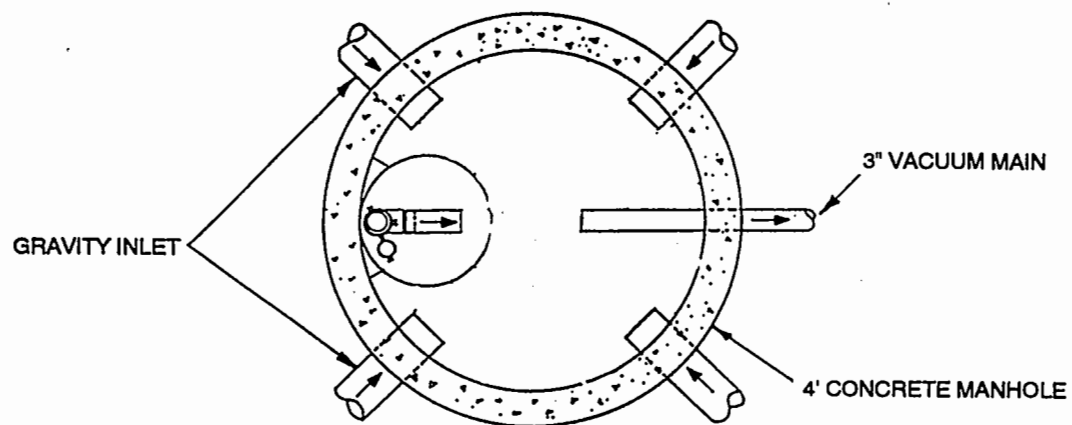
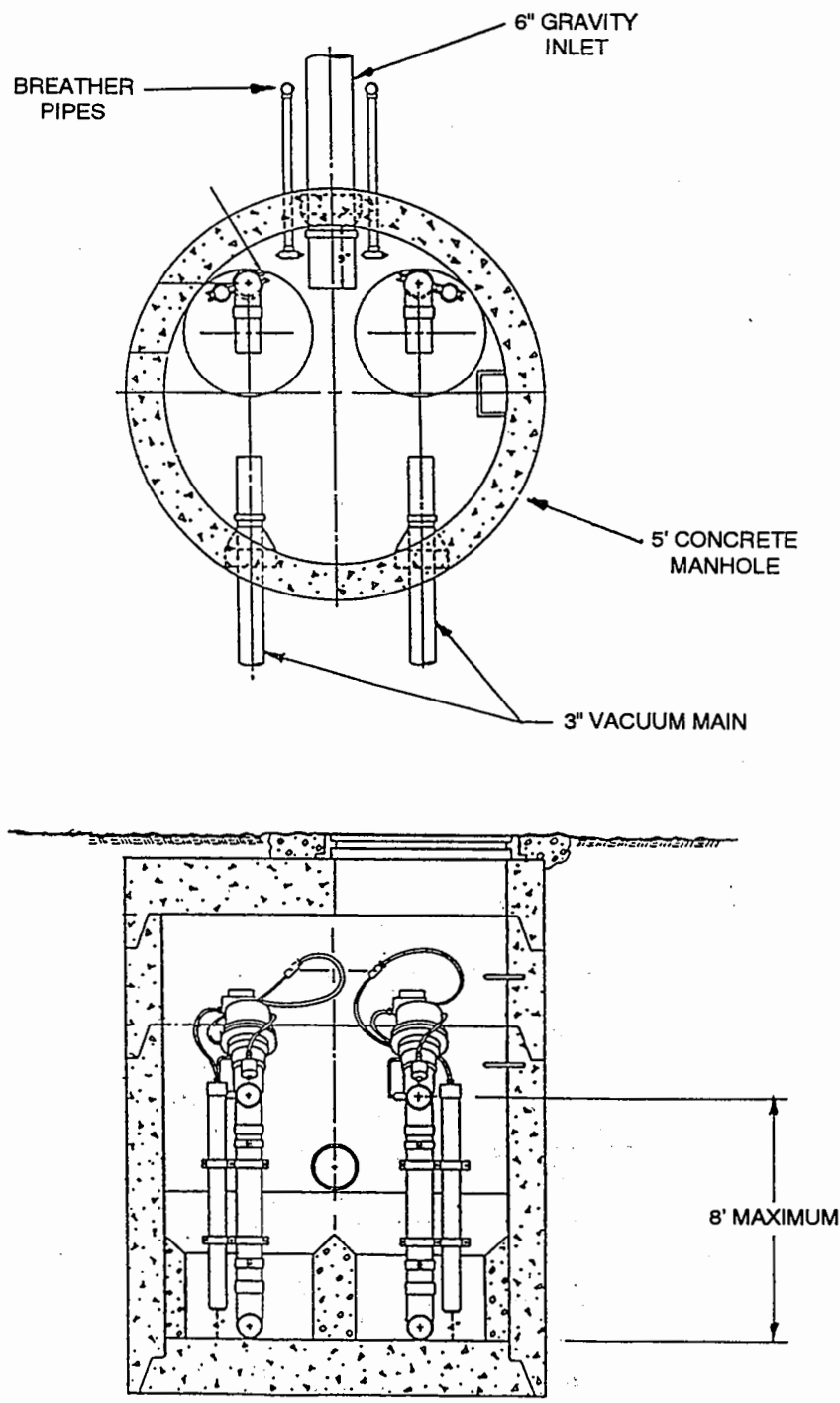


Figure 3-15. Typical concrete dual buffer tank. (Courtesy AIRVAC)



opening using vacuum from the downstream side of the valve. All materials of the valve are chemically resistant to normal domestic wastewater constituents and gases.

The controller/sensor is the key component of the valve. The device relies on three forces for its operation: pressure, vacuum, and atmosphere. As the wastewater level rises in the sump, it compresses air in the sensor tube. This pressure initiates the opening of the valve by overcoming spring tension in the controller and activating a three-way valve. Once opened, the three-way valve allows the controller/sensor to take vacuum from the downstream side of the valve and apply it to the actuator chamber to fully open the valve. The controller/sensor is capable of maintaining the valve fully open for a fixed period of time, which is adjustable over a range of 3-10 seconds. After the time period has elapsed, atmospheric air is admitted to the actuator chamber permitting spring assisted closing of the valve. All materials of the controller/sensor are fabricated from a plastic or elastomer that is chemically resistant to normal domestic wastewater constituents and gases.

Two type of vacuum valve are available: the Model D and the Model S. The valves in both arrangements are identical, but rely on a different piping/plumbing arrangement for their source of atmospheric air needed for proper controller operation.

a. Model D

The Model D arrangement gets atmospheric air through a tube which is connected to an external breather pipe (Figure 3-16).

The Model D arrangement is the most reliable since there is little chance of water entering the controller. However, some dislike this type of arrangement because of aesthetics and/or fear of vandalism to the external breather. Experience has shown that these are problems are relatively minor.

b. Model S

The Model S is a "sump-vented" arrangement. One of the three controller tubes is connected to the cleanout/sensor piping. This piping extends into the lower sump, which is connected to the building sewer. The building sewer is open to atmospheric air through the 10-cm (4-in) auxiliary vent (Figure 3-17).

While eliminating some of the concerns associated with the external breather, the Model S valve has some potential problems.

First, it is necessary that the sump be air and watertight. Should system vacuum at the valve be less than 13 cm

(5 in) Hg, the valve will not operate. Wastewater will continue to fill the sump. If the sump is watertight, it will become pressurized, with a "bubble" of air trapped at the top of the sump. When system vacuum is restored, the bubble of air will be used by the controller in the valve closing process. However, should water completely fill the bottom sump in the same scenario, the valve will open and stay open since it will lack the atmospheric air needed for closure. This open valve will cause a loss of system vacuum, which may affect other valves at different locations in a similar fashion.

Second, the installation of the homeowner's building sewer becomes more critical. A sag in the building sewer alignment will trap water and not allow the free flow of atmospheric air.

Some engineers have experimented with a blend of the two concepts, by utilizing a breather that gets its air from the top chamber. This has been successful in areas where there is no chance for surface water to enter the top chamber. The danger is that water may enter the top sump filling it to a level above the breather. This water will directly enter the controller and cause problems with valve closure. In either the Model D or the Model S valve, water in the top chamber would be of no concern, if the controller itself was watertight. However, this is not always the case if a problem has occurred. Since preventing water from entering the top chamber has proven to be a difficult task, venting from the top chamber is discouraged.

Because the Model D arrangement is less susceptible to problems than the Model S, it is the recommended type. Since the two valve are physically identical, it is possible to convert from a Model S to a Model D, and vice versa.

3.4.4.2 Appurtenances

a. External Breather

The external breather has been discussed in the previous section. An early version of this included a 38-mm (1.5-in) galvanized pipe extending 60-90 cm (2-3 ft) above ground near the valve pit setting (Figure 3-18). A breather dome is needed to prevent clogging from small insects. This size of pipe was necessary for self support. Smaller pipe has been used in concert with imbedded post support as well. Both arrangements have been successfully used in many operating vacuum systems, although some perceived problems with aesthetics and vandalism still exist. AIRVAC also offers an alternative external breather arrangement. This consists of 32-mm (1.25-in) polyurethane pipe that is anchored in the ground by concrete (Figure 3-19). This material is very flexible, making it virtually vandal proof. No matter what

Figure 3-16. Model D arrangement with external breather. (Courtesy AIRVAC)

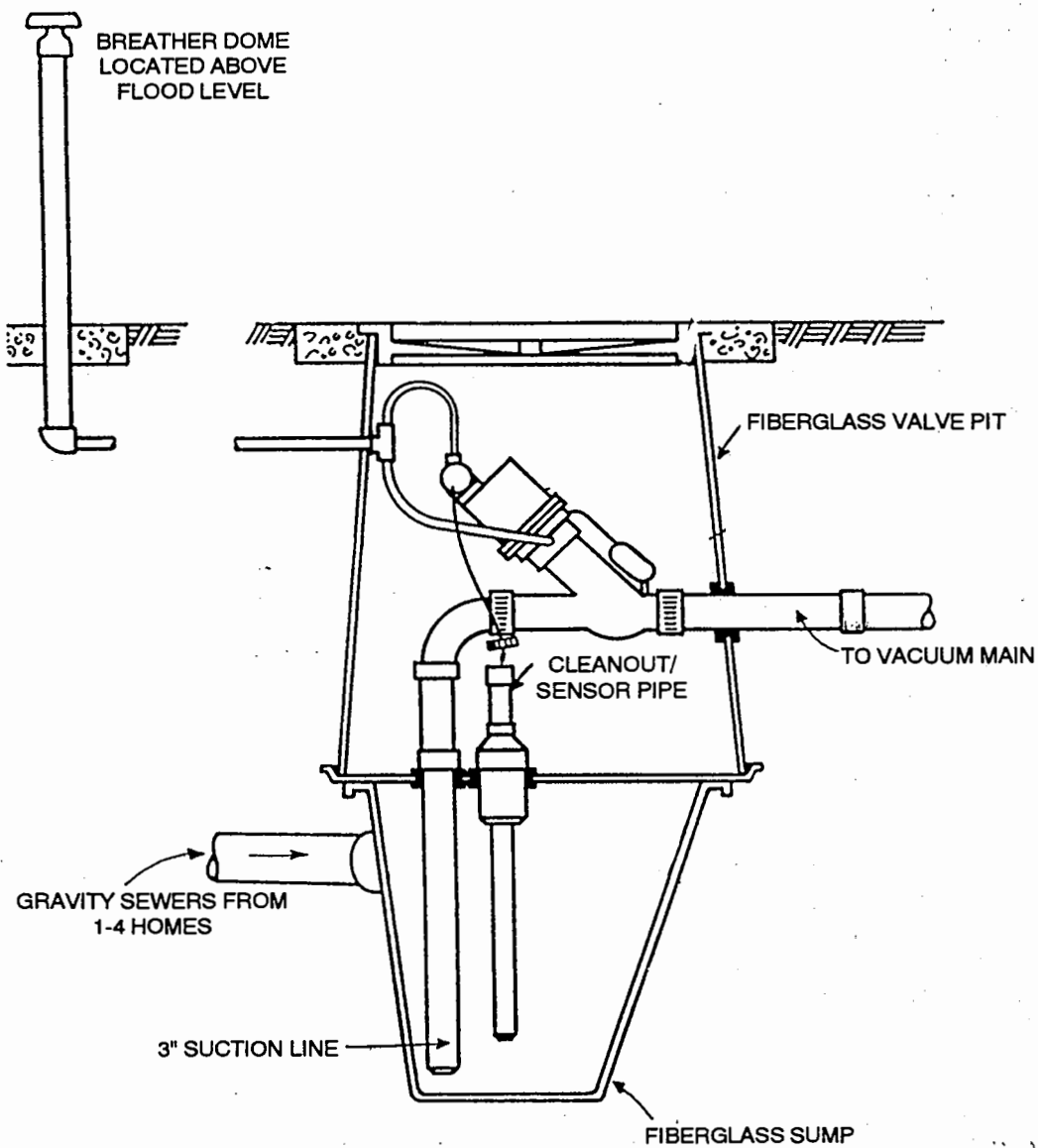


Figure 3-17. Model S arrangement - sump vented. (Courtesy AIRVAC)

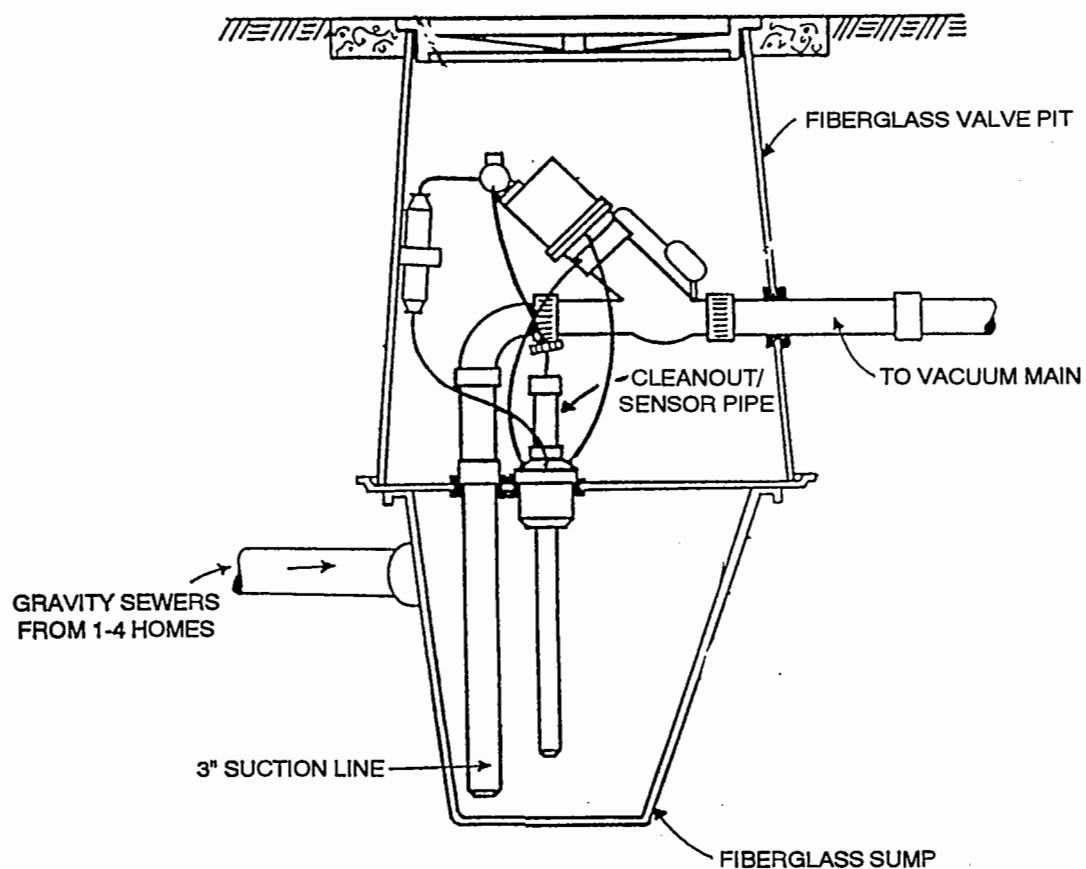


Figure 3-18. Early system external breather dial. (Courtesy AIRVAC)

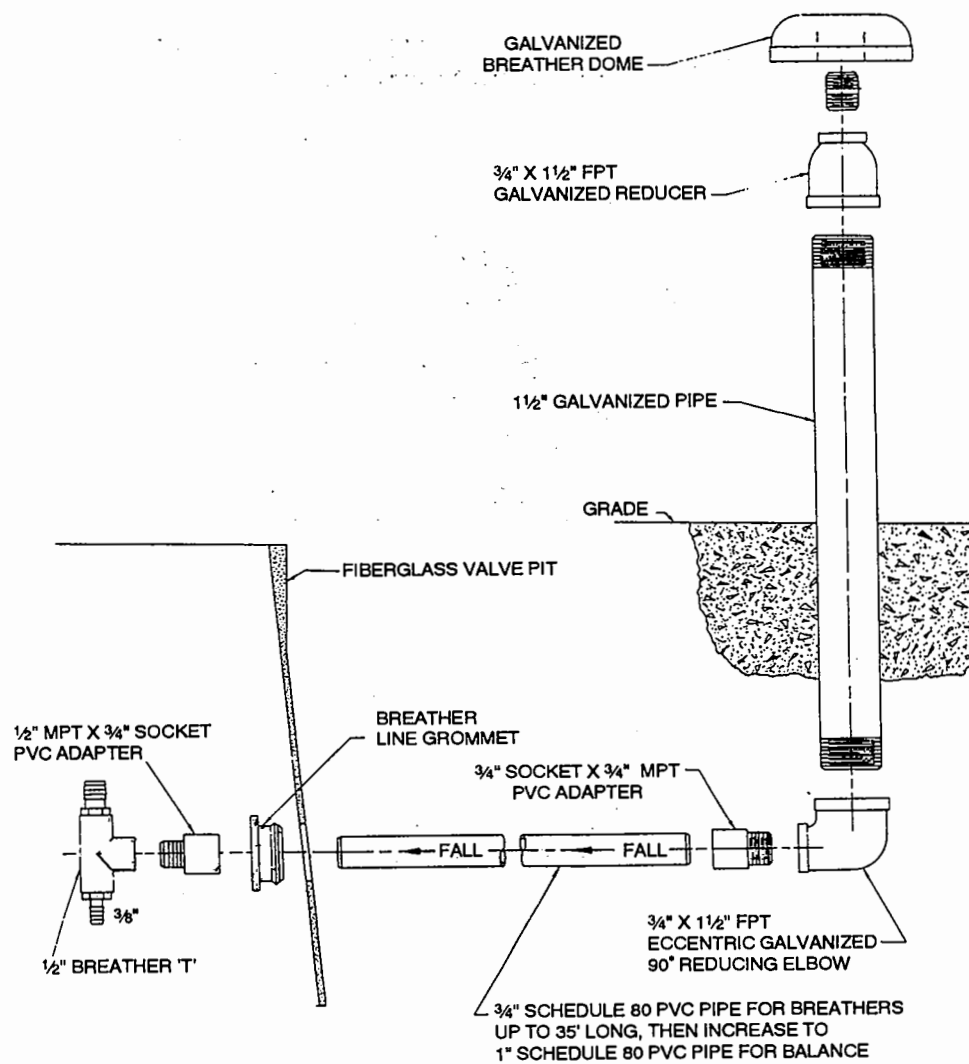


Figure 3-19. Early system external breather dial. (Courtesy AIRVAC)

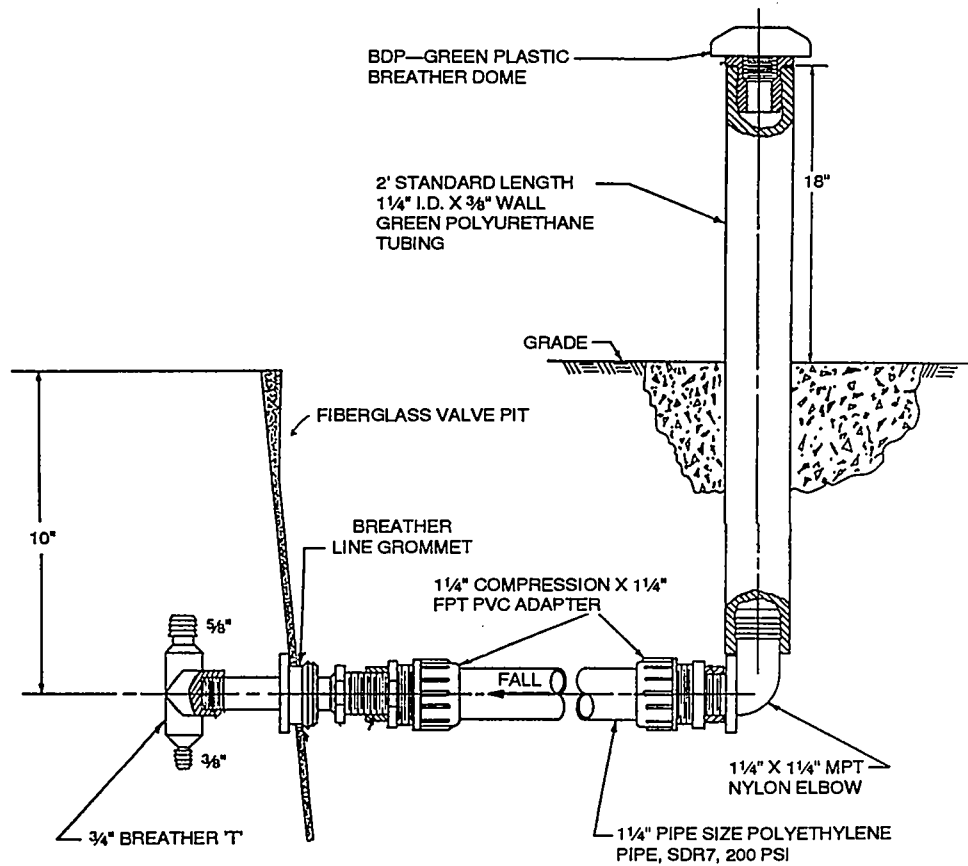
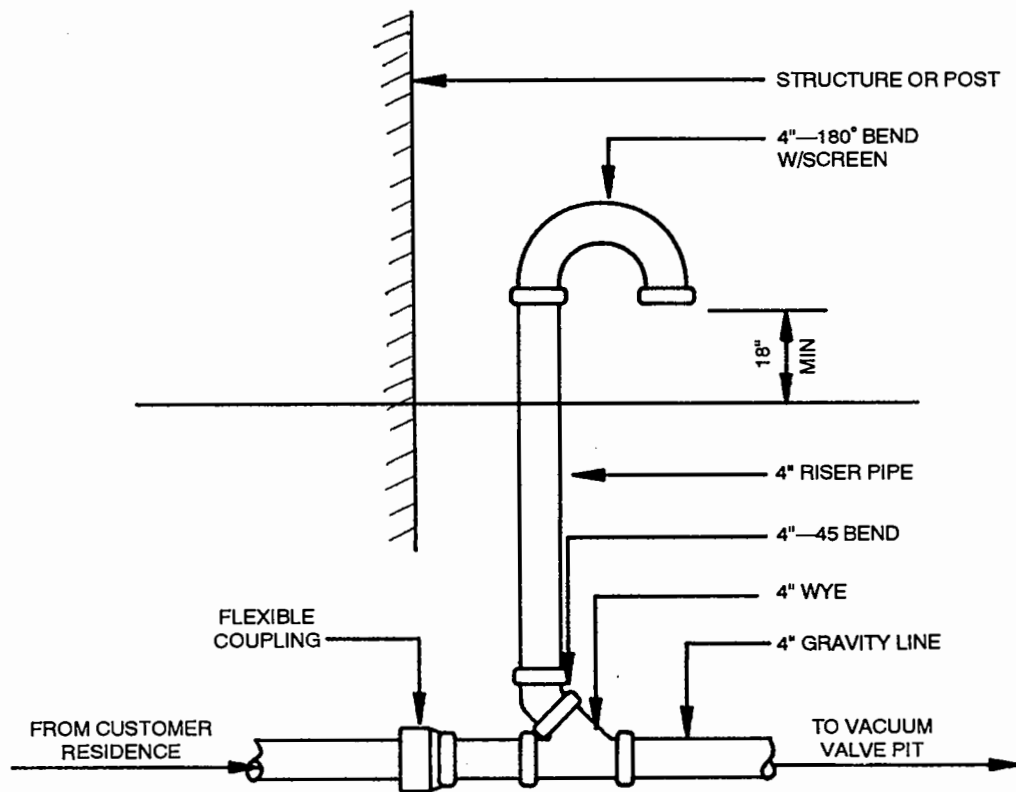


Figure 3-20. Auxiliary vent detail. (Courtesy AIRVAC)



arrangement is used, two items require attention. First, the entire breather piping system from the dome to the connection at the controller must be watertight. Second, the piping must slope toward the valve pit setting.

b. Auxiliary Vent

A 10-cm (4-in) PVC vent is required on the building sewer. Its purpose is to provide a sufficient amount of air to act as the driving force behind the liquid that is evacuated from the lower sump (see Section 1.3 for a discussion on system operation). With a Model S arrangement, a secondary function is to provide the necessary atmospheric air for proper controller operation.

The auxiliary vent is made of 10-cm (4-in) PVC pipe and fittings (Figure 3-20). Most entities require it to be located against a permanent structure, such as the house or a wall. To prevent valve freezing in cold climates, the vent should be a minimum of 6 m (20 ft) from the valve pit setting, thereby allowing the warmth from the wastewater time to warm the air.²

c. Cycle Counter

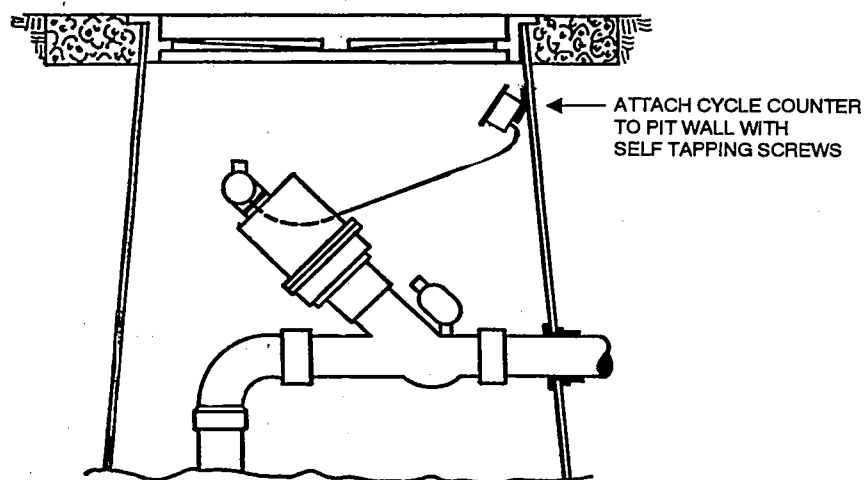
To monitor the number of valve cycles, a cycle counter is available.² This device is designed for mounting directly on the vacuum valve or the valve pit wall (Figure 3-21). The unit is enclosed in a watertight housing with a clear nylon top.

With this device, it is possible to monitor the number of cycles of a particular valve. Cycle counters typically are utilized where a large water use is expected in order to determine if the valve is reasonably capable of keeping up with the flow.

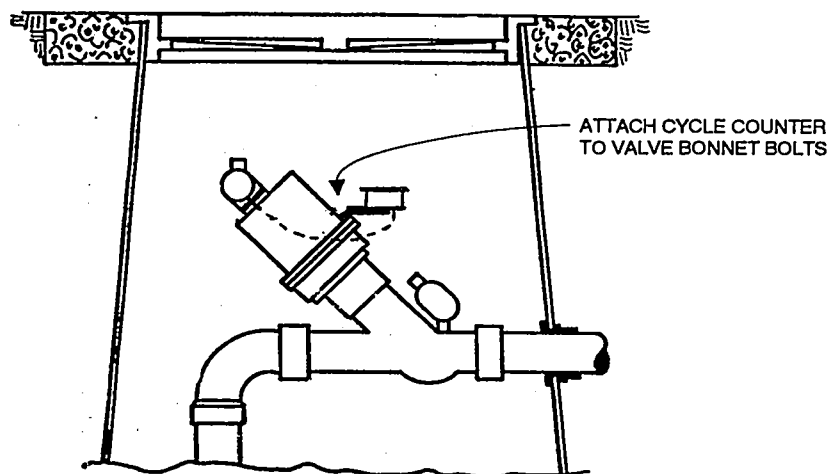
Some entities use the cycle counter as a metering device.⁵ Knowing the number of cycles and the volume approximate per cycle, one can estimate the amount of wastewater through the vacuum valve over a given period.

Others use the device as method of determining illegal storm connections to the vacuum sewer. The flow through

Figure 3-21. AIRVAC cycle counter - two methods of connection.



ON VALVE PIT WALL



ON VALVE

the valve can be estimated and compared to metered water use. From this, it is possible to determine if extraneous water is entering the vacuum sewer and generally in what amounts.

It is not necessary to have a cycle counter for each valve (unless they are being used as a metering device for billing purposes), as they are small and can easily be moved from location to location. It is recommended that the spare parts list include several cycle counters.

3.4.5 Division Valves and Cleanouts

3.4.5.1 Division Valves

Division valves are used on vacuum sewer mains much as they are on water mains. Plug valves and resilient-seated gate valves have both been successfully used, although care must be exercised in the selection process to insure reliability. Typical locations for division valves are at branch/main intersections, at both sides of a bridge crossing, at both sides of areas of unstable soil, and at periodic intervals on long routes. The intervals vary with the judgment of the engineers, but is typically 450-600 m (1,500-2,000 ft).

The valves should be capable of sustaining a vacuum of 60 cm (24 in) Hg. Contract specifications should call for a certified test from an independent laboratory to verify this.

AIRVAC recommends that the body, bonnet, closure element, and trunions be fabricated of cast iron equal to ASTM A126, Class B, with the closure element being covered with a precision molded Buna-N facing to act as the resilient seating surface; with a mating surface of 90 percent pure nickel polished to a 14 RMS finish.²

Valves 10 cm (4 in) and smaller may be directly actuated while all 15-cm (6-in) and larger valves should be provided with gear actuators.

The operating nuts should be of cast iron equal to ANSI A126 Class B. The connecting pin or key should be stainless steel. Aluminum nuts are not acceptable.

The valves should be installed in a valve box conforming to local codes, with the operating nut extended to a position where it is accessible with a standard valve wrench.

Recent designs have included a gauge tap, located on the downstream side of the division valve (Figure 3-22). Its purpose is to allow vacuum monitoring by one person in the field, rather than requiring two people (one to

operate the valve in the field and one to read the vacuum gauge at the vacuum station).

3.4.5.2 Cleanouts

Cleanouts, called access points in vacuum sewer terminology, have been used in the past. Their use is no longer recommended in systems with high valve density since access to the vacuum main can be gained at any valve pit. However, some state codes still require cleanouts to be installed at specified intervals. In these cases and in stretches where valves are non-existent, access points should be constructed similar to Figure 3-23.

3.4.6 Odors and Corrosion

There are few odor problems reported with vacuum sewers. There are three contributing factors responsible for this: 1) the system is sealed, 2) air is introduced in great volumes at each flow input, and 3) detention times are short.

The entire system, from the valve pit setting to the vacuum station, is sealed. The valve pit sump containing the wastewater should be tested for tightness both at the factory and in the field after installation. The piping system contains no air releases. The collection tank at the vacuum station, into which all of the sewer mains empty, is a vacuum-tight vessel.

There is a large amount of air introduced into the system at each valve pit setting. The air to liquid ratio, by volume, typically is 2:1 or higher. This amount of air aids in the prevention of septic wastewater.

The typical valve cycle volume is about 38 L (10 gal). This small volume results in frequent valve cycles. Once in the main, the wastewater travels at velocities in excess of 4.5 m/s (15 fps). Also, the relative liquid to air volume in the main is quite low. These factors result in a short detention time, which also aids in the prevention of septic wastewater.

The one exception to the above discussion on odors occurs when concrete buffer tanks are used. Unlike the fiberglass settings, these tanks are open from the sump to the top of the pit. Operating personnel must be careful of sewer gas buildup in these tanks when performing maintenance, although the volume of wastewater present in the tank usually is not large enough to produce dangerous levels of hydrogen sulfide. Also, these types of tanks typically are used to attenuate large flows, allowing the wastewater more time to turn septic. This does not present a problem in the mains, since the sealed PVC piping is unaffected by septic wastewater.

Figure 3-22. Division valve with gauge tap detail.

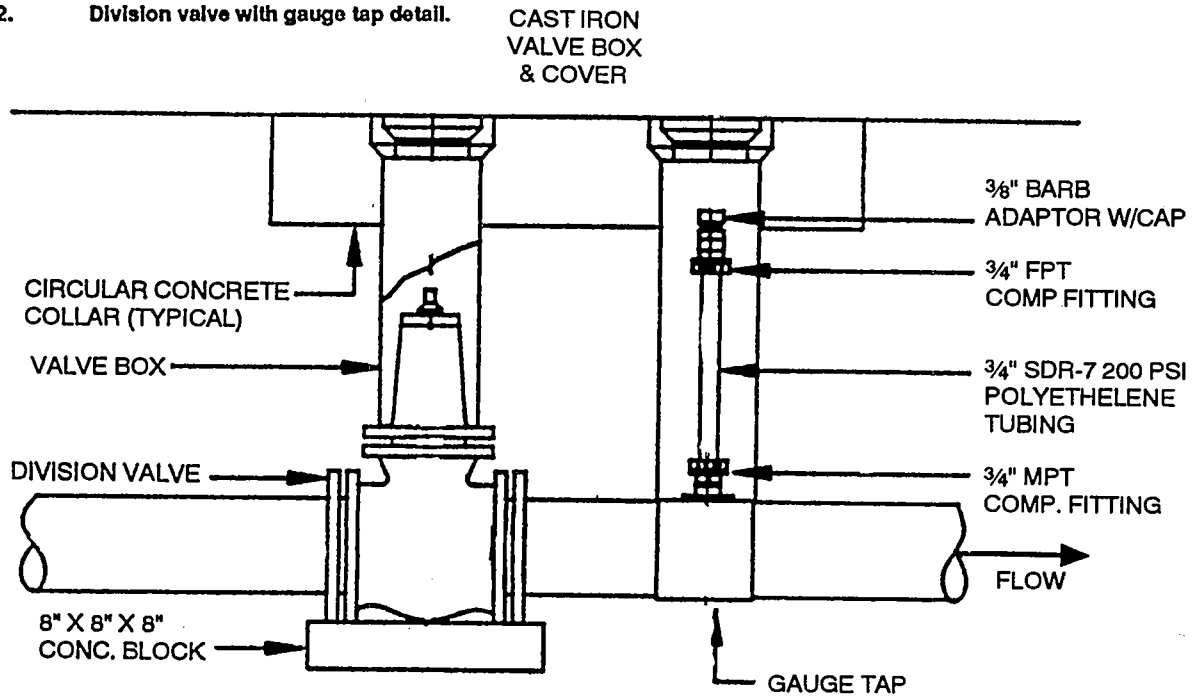
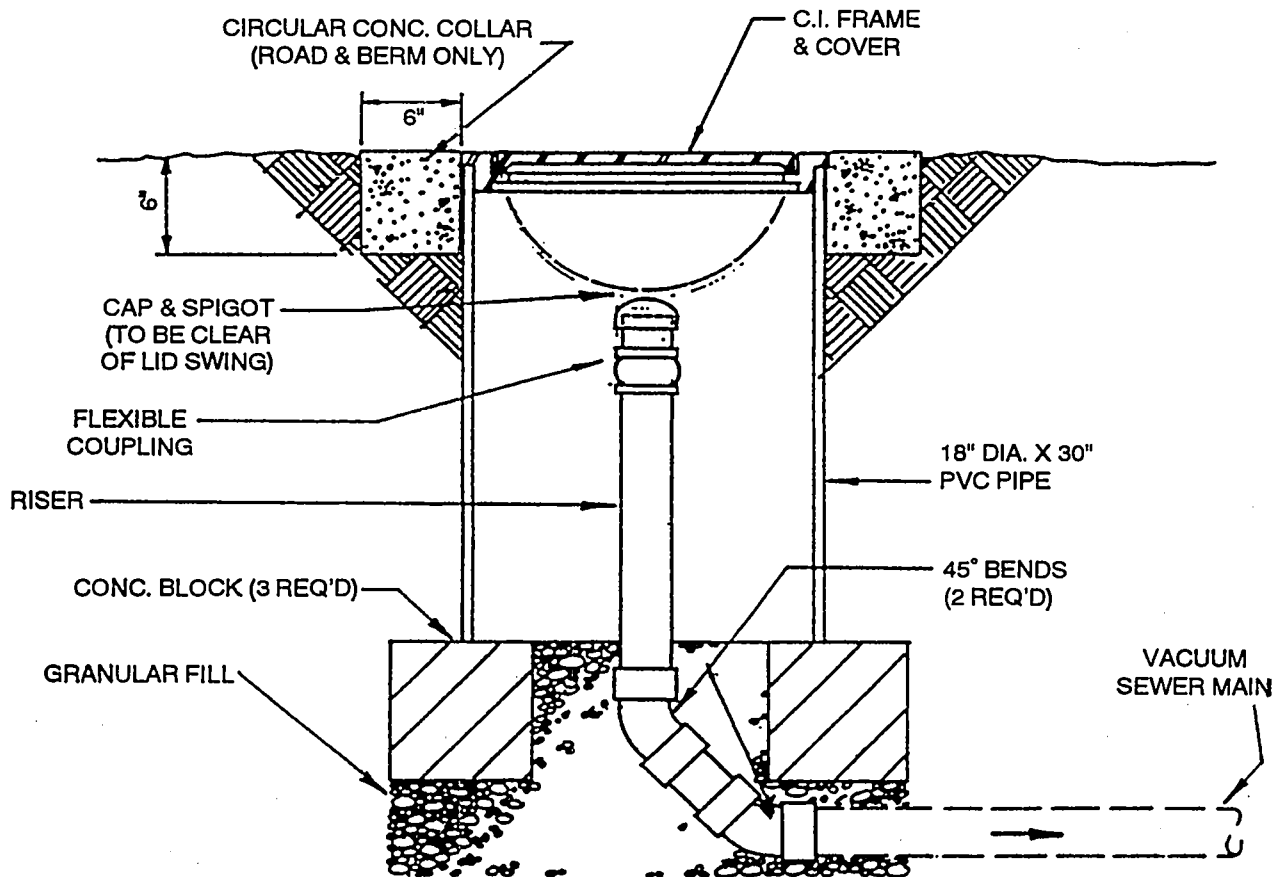


Figure 3-23. Terminal access point detail.



All of the system parts in contact with wastewater are either PVC, ABS, FRP, rubber, or stainless steel, which are corrosion resistant.² As such, corrosion has not been a problem in vacuum sewers.

The accumulation of grease is a cause for concern in conventional lift stations as well as in vacuum stations. Grease builds up on level controls and on the sides of the vacuum collection tank. Greasetraps are typically required in applications such as restaurants to minimize these problems.

Grease has not presented problems in vacuum sewer mains. When the wastewater is evacuated from the sump, the suction generally pulls floatable grease into the vacuum mains. Since the wastewater moves through the mains at high velocities, there is little opportunity for grease in the sewer to build up in the system to any level which could cause a blockage.

3.4.7 Vacuum Station Design

Nomenclature used in the station design is given below:

Term	Definition
Q_{\max}	Station peak flow (gpm)
Q_a	Station average flow (gpm)
Q_{\min}	Station minimum flow (gpm)
Q_{dp}	Discharge pump capacity (gpm)
Q_{vp}	Vacuum pump capacity (cfm)
V_o	Collection tank operating volume (gal)
V_{ct}	Collection tank volume (gal)
V_{rt}	Reservoir tank volume (gal)
t	System pump-down time (min)
V_p	Piping system volume (gal)
V_t	Total system volume (gal)
TDH	Total dynamic head (ft)
H_s	Static head (ft)
H_f	Friction head (ft)
H_v	Vacuum head (ft)

3.4.7.1 Vacuum Pumps

Vacuum pumps may be either the sliding-vane or the liquid-ring type. In either case, the pumps should be air-cooled and have a minimum (ultimate) vacuum of 74.4 cm (29.3 in) Hg at sea level. The pumps should be capable of continuous operation. Duplicate pumps, each capable of delivering 100 percent of the required air flow, should be provided.

To size the vacuum pumps, the following empirical equation has been successful:

$$Q_{vp} = A Q_{\max} / 7.5 \text{ gal/cu ft}$$

"A" varies empirically with mainline length as shown in Table 3-8.¹ The minimum recommended vacuum pump size is 70 L/s (150 cfm).

Lubrication should be provided by an integral, fully recirculating oil supply. The oil separation system should also be integral. The entire pump, motor, and exhaust should be factory assembled and tested with the unit mounted on vibration isolators, and should not require special mounting or foundation considerations.

3.4.7.2 Discharge Pumps

Duplicate pumps, each capable of delivering the design capacity at the specified TDH should be used.

Each pump should be equipped with an enclosed, non-clog type, two port, grey iron impeller, statically and dynamically balanced, capable of passing a 7.5-cm (3-in) sphere. The impeller should be keyed and fastened to a stress proof steel shaft by a stainless steel lock screw or locknut. Pumps should have an inspection opening in the discharge casing.

A certification from the pump manufacturer that the pumps are suitable for use in a vacuum sewerage installation is strongly recommended.

Equalizing lines are to be installed on each pump. Their purpose is to remove air from the pump and equalize the vacuum across the impeller.¹ Clear PVC pipe is recommended for use as small air leaks and blockages will be clearly visible to the system operator. On small discharge pumps (generally less than 100 gpm), the equalizing lines should be fitted with motorized full port valves which close when the pumps are in operation.

To size the discharge pumps, use the following equation:

$$Q_{dp} = Q_{\max} = Q_a \times \text{Peak Factor}$$

(Typical peak factors are 3-4.)

The TDH is calculated using the following equation:

$$\text{TDH} = H_s + H_f + H_v$$

TDH is calculated using standard procedures for force mains. However, head attributed to overcoming the vacuum in the collection tank (H_v) must also be considered. This value is usually 7 m (23 ft), which is roughly equivalent to 50 cm (20 in) Hg (typical upper operating value). Since H_v will vary depending on the tank vacuum level (40-50 cm [16-20 in] Hg, with possible operation at much lower and higher levels during problem periods), it

Table 3-8. "A" Factor for Use in Vacuum Pump Sizing

Longest Line Length (ft)	A
0-3,000	5
3,001-5,000	6
5,001-7,000	7
7,001-10,000	8
>12,000	11

is prudent to avoid a pump with a flat capacity/head curve.

Where possible, horizontal wastewater pumps should be used, as they have smaller suction losses compared to vertical pumps. To reduce the risk of vortexing in the collection tank, the pump suction line should be 5 cm (2 in) larger than the discharge line. Wastewater pump shafts should be fitted with double mechanical shaft seals with the seal chamber pressurized with light oil.

Net positive suction head (NPSH) calculations are important in the discharge pump selection process. In Nomenclature and typical values used in the NPSH calculations are given in Table 3-9.

To calculate $NPSH_a$, use the following equations:

$$NPSH_a = h_{avl} + h_s - h_{vpa} + h_{eq}$$

$$h_{avl} = h_a - V_{max}$$

$NPSH_a$ must be greater than $NPSH_r$. $NPSH_a$ and TDH should be calculated for both the high and low vacuum operating levels and compared to the $NPSH_r$ at the corresponding point on the head/capacity curve. Figure 3-24 is a diagram for calculation of $NPSH_a$ in a vacuum system.

3.4.7.3 Vacuum Tanks

Two vacuum tanks are required by AIRVAC for each custom station: the collection tank and the reservoir tank. Other manufacturers may not require the reservoir tank. Basic construction of the tanks is similar, differing only in size, shape, and type and location of the openings. Both steel and fiberglass tanks are acceptable. Steel tanks should be of a welded construction and fabricated from not less than 6-mm (1/4-in) thick steel plates. The tanks should be designed for a working pressure of 50 cm (20 in) Hg vacuum and tested to 71 cm (28 in) Hg vacuum.

Each tank should be furnished with the required number and size of openings, manways, and taps, as shown on

Table 3-9. Discharge Pump NPSH Calculation

Term	Definition	Typical Value
$NPSH_a$	Net positive suction head available, ft	-
h_a	Head available due to atmospheric pressure, ft	33.9 @ Sea level 33.2 @ 500 ft 32.8 @ 1,000 ft 29.4 @ 4,000 ft
h_{avl}	Head available due to atmospheric pressure at liquid level less vacuum in collection tank, ft	-
V_{max}	Maximum collection tank vacuum, ft	18.1 @ 16-inHg 22.6 @ 20-inHg
h_s	Depth of wastewater above pump centerline, ft	1.0 (min.)
h_{vpa}	Absolute vapor pressure of wastewater at its pumping temperature, ft	0.8
h_f	Friction loss in suction pipes, ft	2.0 (vert. pump) 0.0 (hor. pump)
h_{eq}	Vacuum equalizing head provided by 1-in equalizing lines, ft	3.0 (min.)
$NPSH_r$	Net positive suction head required by the pump selected, ft	-

the plans. The tanks should be sand-blasted and painted as follows:

- **Internally:** One coat of epoxy primer and two coats of coal tar epoxy.
- **Externally:** One coat of epoxy primer and one coat of epoxy finish.

Each tank should be supplied complete with sight glass and its associated valves. Fiberglass tanks may be substituted using the same specifications. Fiberglass tanks are to have 1,000-kPa (150-psi) rated flanges.

The operating volume of the collection tank is the wastewater accumulation required to restart the discharge pump. It usually is sized so that at minimum design flow the pump will operate once every 15 minutes. This is represented by the following equation:

$$V_o = 15 (Q_{min}/Q_{dp}) (Q_{dp} - Q_{min})$$

where:

$$Q_{min} = Q_a/2$$

$$Q_{dp} = Q_{max} = Q_a \times \text{Peak Factor}$$

Figure 3-24. NPSHa calculation diagram with typical values. (Courtesy AIRVAC)

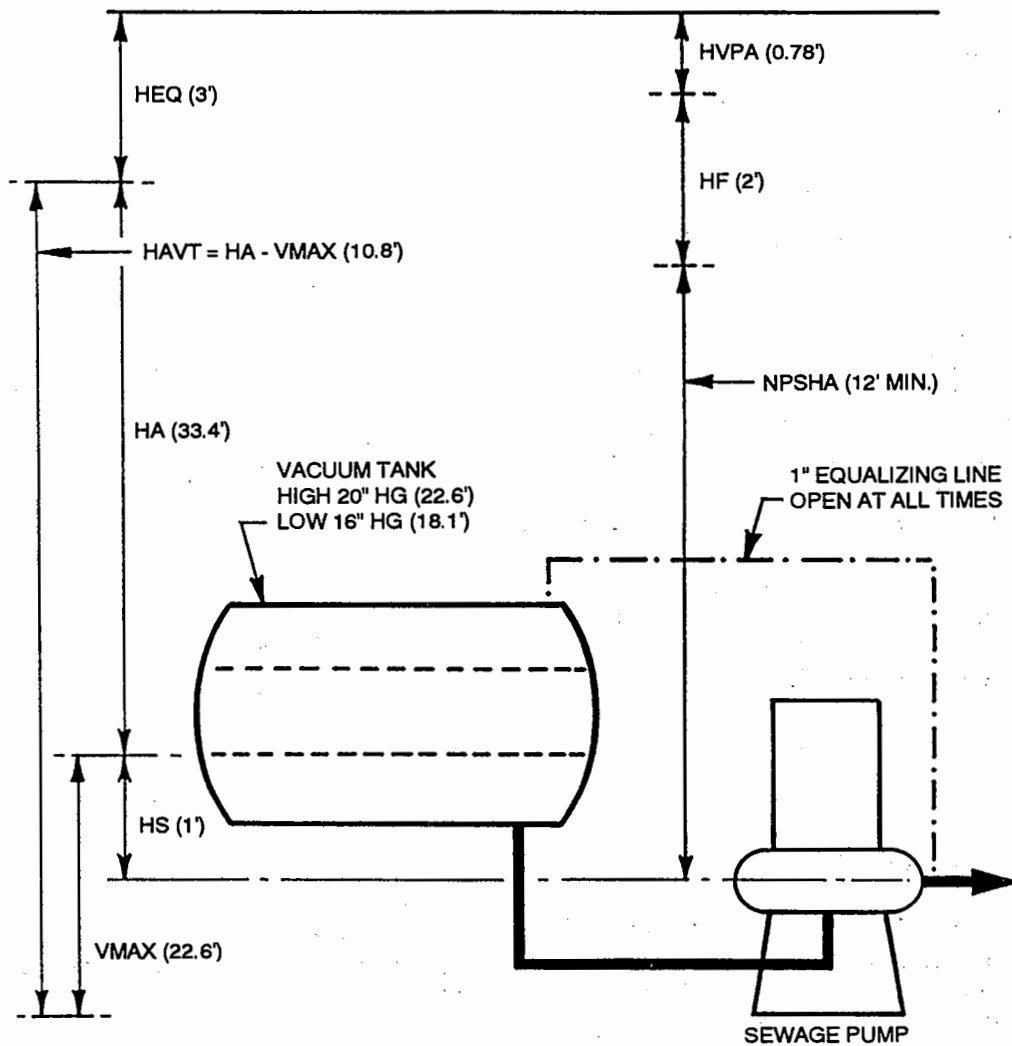


Table 3-10. Values of V_o for a 15-Minute Cycle at Q_{min} for Different Peaking Factors

Peaking Factor	V_o
3.0	$2.08 \times Q_{max}$
3.5	$1.84 \times Q_{max}$
4.0	$1.64 \times Q_{max}$

Table 3-10 gives the value of V_o for a 15-minute cycle at Q_{min} for different peaking factors. The total volume of the collection tank should be 3 times the operating volume ($V_t = 3V_o$), with a minimum recommended size of 1,500 L (400 gal).

After sizing the operating volume, the designer should check to ensure an excessive number of pump starts per hour will not occur. This check should be performed for a wastewater inflow equal to one-half the pump capacity.

When designing the collection tank, the wastewater pump suction lines should be placed at the lowest point on the tank and as far away as possible from the main line inlets. The main line inlet elbows inside the tank should be turned at an angle away from the pump suction openings.

The recommended size of the reservoir tank for most applications is 1,500 L (400 gal). In special cases, it may be larger.

After the vacuum pump, collection tank, and reservoir tank are sized, system pump-down time for an operating range of 40-50 cm (16-20 in) Hg should be checked.¹ This calculation will show the amount of time it will take the selected vacuum pumps to evacuate (pump-down) the collection piping from 40-50 cm (16-20 in) Hg. This equation is shown below:

$$t = 0.045 [(2/3)(V_p) + (V_\alpha - V_o) + V_{rt}] / Q_{vp}$$

where:

- t = System pump-down time (min)
- V_p = Volume of collection system piping (gal)
- V_α = Volume of collection tank (gal)
- V_o = Operating volume of collection tank (gal)
- V_{rt} = Volume of reservoir tank (gal)
- Q_{vp} = Vacuum pump capacity (cfm)

In no case should "t" be greater than 3 minutes or less than 1 minute. If greater than 3 minutes, the capacity of the vacuum pumps should be increased and if less than 1 minute, the size of the reservoir tank should be increased.

3.4.7.4 Standby Generator

The standby generator should be capable of providing 100 percent of standby power required for the station operation. It typically is located inside the station, although generators located outside the station in an enclosure and portable generators are also acceptable.

3.4.7.5 Station Piping

This item includes piping, valves, fittings, pipe supports, fixtures, drains, and other work involved in providing a complete installation.

Station piping includes all piping within the station, connecting piping to the vacuum reservoir tank, collection tank, vacuum sewer lines, and force mains.

Wastewater, vacuum, and drain lines larger than 10 cm (4 in) should be cast iron, ANSI B16.1, 860 kPa (125 psi) for exposed installations. For buried installations, mechanical joint, ANSI A21.11, AWWA C111, cast iron should be used. Fittings should be flanged and mechanical joint as appropriate (ANSI AS1.10, AWWA C110). Red rubber gaskets 3-mm (1/8-in) in thickness should be used on all flanges. Vacuum lines as well as other lines under 10 cm (4 in) should be Schedule 80 PVC. Building sanitary drains are to be PVC DWV pipe and fittings.

The piping should be adequately supported to prevent sagging and vibration. It also should be installed in a manner to permit expansion, venting, and drainage.

For fiberglass tanks, all piping must be supported so that no weight is supported by the tank flanges. Flange bolts should only be tightened to the manufacturer's recommendations. Provisions must be allowed for inaccurate opening alignment.

All shut-off valves fitted within the collection station should be identical to those used in the collection system piping, with the exception that they be flanged.

Check valves fitted to the vacuum piping are to be of the 57-kg (125-lb) bolted bonnet, rubber flapper, horizontal swing variety. Check valves are to be fitted with Buna-N soft seats.

Check valves fitted to the wastewater discharge piping are to be supplied with an external lever and weight to ensure positive closing. They also should be fitted with soft rubber seats.

On the upstream side of each side of each vacuum sewer isolation valve, a vacuum gauge of not less than 11 cm (4.5 in) in diameter should be installed. Gauges should be positioned so that they are easily viewed when the

isolation valves are operated. Diaphragm seals should not be used with compound gauges.

3.4.7.6 Motor Control Center

The Motor Control Center (MCC) is to be manufactured, assembled, wired, and tested by the factory in accordance with the latest issue of NEMA Publication ISC2-322, for Industrial Controls and Systems. The vertical section and the individual units shall bear a UL label, where applicable, as evidence of compliance with UL Standard 845.

Wiring inside the MCC is to be NEMA Class II, Type B. Where Type B wiring is indicated, the terminal blocks should be located in each section of the MCC.

The enclosure should be NEMA Type 12-with-Gasketed Doors. Vertical sections shall be constructed with steel divider side sheet assemblies formed or otherwise fabricated to eliminate open framework between adjacent sections or full-length bolted-on side sheet assemblies at ends of the MCC.

The MCC should be assembled in such a manner that it is not necessary to have rear accessibility to remove any internal devices or components. All future spaces and wireways are to be covered by blank doors.

3.4.7.7 Level Controls

The discharge pumps and alarms are controlled by seven probes inside the collection tank. These probes are 6-mm (1/4-in) stainless steel with a PVC coating. The seven positions are:

1. Ground probe
2. Both discharge pumps stop
3. Lead discharge pump start
4. Lag discharge pump start
5. High level alarm
6. Reset for probe #7
7. High level cut-off: stops all discharge pumps (auto position only) and vacuum pumps (auto and manual positions)

Figure 3-25 presents approximate elevations of these probes in the collection tank relative to the discharge pumps and incoming vacuum mains.

An acceptable alternative to the seven probes is a single capacitance-inductive type probe capable of monitoring all seven set points. This type of probe requires a transmitter/transducer to send a 4-20 mA signal to the MCC.

3.4.7.8 Telephone Dialer

A voice communication-type automatic telephone dialing alarm system should be mounted on a wall adjacent to the MCC. The system should be self-contained and capable of automatically monitoring up to four independent alarm conditions.

The monitoring system shall, upon the opening of any one alarm point, access the telephone lines, wait for the dial tone, and begin to dial the first of four field programmed telephone numbers. The system will then deliver a voice message indicating a two digit station number and the fault status at that station. The message will be repeated a preset amount of times with sufficient space between messages to allow the called individual to acknowledge receipt of the call. Acknowledgment of the message is accomplished by pressing a touch tone star (*) key on the telephone between messages. Following the acknowledgment, the system will vocalize a sign-off and hang up. The system then enters a 30-minute delay to allow adequate time for follow-up measures to be taken.

If, during the delay, another fault occurs, the system will begin recalling. Additionally, the system can be called at any time from a standard telephone, whereupon it will answer the call and deliver a vocalized message indicating the station number and fault status at the location.

If the delay elapses and faults still exist, the system will begin dialing in 1-minute intervals attempting to deliver the fault message. If no acknowledgment is received, the system will hang up, wait 60 seconds, and call the next priority number. After dialing the last priority number, the system will, if necessary, return to the first priority number and repeat the sequence indefinitely.

If the monitoring system is to be housed in the MCC, provisions must be made to isolate the system from interference.

The monitoring system should be provided with continuously charged batteries for 24 hours standby operation in the event of a power outage.

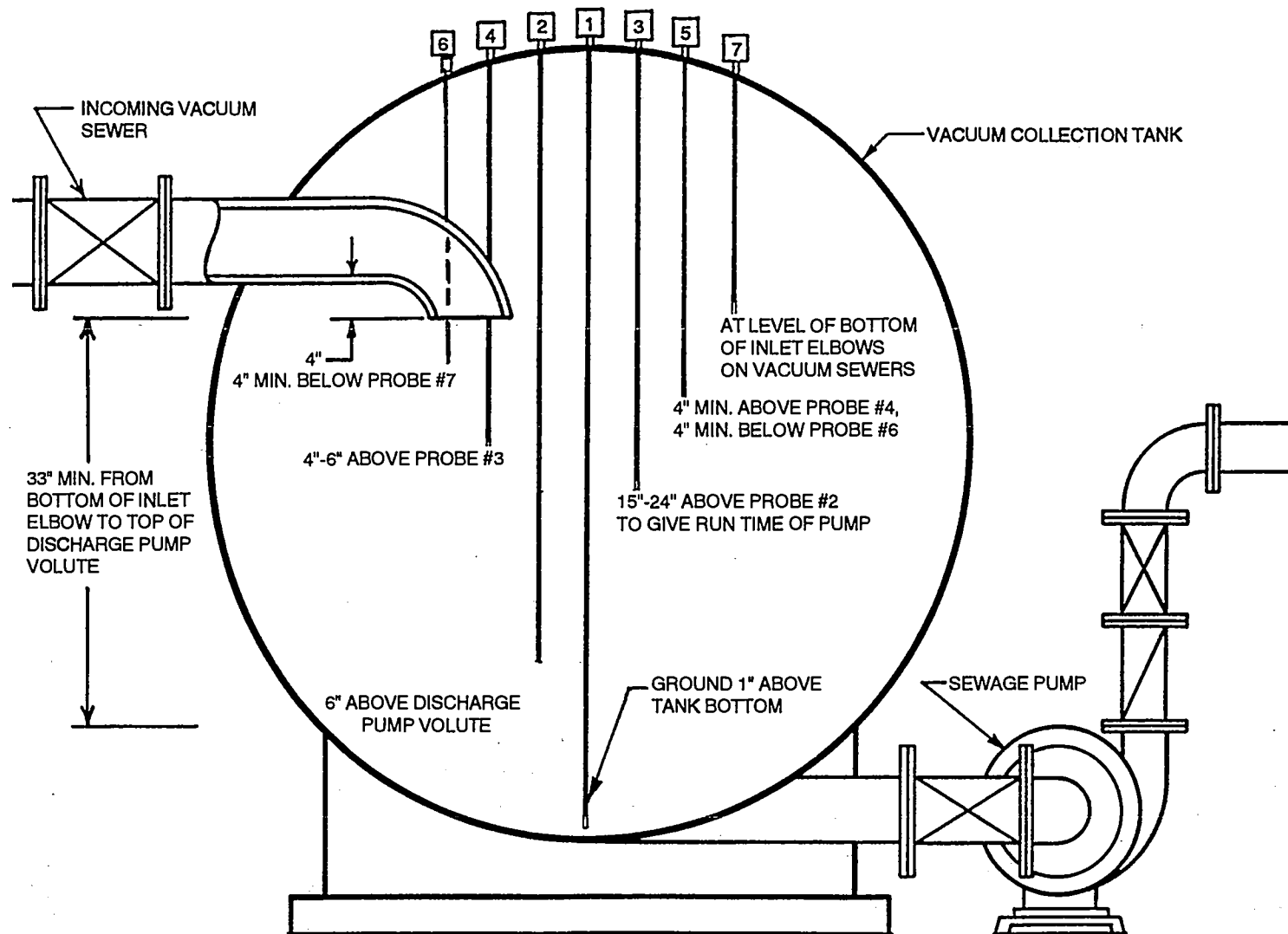
3.4.7.9 Vacuum Gauges

All vacuum gauges should be specified to have a stainless steel bourdon tube and socket to be provided with 13-mm (1/2-in) bottom outlets. Polypropylene or stainless steel ball valves should be used as gauge cocks.

Vacuum gauges should be provided at the following locations¹:

- On the side of the vacuum reservoir tank in a position that is easily viewed from the entrance door.

Figure 3-25. Typical elevations of level control probes. (Courtesy AIRVAC)



- On the collection tank in a position that is easily viewed from the stairway leading to the basement.
- On each incoming main line to the collection tank, immediately upstream of the isolation valve on the line. These gauges should be in a position above the incoming main lines that is easily viewed from the operating position of the isolation valves.

The connection from the incoming main lines to the vacuum gauges should be made of PVC or CPVC pipe. Copper pipe is not to be used for this purpose.

3.4.7.10 Vacuum Recorder

The MCC should contain a 7-day circular chart recorder with a minimum chart diameter of 30 cm (12 in). The recording range should be 0-75 cm (0-30 in) Hg vacuum, with the 0 position at the center of the chart. The chart recorder should have stainless steel bellows.

3.4.7.11 Sump Valve

The basement of the vacuum station should be provided with a 38 cm x 38 cm x 30 cm (15 in x 15 in x 12 in) deep sump to collect washdown water. This sump will be emptied by a vacuum valve that is connected by piping to the collection tank. A check valve and eccentric plug valve should be fitted between the sump valve and the collection tank.

3.4.7.12 Spare Parts Inventory

For optimum operating efficiency, it is necessary that a sufficient inventory of spare parts be kept. Some of the spare parts, such as fittings and pipe, can be purchased through local builder's supply companies. However, there are parts that are unique to vacuum systems that cannot be purchased locally. Typically, these spare parts are included as part of the construction contract. Table 3-11 is a recommended list of spare parts that should be supplied to the owner during the construction phase.

In addition to spare parts, certain specialty maintenance tools and equipment are needed and are listed in Table 3-12.

The vacuum station also requires spare parts. These range from spare pump seals to fuses. Specialty items that should be considered are given in Table 3-13.

Especially vital for the vacuum station are spare microprocessor based electronic components. This type of equipment is used for the level controls and the fault monitoring systems and is very sensitive to power spikes. These system components are vital to the station, as they essentially operate and monitor the system. Losing level controls to some type of failure will quickly cause severe operational problems, such as loss of vacuum or

discharge pump malfunctions. Not having spare equipment amplifies the problem since this would require the system to be operated manually. This would require an operator on a continual basis (until the spare part arrived) to cycle both the vacuum pumps and the wastewater pumps manually. Loss of the fault monitoring system also results in significant O&M increases, as witnessed by early system problems before such systems were included in the vacuum station designs. Similarly, response time to system malfunctions will be extended.

3.5 Construction Considerations

Construction of a vacuum sewer system is similar to conventional systems. Utilizing small diameter pipes in shallow trenches and having the ability to avoid underground obstacles virtually at will makes this type of construction attractive to contractors. There are, however, certain inherent construction problems associated with vacuum sewers.

It is imperative that inspection be performed by those with a thorough knowledge of vacuum sewer technology. The design of the system and its hydraulic limits must be understood by at least one member of the construction team.

3.5.1 Pipeline Construction

The use of chain-type trenchers is sometimes specified for service line installation where soil types allow, as they cause less disruption to the property owner's yard than does a backhoe. Rocky soils and some clayey soils that will not self clean from the trencher teeth may be impractical to excavate using a trencher.

Street crossings are often accomplished by the bore method in which an auger is used and a steel casing is pushed in the resulting opening under the street. The casing acts as a sleeve for the service line that is installed inside. Other street crossings are "free bored" by the use of a "hog". Open cutting of the street is done where boring is impractical.

Vacuum service lines are buried a minimum of 75 cm (30 in), since the vacuum line that exits the valve pit does so at a depth of 68 cm (27 in).

Many contractors use a backhoe for the service line excavation, since this same equipment is also required for the excavation of the valve pit, which typically is located close to the main sewer. Many times this results in over-excavation of the service line trench. Over-excavation, coupled with the use of fittings which are typically required between the valve pit and main, can

Table 3-11. Spare Parts List Per Every 50 Valves

2 each	Vacuum valves
4 each	Controllers/sensors
2 each	Sensor/cleanout tubes
2 each	Controller/sensor rebuilding kit
5 each	Valve cycle counters
4 each	Three-inch "no hub" couplings
2 each	Valve pits
2 each	Valve pit bottom plates
1 each	Standard collection sump
1 each	Deep collection sump
2 each	Valve pit covers
5 ft	Clear valve tubing: 3/8-in.
10 ft	Breather tubing: 5/8-in.

Table 3-12. Specialty Tools and Equipment for Collection Systems

1 each	Portable vacuum pump
2 each	Portable vacuum chart recorders
100 each	Vacuum charts
3 each	Chart pens
2 each	0-20 in W.G. magnehelic gauges
2 each	0-50 in W.G. magnehelic gauges
1 each	12 VOLT DC submersible pump
15 ft	Pump discharge hose
2 each	No-hub torque wrenches
2 each	Vacuum gauges
1 each	Flexible mercury manometer
1 each	Controller test box
1 each	Pipe locator

Table 3-13. Specialty Equipment for Vacuum Station

1 each	Inductance probe
1 each	Probe transmitter
1 each	Probe microprocessor card
2 each	Vacuum switch
2 each	Vacuum gauge
1 each	Auto dialer microprocessor card

lead to future problems if proper bedding and backfill materials are not used.

Since the native material and intended contractor equipment are not always known, it is recommended that the contract documents specify surrounding the service line with imported pipe zone backfill.

3.5.1.1 Line Changes

Unforeseen underground obstacles are a reality in sewer line construction. Water and gas lines, storm sewers, and culverts at unanticipated locations all may present difficulties during construction. Natural underground conditions, such as rock, water, or sand also may present more problems than anticipated.

With the "straight line, constant grade" nature of gravity sewer construction, these obstacles usually result in field changes. These field changes might include installing an additional manhole and/or removing and relaying part of the pipe at a different grade. The grade change could affect the depth and grade of the entire gravity sewer system. Another lift station may have to be installed. Alterations at the treatment plant could be required. Unfortunately, this scenario is all too common. The end result is an increase in contract price through change orders.

One key advantage of vacuum sewers is the flexibility they allow for line changes during construction. Unforeseen underground obstacles usually can be avoided simply by going under, over, or around them. There may be cases where line changes will be necessary, due to hydraulic limitations. However, the likelihood of this is greatly reduced when compared to conventional gravity sewers.

One must be very careful not to make a change for the sole sake of making construction easier. Every line change should be carefully evaluated for its effect on the performance of the overall system. Will the change increase the amount of lift in the system (and ultimately result in increased power costs)? Will the change result in an undesirable hydraulic condition at a key location in the system? How will the operation and maintenance be affected? Will the change put the pipeline in a location that the O&M equipment cannot reach? Will it result in operational problems in the future? All of these concerns must be weighed against the potential construction cost savings prior to a change being authorized.

Line changes are made through the use of fittings. No 90-degree bends should be used in vertical or horizontal line changes.² Concrete thrust blocking generally is not

necessary, however, backfill compaction in this zone of abrupt change in direction is vital.

3.5.1.2 Grade Control

Like line changes, grade changes should not be made without a thorough evaluation of how that change will affect overall system performance. The ability to make grade changes to avoid obstacles is an advantage but the abuse of this freedom can result in major problems. This issue has been the cause of conflicts between the contractor and the engineer in past projects. The engineer's inspector instinctively desires to eliminate lifts to improve the system hydraulics. This results in a deeper installation. The contractor, on the other hand, is constantly wanting to add lifts to result in a shallower installation. As long as neither party loses sight of the system's hydraulic limits and the effect on operational costs, a conflict does not have to take place.

Vacuum sewers must be laid with a slope toward the vacuum station. The only exception to this is where vertical profile changes (lifts) are located. The pipe must slope toward the vacuum station between lifts.

A minimum of 0.2-percent slope must be maintained at all times.² To ensure this, a laser typically is required. The use of automatic levels also is acceptable when handled by an experienced instrument operator. In areas where an obvious (>0.2 percent) downhill slope exists, the pipeline may follow the contour of the ground. Grade should routinely be checked by the engineer's inspector.

3.5.1.3 Service Connections

Most contractors have a crew installing main lines and a second crew installing the services (valve pit settings). It is common for the line crew to install a wye fitting on the main to accept later piping from the pit crew. Typically, the pit crew installs the pit and then connects the pit to the main. Connecting these two fixed points, which have different elevations, with rigid piping sometimes can be difficult. Many times the result is the excessive use of fittings. This situation can be avoided by proper planning and coordination between crews.

The depth of each service setting typically is custom designed. The relationship between the ground elevation where the pit setting will be situated and the elevation of the customer's basement/building sewer dictates the depth of service required. In addition, the length of connecting lateral required must be considered to allow for sufficient slope of the building sewer. Prefabricated valve pits with fixed dimensions can sometimes make pit location critical. Moving the pit to a lower elevation, while allowing additional fall for the building sewer, may result in lift being necessary to connect to the main (elevation

of main is generally independent of elevation of the pit). Moving the pit to a higher elevation may result in insufficient fall available for the building sewer. Each valve pit location should be evaluated for adequacy and verified by the engineer to the contractor prior to shipment of the valve pits.

For service lines, the construction is almost always within private property. For this reason, easements are required from property owners for the installation and future maintenance of the system. Easement acquisition is the responsibility of the Sewer Authority, either directly or through contract with a right-of-way agent. In either case, the hydraulic limits of the system must be understood prior to making any changes that may be requested by the property owner. For this reason, it is recommended that Authorities employ the services of the design engineer for all or part of this task.

The user's responsibility begins at the vacuum pit stub-out. The length of the stub-out typically is 1.8 m (6 ft). Shorter stub-out lengths are undesirable. They would require the homeowner to excavate closer to the fiberglass valve pit to connect to it, possibly causing damage or disturbing the backfill/compaction around the pit in the process.

Most operating entities require the homeowner to replace or be responsible for the replacement of the building sewer from the house foundation to the stub-out connection, since vacuum sewers are not designed to handle extraneous water. By accepting old, possibly defective building sewers, the operating entity is taking a risk on operation and maintenance problems, particularly "waterlogging".

The building sewer is temporarily under vacuum during the valve's open cycle. For this reason, the pipe material must be able to withstand those forces without collapsing. It is standard practice for 10-cm (4-in), Schedule 40, SDR 21, or SDR 26 PVC pipe to be used for this purpose; 680 kg (1,500 lb) crush-type pipe is not acceptable, nor is SDR 35 PVC.

The homeowner is usually responsible for the installation of the 10-cm (4-in) auxiliary vent also. This vent is necessary for the proper operation of the valve. It should be located no closer than 6 m (20 ft) from the valve pit. It is desirable for this vent to be located against a permanent structure, such as the house itself, a fence, or a wall.

There have been attempts by some engineers in the past to include this work as part of the construction project. This was found to be unworkable, as it required the

contractor to have complete knowledge of the homeowner's plumbing system prior to the project bid. Many times, the homeowner was unsure of the exact location of his building sewer. Contractor liability was increased since excavation near the foundation was required. This led to high unit bid prices. Finally, installing a vent on the building sewer before the system was ready for operation often did nothing more than vent the septic tank, which created odor problems.

All of the work required by the homeowner must be inspected by the operating entity prior to final connection. This ensures the proper and efficient operation of the system. Compliance with the Sewer Use Ordinance is the only remaining user responsibility.

The vacuum valve is not installed until the customer is ready to connect to the valve pit setting. It is common for the contractor to install the valve pit/sump, including all of the necessary piping, during collection system construction. The valve is supplied to the Authority for their installation at a later date. In this manner, the Authority can systematically install the valves as each customer requests connection. Each valve is "timed-out" with the controller time setting being recorded for future reference. The time setting on the first few valves is typically changed once or twice after startup as system hydraulics continually change until all customers are connected. All valves are then fine tuned to operate as a complete system.

3.5.2 Equipment Substitutions

Equipment submittals should be approved by the engineer prior to the contractor ordering the specific equipment. Virtually all of the components in a vacuum system are available from more than one manufacturer. Even though much research and development currently is taking place, the vacuum sewer industry has grown and improved largely by the trial and error method. For this reason, the engineer should be extremely careful of substitutions of specified equipment, especially in a piece-meal fashion. This is not to say that new or alternative brands should automatically be ignored; it simply means that care and judgment should be exercised prior to any major deviation.

Should a substitution be desired, the contractor should submit the following information to the engineer to allow for a complete evaluation of the situation:

- Identify the product by stating the manufacturer's name and address, trade name of product, and the catalog or model number.
- Include product data such as shop drawings, samples, etc.

- Give itemized comparison of substitution with specified equipment, listing variations.
- Give quality and performance comparison of substitution with specified equipment.
- Give cost data comparing substitution with specified equipment.
- List availability of maintenance services as well as replacement parts.
- Show the effect of substitution on the project schedule.
- Show the effect of substitution on other related equipment.

The engineer may require a bond if there is no precedent information on the proposed substitution.

3.5.3 Testing

3.5.3.1 Sewers

Prior to the installation/connection of any valve, the complete system of sewers should be vacuum tested. The engineer should be present during the entire testing period. Any leak not discovered due to flawed testing procedures, either intentional or unintentional, will quickly become evident once the system is operational, as the operator can simply check the vacuum charts daily to see if any leaks are present. Testing generally involves the following:¹

- At the end of each day's work, the mains and crossovers laid that day should be plugged and subjected to a vacuum of 60 cm (24 in) Hg, allowed to stabilize for 15 minutes and then not lose more than 1 percent vacuum pressure/hr test period. During the daily testing, all joints should be exposed. If any section of the sewer fails the test, it should be reworked prior to laying new sections of sewer.
- When the system of sewers and crossovers has been completed, the complete network should be subjected to 60 cm (24 in) Hg vacuum pressure, allowed to stabilize for 15 minutes then not lose more than 1 percent vacuum pressure/hr for a 4-hr period.

During testing, temperature and/or climatic conditions may vary. The following conditions may affect the vacuum readings in the pipe being tested:

- A drop in temperature may occur. The effect will be cooling of the pipe and the air in it thus causing contraction of both. The contracting of the air within the pipe will cause an increase in vacuum.
- A change in the barometric pressure may also occur. Before rainfall, the barometric pressure may drop by approximately 12 mm (0.5 in) Hg. A vacuum gauge measures the difference in pressure between the volume being tested and the atmospheric pressure.

Therefore, any change in barometric pressure will cause an equivalent change in pressure on the gauge being used in the vacuum test.

Where climatic changes may occur during a vacuum test, it is recommended that pipe temperature and atmospheric pressure be recorded at the beginning and end of the test, and the test results adjusted to correct for these changes.

3.5.3.2 Vacuum Station

All vacuum piping and connected appurtenances in the vacuum station should be tested for tightness. A final test of the station piping should be done. In this test the station piping is subjected to 60 cm (24 in) Hg. There should be no loss of vacuum in the 4-hr test period.²

All of the controls should be tested at startup to see that the system is functioning as designed. This includes the vacuum pump controls, the wastewater pump controls, and the telephone dialer.

3.5.4 Historical Construction Problems

The above sections provide insight into some of the inherent problems associated with vacuum sewer construction. Problems can be avoided by sound design, proper inspection, and preconstruction planning/coordination between the engineer and the contractor.

As part of the development of this manual, six operating systems were visited in 1989. Based on these visits, four problems were prevalent during construction. Two of these were short-term and two resulted in later, long-term problems.

3.5.4.1 Short Term

a. Solvent Welding in Cold Weather

Solvent welding PVC pipe in temperatures approaching or below freezing led to vacuum leaks. Some contractors made the mistake of keeping the glue warm, only to apply it to a pipe that was much colder. This led to leaking joints and difficulty in passing the final leakage test.

This problem can be avoided by not solvent-welding joints during temperatures of 4°C (40°F) and colder. However, since this may not be practical for some jobs, a better solution would be to minimize the number of solvent-welded joints in the system.

Along these lines, there has been a significant move in the vacuum industry toward the use of gasketed pipe and fittings. In all cases, installation of piping should be in accordance with the proper specification of the Plastic Pipe Institute, ASTM F-645-80 or ASTM D2774-72.

b. Pit Alignment

The prefabricated valve pit setting allows for gravity stub-out connections only at predetermined locations. Likewise the location of the 7.5-cm (3-in) vacuum service line is predetermined. Collectively, the top and bottom chambers may only be assembled in a few different arrangements.

Some contractors, concerned with facing the stub-out direction toward the house, failed to consider the already existing location of the wye connection to which the 7.5-cm (3-in) service line would connect. Some corrected the situation by re-installing the pit at a location that could be accepted by both connection points. Others used fittings to make the necessary adjustment.

Pre-installation planning, rather than last minute decision making will eliminate the alignment problems.

3.5.4.2 Long Term

a. Valve Pit Settlement

Poor workmanship by the contractor led to valve pit settlement. This resulted in alignment problems for the owner at the time of the valve installation (vacuum line entering the pit moved from its level position). Improper valve alignment can lead to future valve malfunctions.

Valve pit settlement problems can be avoided by better quality control on both the contractor's and inspector's part during construction. Taking time to ensure proper alignment and proper compaction around the pit will greatly reduce the likelihood of this problem occurring.

b. Excessive Use of Fittings

Two fixed points, at varying inverts and locations, but requiring rigid connection piping, resulted in the contractor using an amount excessive use of fittings. These fittings many times were located within the pit excavation. This overexcavated zone is one where lack of compaction could easily lead to future settlement, which can lead to fitting failures.

The use of fittings in the service lines can be minimized by proper planning and coordination between line and pit crews. To minimize the difficulties, some contractors install the valve pits first.⁶ The use of gasketed fittings, which adds a certain degree of flexibility, will also alleviate some of these problems.

3.6 Operation and Maintenance Considerations

3.6.1 Operation and Maintenance Manual

To operate a vacuum sewer system requires proper training. O&M Manuals are a vital part of this training process. Problems arose in some of the early vacuum systems due to the lack of such aids. Manufacturers and engineers are now recognizing this fact and are reacting accordingly with improved technical assistance and O&M Manuals.

A well written O&M Manual should contain the information necessary to achieve the following goals:³

- To provide an accessible reference for the wastewater collection system operators in developing standard operating and maintenance procedures and schedules.
- To provide a readily available source of data, including permits, design data, and equipment shop drawings which are pertinent to the particular system.
- To provide the system operators assistance and guidance in analyzing and predicting the system efficiency.
- To provide the system operators assistance and guidance in troubleshooting the system.

While an O&M Manual is a valuable tool, it should not be viewed as the source of the ultimate solution to every problem. The degree of efficiency of the system depends on the initiative, ingenuity, and sense of responsibility of the system operator. Also, the manual should be constantly updated to reflect actual operational experience, equipment data, problems, and implemented solutions.

The O&M Manual should contain the following information as a minimum.

3.6.1.1 Design Data

All design data should be given. Included would be information relating to the system make-up, such as the number of valves, line footage, and line sizes. Also included would be component sizing information, anticipated operating ranges, and other important design considerations. As-built drawings showing all system components should be included.

3.6.1.2 Equipment Manuals

Installation and maintenance manuals from the manufacturers of the major equipment should be included. A list showing the manufacturer and supplier as well as contact persons, addresses, and phone numbers should be compiled.

3.6.1.3 Warranty Information

All warranties, including effective dates, should be listed.

3.6.1.4 Shop Drawings

A list of all approval drawings should be made which identifies the manufacturer, model number, and a general description of the equipment. A copy of each approval drawing should be included with the O&M Manual.

3.6.1.5 Permits and Standards

All applicable permits, such as the National Pollutant Discharge Elimination System (NPDES) permit, should be included in the manual. Applicable water quality standards should also be included.

3.6.1.6 Operation and Control Information

This section should include a description of the overall system. The major components should be identified. The following information should be given for each major component:

- Relationship to adjacent units
- Operation
- Controls
- Problems and troubleshooting guides
- Maintenance
- Preventive maintenance schedule
- Equipment data sheet

3.6.1.7 Personnel Information

A description of the manpower requirements, including qualifications and responsibilities should be listed.

3.6.1.8 Records

A list of the type of records, as well as a list of reference materials that are important, should be included.

3.6.1.9 Preventive Maintenance

All equipment should be listed and cross-referenced to equipment catalogs. Maintenance schedules should be established.

3.6.1.10 Emergency Operating and Response Program

This section should include a description of actions and responses to be followed during emergency situations. Included should be a list of contact persons, including addresses and phone numbers for those responsible for various community services.

3.6.1.11 Safety Information

A safety plan should be developed which includes practices, precautions, and reference materials.

3.6.1.12 Utility Listing

A list of all utilities in the system area should be given, including contact persons, addresses, and phone numbers.

Much of the information contained in the O&M Manual can easily be recorded on a database-type computer program. Computer software is becoming more affordable to small communities and can provide powerful aids to the O&M staff.

3.6.2 Staffing Requirements

3.6.2.1 General Information

Information gathered from operating systems suggests that the effort to operate and maintain modern vacuum systems has been overstated. Vacuum systems are mechanized and will, therefore, normally require more O&M than a conventional gravity sewer system. This must be allowed for in system planning.

3.6.2.2 Operator Responsibilities

The system operator is responsible for the following activities:

- Analyzes and evaluates operation and maintenance functions and initiates new procedures to insure continued system efficiency
- Gathers and reviews all data and records same for the preparation of reports and purchase requests
- Recommends all major equipment purchases and system improvements
- Maintains effective communication with other employees, municipal and government officials, and the general public
- Conducts daily operation and maintenance of the system
- Inspects the system daily to determine the efficiency of operation, cleanliness, and maintenance needs
- Prepares work schedules
- Prepares operational reports and maintenance reports
- Determines remedial action necessary during emergencies

3.6.3 Operator Training

It is desirable for the operating entity to hire the system operator while the system is under construction. This allows the operator to become familiar with the system, including the locations of all lines, valve pits, division valves, and other key components. To add further training, manufacturers may offer lengthy (e.g., 2 weeks) training program at their facility.

For example, AIRVAC provides a small-scale vacuum system at their manufacturing center. This setup includes

clear PVC pipe with various lift arrangements where trainees can watch the flow inside a clear pipe during a wide variety of vacuum conditions. Faults are simulated so that the trainee can gain troubleshooting experience. The operator is taught valve operation and its overhaul. Finally, vacuum station maintenance is taught.

The best training is gained by actual operating experience. Many times, however, the knowledge is gained at the expense of costly mistakes. This is especially true at startup time. During this time, the engineer, who provided day-to-day inspection services during construction, is gradually spending less time on the system. The operator is busy setting vacuum valves and inspecting customer hookups. Complicating the situation is the fact that the operating characteristics of the system continually change until all of the customers are connected and all of the valves are fine-tuned. However, with the operator(s) being preoccupied with other tasks, this fine tuning sometimes is not done; problems develop; and system credibility can be lost.

This "training gap" is present at the startup of virtually every vacuum system. This is an area of the technology that needs improvement. One solution is for the engineer to budget a 3-6 month, on-site training service to aid the system operator in the fine tuning and troubleshooting of the early problems. The operator will benefit from the engineer's systematic approach to problem solving. This most likely will instill a certain degree of confidence in the operator(s) concerning the system. Operator attitude is vital to the efficient operation of a vacuum system.

3.6.4 As-built Drawings and Mapping

It is common in the industry for changes to be made during construction. The changes should be reflected on the as-built drawings. As the name implies, these drawings depict exactly how the system was built. This is a vital tool to the operating entity for maintenance, troubleshooting, and future improvements or extensions to the system.

An index map showing the entire system should be included in the as-built drawings. Shown on this map will be all key components, line sizes, line identifications, valve pit numbering and locations, and division valve locations. Detailed plan sheets of each line of the collection system should be included, with dimensions necessary to allow the operator to locate the line as well as all related appurtenances.

Unique to a vacuum system is the need for an as-built hydraulic map. This is similar to an index map but also includes special hydraulic information:

- The locations of every lift.

- The amount of vacuum loss at key locations, such as the end of a line or the intersection of a main and branch line.
- Number of main branches, number of valves in each branch, and total footage (or volume) of pipe in each branch.

This simple but vital information allows the operator to make intelligent decisions when fine tuning or troubleshooting the system.

Another tool that is helpful to the operator is an as-built drawing of each valve pit setting. These drawings will show the location of the setting relative to some permanent markers (house, power pole, etc.), the orientation of the gravity stub-outs, the depth of the stub-outs, and any other pertinent site-specific information. These records are used by the operator as new customers connect to the system.

The vacuum station drawings should be altered to reflect changes made during construction. Especially important in these drawings are dimensions, since any future modification will depend on available space.

3.6.5 Maintenance

3.6.5.1 Normal Maintenance

A properly designed vacuum station will be equipped with a fault monitoring system, such as a telephone dialer. This system monitors the operation of both the vacuum station and the collection system, and automatically notifies the operator of low vacuum, high levels of wastewater in the collection tank, and power outages.

Normal operation includes visiting each vacuum station daily. Some daily maintenance procedures include the recording of pump running hours, and oil and block temperature checks. Once an operator is familiar with the operating characteristics of the system, a simple visual check of the gauges and the charts in the station will provide an adequate alert of any problems. This visual check along with recording operating data generally takes about 30 minutes. Weekly procedures include checking battery terminals, battery conditions, and operational testing of the standby generator. Monthly procedures include cleaning of the collection tank sight glass, a check of the mechanical seal pressurizers of the wastewater discharge pumps, and a test of the telephone alarm system.

On a normal day, the operator will not be required to visit the collection system. Normal station gauge and chart readings are an indication that the collection system is fine. Depending on a system's history of breakdown

Table 3-14. Normal Operating Tasks and Frequencies

Daily
Visually Check Gauges/Charts
Record Pump Run-Times
Check Oil and Block Temperatures
Weekly
Check Battery Conditions
Exercise Generator
Change Charts
Monthly
Clean Sight Glass
Check Mechanical Seal Pressurizers
Test Alarm System

maintenance, some periodic inspection may be required. This would include the inspection and manual operation of each valve at some regular interval. The breather lines should be inspected for the accumulation of moisture. An experienced operator will quickly learn the sounds of a properly functioning valve.

Table 3-14 summarizes the daily, weekly and monthly tasks.

3.6.5.2 Preventive Maintenance

Wastewater collection systems operate and must be maintained 365 days a year. Variations in operation and maintenance workloads occur, making it imperative that preventive maintenance be planned and scheduled.³ This will ensure that there is no idle time during non-peak workload periods. Inspection and maintenance planning and scheduling involves time, personnel, equipment, costs, work orders, and priorities.

A preventive maintenance schedule for all major equipment should be developed. To initiate the preventive maintenance tasks, a work order system must be established. This system identifies the required work, priority of task, and any special information, such as the tools or parts required for the job. These work orders provide a record of work completed.

Scheduled maintenance on the collection piping should be minimal. Areas where difficult or unusual conditions were encountered during construction should be visited periodically. Other areas to be visited include steep slopes and potential slippage areas.

At least twice a year, the division valves should be checked. This is done by moving the valve through the entire opening and closing cycle at least once. This procedure will keep valves in operating condition. In

Table 3-15. Preventive Maintenance Tasks and Frequencies

Yearly
Exercise Division Valves
Inspect Vacuum Valves
Check Controller Timing
Check Plug and Check Valves at Station
Inspect Vacuum and Station Pumps For Wear
5 - 6 Years
Remove Valve and Replace Worn Parts
Rebuild Controller

addition, it will familiarize the operating personnel with the location of all valves.

All vacuum valves should be inspected once a year.² They should be manually cycled to see that they are operating properly. The controller timing cycle should be recorded and compared to the original setting. If necessary, the timing should be reset. This entire procedure can be done by one person, requiring about 10-15 minutes/valve.

About every 10 years, each vacuum valve should be removed, a spare put in its place, and the old valve returned to the workshop.³ The valve should be taken apart and inspected for wear. If needed, the seat should be replaced. When the valve is reassembled, a new shaft seal and bearing should be fitted. The seals and diaphragms of the controller/sensor should be replaced every 5 years. These procedure can be done by one person, requiring 45 minutes for the valve and 1 hour for the controller.

Preventive maintenance for the major equipment at the vacuum station should be done in accordance with manufacturers' recommendations. Yearly maintenance might include removal from service and comprehensive inspection of check valves, plug valves, vacuum pumps, wastewater pumps, generator, and the telephone dialer.

Table 3-15 summarizes the preventive maintenance tasks and their frequencies.

3.6.5.3 Emergency Maintenance

Although very little effort is required on a day-to-day basis, there will be times that emergency maintenance is necessary. This effort usually requires more than one person, particularly when it involves searching for a malfunctioning valve. Many times problems develop after normal working hours, requiring personnel to be called out on an overtime basis. Emergency or breakdown

maintenance can occur in the piping system, at the vacuum station, or at the vacuum valve.

Assuming proper design and construction, there is very little that can go wrong in the piping system. Occasionally, a line break will occur, due to excavation for other utilities or landslides, causing a loss of system vacuum. Using the division valves, the operator can easily isolate the defective section.

Malfunctions at the vacuum station are generally caused by pump, motor, or electrical control breakdowns. Redundancy of most components allows for the continued operation of the system when this occurs.

Most emergency maintenance is related to malfunctioning vacuum valves caused by either low system vacuum or extraneous water. Failure of the valve is possible in either the closed or open position. A valve failing in the closed position will give the same symptoms as a blocked gravity line, that is, the customer will experience problems with toilet flushing or backup of wastewater on the property. A phone call from the affected party makes identification of this problem easily rectifiable. This rarely happens since virtually all valve failures occur in the open position. When this happens, a loss of system vacuum occurs as the system is temporarily open to atmosphere. The fault monitoring system will recognize this low vacuum condition and alert the operator of the problem. A common cause of failure in this position is the entrance of extraneous water into the controller.

A procedure for locating the source of a vacuum failure has been developed by AIRVAC as follows:⁴

- When a low vacuum condition occurs in the system, isolate each incoming line to the collection tank to identify the problem line.
- Close off the problem line. Open the remaining lines to clear the wastewater from them.
- Allow vacuum in the operational lines to reach the maximum vacuum level possible; then close these lines off.
- Open the line with the problem.
- Starting at the collection tank, go to the first division valve on the problem line. Connect a vacuum gauge to a nearby vacuum valve (or to a gauge tap, if one exists) downstream of the division valve. Close the division valve and observe if vacuum builds up. If it does not, the problem is between the vacuum station and the division valve. If vacuum rises, repeat the process on the next division valve. Before reopening each division valve, allow vacuum to build up in the nonproblem sections of the sewer to clear those sections' wastewater.

- After isolating the problem section, check each valve pit to locate the malfunction. Often this can be accomplished by driving to each pit and listening for the sound of rushing air in the auxiliary vent.
- After locating the malfunctioning valve, follow the manufacturer's valve troubleshooting procedures.
- If no valves are malfunctioning, check for underground construction that could have caused a break in the transport piping. Also, walk the route of the problem sewer and look for evidence of a break, such as a sunken area.

The above procedure is a systematic approach to locating the source of vacuum loss. The time for the first 4 steps is generally about 2-3 minutes, while the entire procedure generally can be completed within 30 minutes.⁴ Sometimes a shortcut can be taken. In the recent study of operating systems, it was found that many times the same valve(s) fail. This is usually due to some particular hydraulic condition at that specific locale. In these situations, the operators check these valves before any other isolation is done. In another situation, a skilled operator can usually tell how far from the vacuum station the problem is by analyzing the vacuum charts as the degree of vacuum loss is inversely proportional to distance from the station. This allows for the simplification of the isolating procedure.

Valve failures, if not located and corrected within a couple of hours, may cause failures in other parts of the system. A valve that is hung open or that continuously cycles will cause system vacuum to drop. If the vacuum pumps cannot keep up with this vacuum loss, the result is insufficient vacuum to open other valves. This may lead to backups. When vacuum is finally restored, a large amount of wastewater, in relation to the amount of air, will be introduced into the system possibly resulting in "waterlogging." When this occurs, the system must be manually operated, allowing the vacuum pumps to run longer than usual. The manual repetitive cycling of the vacuum and wastewater pumps in effect increases the capacity of the vacuum station. This repetitive cycling is continued until the system "catches up." At that point, the system is returned to its automatic mode.

There have been attempts made to determine the time necessary to locate a failed valve.⁴ At the Plainville, Indiana system, a valve was caused to fail at a location unknown to the maintenance personnel. This valve was located and the problem corrected in 21 minutes. System operators report that the typical valve failure is located within 30-45 minutes. Most also cite driving time from their house to the system as being the critical factor in this response time. A key component in continual operation

is an effective alarm system, along with available maintenance personnel.

3.6.6 Record Keeping

Good records are important for the efficient, orderly operation of the system. Pertinent and complete records provide a necessary aid to control procedures as they are used as a basis of the system operation. The very first step of any troubleshooting procedure is an analysis of the records. This is especially true of the collection system. A wealth of information is contained in the basic records kept on a daily basis. The following types of records should be kept:

- Normal maintenance records
- Preventive maintenance records
- Emergency maintenance records
- Operating costs records

These records should be carefully preserved and filed where they are readily available to operating personnel. All records should be neat and accurate and made at the time the data are obtained. It is good practice to summarize this data in a brief monthly report and a more complete annual report. These reports should be submitted to the local authorities such as Town Council and the Mayor. This keeps those officials apprised of progress, problems and long term needs of the facility.

3.6.6.1 Normal Maintenance Records

The following information should be recorded on a daily basis:

- Date
- Personnel on duty
- Weather conditions
- Routine duties performed
- Operating range of vacuum pumps
- Run-times of vacuum pumps
- Run-times of wastewater discharge pumps
- Run-time of standby generator
- Flow data
- Complaints received and the remedies
- Facilities visitors
- Accidents or injuries
- Unusual conditions
- Alterations to the system

3.6.6.2 Preventive Maintenance Records

Adequate records provide information that tells operational personnel when service was last performed on each system component and indicates approaching service or preventive maintenance requirements. Efficient scheduling of these maintenance tasks can then be

made which avoid interference with other important aspects of system operation.

Results of periodic inspections should be kept. This would include a list of all potential problems, the likely cause of these problems, the repairs necessary to solve the problem, and recommendations for future improvements to minimize recurrence.

3.6.6.3 Emergency Maintenance Records

Records should be kept concerning all emergency maintenance. This includes the following:

- Date and time of occurrence
- Person(s) responding to problem
- Description of problem
- Remedy of problem
- Parts and equipment used
- Total time to correct problem
- Recommendations for future improvements

3.6.6.4 Operating Cost Records

To insure budget adequacy, it is very important to keep accurate information concerning the costs of all operation and maintenance items. Costs include:

- Wages and fringe benefits
- Power and fuel consumption
- Utility charges
- Equipment purchases
- Repair and replacement expenses
- Chemicals
- Miscellaneous costs

3.7 Evaluation of Operating Systems

3.7.1 Early Vacuum Systems

Early vacuum systems were often plagued with consistent operational problems. These systems were installed without sufficient field experience with system components. In addition, operation and maintenance guidelines were not yet available. As a result, several operational problems were encountered.

Early vacuum systems experienced problems because of the lack of knowledge of two-phase transport. Small vacuum mains, improperly planned vacuum main profiles, too large liquid slug volumes, and insufficient air all resulted in transport problems.⁵

Vac-Q-Tec systems located sensitive electronic valve control equipment in 208-L (55-gal) drums near the wastewater holding tanks. Corrosion of these drums and the control boxes caused numerous problems and the

complexity necessitated skilled technicians to successfully operate the system.⁴

Early Colt and AIRVAC systems lacked components that are now generally accepted as minimum design standards.² The lack of standby power indirectly caused some vacuum valve boots to rupture. During power outages, liquid built up behind these valves. When power was restored and the valves cycled, the large volume of water could not be completely drained before the timed valve operation sequence closed the boot on the fast-moving water instead of on air. This resulted in unusually high forces which ruptured the valve boots. These problems were alleviated to a large degree when standby power was added to the system.

AIRVAC's early valve pits were made of a tar-impregnated paper which deformed when placed in unstable soil or in areas subjected to vehicle traffic. This deformation eventually led to damaged valves. Additional problems resulted from the use of valve pits without bottoms in areas of high ground water.⁴ In this case, water entered the sensor-controller causing the valves to continually cycle and eventually deplete system vacuum. Corrective measures included replacement of the early valve pits with fiberglass pits capable of withstanding traffic loadings. Breather tube extensions aboveground and controller modifications have minimized these past problems.

A better understanding of vacuum sewer hydraulics, improved system components, and established operation and maintenance guidelines have led to significant operational improvements.

3.7.2 Recent Vacuum Systems

Although operational reliability has improved with each successive generation of systems, some problems still exist. Six operating systems were visited in 1989 so that meaningful operation and maintenance data could be generated. An attempt was made to visit systems that would give a good cross section of the technology. Topography, geographical location, size, and varying design concepts were considered in the selection process. One early system was visited to see if improvements through the years have resulted in increased reliability. Table 3-16 presents information on the operating systems visited.

3.7.2.1 General Information

Table 3-17 presents general information on each of the systems visited.

Table 3-16. Operating Systems Visited in 1989

Project Name	Location	Date Operational	System Type
Ocean Pines	Berlin, MD	1970	VAC-Q-TEC
Westmoreland	Westmoreland, TN	1979	AIRVAC
Ohio Co-Phase I	Wheeling, WV	1984	AIRVAC
Lake Chautauqua	Celeron, NY	1986	AIRVAC
Central Boaz PSD	Parkersburg, WV	1988	AIRVAC
White House	White House, TN	1988	AIRVAC

3.7.2.2 Design/Construction Data

Table 3-18 shows design and construction data as they relate to the collection systems of each of the systems visited.

Table 3-19 shows design and construction data as they relate to the vacuum stations of each of the systems visited.

3.7.2.3 Operation and Maintenance Data

Significant improvements have been made in the components in the last 10 years, particularly with the valve controller unit. This has been attributed to a combination of research and testing and an increased quality control effort. Continuing to educate the designers, builders, and operators of proper techniques will result in a further reduction of the problems. Evidence of this is starting to surface in some of the more recently constructed systems.

Operation and maintenance data were gathered on each of the systems visited. These data are presented in Tables 3-20 through 3-23.

3.7.3 Trend

The failure rate of some of the early vacuum systems has been documented: in general, the mean time between service calls (MTBSC) of some of these systems ranged from less than 1 to more than 8 year; all but one of these systems had a MTBSC of less than 4 years.⁴ By contrast, all of the systems studied in 1989, with the exception of the early system, had a MTBSC of greater than 6 years, with the average being almost 10 years. This indicates that component improvements and design advancements have had a positive impact on the reliability of vacuum systems.

3.7.4 Historical Operating Problems

Each of the systems visited experienced some type of problem which predominated as a demand on O&M staff time. However, most were short lived. Table 3-24 describes the types of problems found.

A sophisticated statistical analysis was not performed to develop the above percentages. The percentages were determined by a combination of frequency of occurrence and demand on staff time as reported by the system operators that were interviewed. They are presented only for the purposes of putting the different problems into perspective.

Assuming the percentages roughly approximate reality, 80 percent of the problems to date can be categorized as avoidable. This does not mean that they were not or are not problems. With good design, construction, inspection, training, and quality control, however, these problems can be avoided in future systems.

3.7.4.1 Component Defects

a. Broken Spring-Valve Failure in Open Position

Shortly after startup of one system, an unusual amount of valve failures were occurring. It was determined that these failures were caused by a broken spring in the valve controller. An investigation revealed that the springs were made of defective material. The springs were systematically replaced with new ones, an effort that two people accomplished on a part-time basis over the span of a month.

This effort did not require the removal of the valve itself. Using spare parts, the District put new springs in the controller component of the valve at their workshop. After a sufficient amount of controllers were rebuilt, they were taken to the field and replaced the controllers with the defective springs, a procedure that took 10 minutes per valve. These defective controllers were then brought back to the shop where the procedure was repeated until all controllers were rebuilt with the proper spring. This problem has not since returned.

b. Unreliable Valve Controllers

The original valves in one system had a controller that was different from the ones used presently. They were found to be very unreliable. The result was more valve failures, and, hence, more O&M expense than originally anticipated. In the 1970s, AIRVAC designed and patented their own controller. After the successful testing of these controllers at their Indiana facility, they began mass production.

Every valve in the system has since been retrofitted with the AIRVAC controller. The failure rate has been greatly reduced since the changeover.

Table 3-17. General Information on Operating Systems

	Ocean Pines	Westmoreland	Ohio County	Lake Chautauqua	Central Boaz	White House
Feet of Pipe	285,000	83,000	43,000	121,000	39,000	65,000
No. Vacuum Stations	12	4	1	4	1	2
No. Valves	1,500	490	200	900	180	260
No. Homes Served	3,500	540	250	2,500	350	360
Topography	Flat	Rolling	Hilly	Flat	Flat	Rolling
Soils	Sandy	Rock	Clay	Sandy	Sandy	Rock
Community Age	New	Old/New	Old	Old	Old/New	Old/New
Seasonal Population	No	No	No	Yes	No	No
Mean income	High	Middle	Middle	Middle	Middle	Middle

Table 3-18. Design/Construction Data - Collection Systems

	Ocean Pines	Westmoreland	Ohio County	Lake Chautauqua	Central Boaz	White House
Valve Type	VAC-Q-TEC	AIRVAC Model-D	AIRVAC Model-S	AIRVAC Model-S	AIRVAC Model-D	AIRVAC Model-D
Pipe Material	Solvent Welded	Solvent Welded	Solvent Welded	Rubber Gasket	Rubber Gasket	Solvent Welded
Diameters, in	4	3,4,6	3,4,6	3,4,6,8	3,4,6	3,4,6,8,10
Min. Cover, ft	3	4	3	4	3	4
Min. Slope, percent	None	0.2	0.2	0.2	0.2	0.2
Div. Valve	Plug	Plug	Plug	Plug	Gate	Plug
Thrust Blocking	No	Yes	No	Yes	No	No
Multi-branches	Yes	Yes	Yes	Yes	Yes	Yes
Longest Line, ft	Unknown	Unknown	8,000	8,500	6,500	14,000
Design Concept	None	Reformer Pocket*	Early AIRVAC	Early AIRVAC	Early AIRVAC	Current AIRVAC
Pit/House Ratio	0.43	0.91	0.80	0.36	0.51	0.72
Type Sumps	Concrete 700 gal.	2 pit Fiberglass	Fiberglass	Fiberglass	Fiberglass/Concrete	Fiberglass

* Converted over the years to meet "early AIRVAC" design standards.

Table 3-19. Design Construction Data - Vacuum Stations

	Ocean Pines	Westmoreland	Ohio County	Lake Chautauqua	Central Boaz	White House
No. Probes	Multi	Multi	Single	Single	Single	Multi
Equalizing Lines	No	Yes	Yes	Yes	No	Yes
Odor Filters	Yes	No	No	No	Yes	No

Table 3-20. O&M Data - General Information

	Ocean Pines	West Moreland	Ohio County	Lake Chautauqua	Central Boaz	White House
No. Operating Personnel	8	6	5	7	1	3
Other duties?	No	Yes	Yes	Yes	Yes	Yes
No. Persons Needed for Vacuum Part of System	8	1	1	2	1	1

Table 3-21. O&M Data - Person-Hours/Year

	Ocean Pines	West Moreland	Ohio County	Lake Chautauqua	Central Boaz	White House
Normal Maint., hr/yr	16,640	1,915	260	365	315	260
Prev. Maint., hr/yr	2,500	245	100	1,013	90	200
Emerg. Maint., hr/yr	1,660	192	240	48	384	60
Total Person-Hours/yr	20,800	2,352	600	1,426	789	520
No. of Valves	1,500	490	200	900	180	260
Person-Hours/yr/Valve	13.9	4.8	3.0	1.6	4.4	2.0
No. of Customers	3,500	540	250	2,500	350	360
Person-Hours/yr/Cust.	5.9	4.4	2.4	0.6	2.3	1.5

Table 3-22. O&M Data - Power Consumption/Year

	Ocean Pines	West Moreland	Ohio County	Lake Chautauqua	Central Boaz	White House
Power Cost/yr, \$	120,000	15,000	2,400	27,540	4,800	3,900
No. Valves	1,500	490	200	900	180	260
Cost/yr/Valve, \$	80.00	30.60	12.00	30.60	26.51	15.00
No. Customers	3,500	540	250	2,500	350	360
Cost/yr/Customer, \$	34.29	27.77	9.60	11.30	13.71	10.83
kWh/yr/Customer	570	460	160	190	230	180

Table 3-23. O&M Data - Mean Time Between Service Calls (MTBSC)

	Ocean Pines	West Moreland	Ohio County	Lake Chautauqua	Central Boaz	White House
No. Valves	1,500	490	200	900	180	260
No. Service Calls/yr	1,500	48	24	40	30	24
MTBSC, yr	1.0	10.2	8.3	22.5	6.0	10.8

Table 3-24. Problem Classification

Problem	Responsible Party	Percent of Total Problems
Component Defect	Manufacturer	40
Design Shortcomings	Engineer	10
Operator Error	Operator	5
Construction Related	Contractor	25
Equipment Malfunction	Manufacturer	5
Extraneous Water Related	Customer	15

c. Controller Shaft/Seal Problems Multi-Firing Valves

Some valves were found to cycle more than once after the sump was emptied. A redesigned controller shaft and seal has solved this problem. Controllers with the old shaft and seal have been retrofitted with the latest version.

d. Plug Valve Problem

The type of division valve used in most operating systems is the plug valve. Some systems have experienced major problems with plug valves while others have not.

Problems reported in one system included times when system vacuum pulled the division valve closed thereby cutting off system vacuum beyond that point. As workers attempted to re-open these valves, frequently the valve shaft was twisted off due to the heavy load applied by system vacuum. When this happened, the division valve could not be opened, resulting in part of system being out of service until corrective measures were taken.

Some system operators reported problems with plug valves not holding vacuum when closed. This renders them useless as a troubleshooting tool, which is their primary purpose.

Problems with plug valves have been attributed to quality differences between manufacturers, in some cases, and the defective materials in others. Properly manufactured plug valves can and have been used successfully.

Some recent systems have used resilient-wedge gate valves instead of plug valves with success. With proper care in the selection process, both types of valves can successfully be used.

e. Defective Tubing-Valve Failure in Open Position

Some valve failures that occurred after startup of one particular system were caused by defective tubing in the controller. These tubes were systematically replaced with new ones and this problem disappeared.

3.7.4.2 Design Shortcomings

a. Discharge Pump Cavitation

Some systems have reported problems with wastewater discharge pump cavitation. This was due to the characteristics of the pump itself. A vortex plate installed in the bottom of the collection tank corrected this problem.

The real solution lies in proper design. Net positive suction head (NPSH) calculations should be performed. Section 3.4 discusses these calculations. A pump having sufficient NPSH available should be selected.

b. Leaking Check Valves

Check valves between the vacuum pumps and the reservoir tank installed in a vertical pipe run resulted in vacuum loss problems in the station piping. Locating the check valves in a horizontal run of station piping corrected this problem.

c. Oversized Vacuum Pumps Keep up with Open Valve

One of the newest systems in operation was designed with the more recent and more conservative design guidelines. This resulted in larger vacuum pumps than would be selected using the old design standards. While this additional capacity has helped in terms of system pump down-time, it also has caused a small problem.

The vacuum pumps appear to have sufficient capacity to keep up with an open valve. This being the case, low vacuum is not recorded at the station, even though it is occurring at the location of the open valve. In addition, the automatic telephone dialer is not activated. This results in increased run-time of the vacuum pump and increased power costs. The operator must be very observant when analyzing the daily vacuum charts to notice that the pumps are cycling more frequently than normal. Otherwise, a valve that is hung open may go unnoticed for days resulting in a waste of power.

A simple solution to this problem involves installing another relay in the control wiring that causes the dialer to call the operator if both pumps are running together for a predetermined amount of time (say 10 minutes), despite the vacuum level.

3.7.4.3 Operator Error

a. Wastewater Pulled Into Vacuum Pumps

A high wastewater level in the collection tank can be caused by pump failure (usually control related rather than a pump malfunction) or by more flow coming in than the wastewater pumps are capable of pumping out. Most

system designs call for an automatic shutdown of both vacuum and discharge pumps in the event of this happening. Some systems, however, do not have provisions to prevent the automatic mode from being overridden by manual operation.

The natural inclination, when faced with a zero-vacuum situation, is for the operator to manually operate the vacuum pumps in an attempt to restore system vacuum. Doing this with a full collection tank can result in wastewater being pulled into the vacuum pumps. This results in damage to the vacuum pumps, especially with the sliding-vane type.

The proper procedure, assuming the discharge pumps work, is to valve off the incoming lines and turn the vacuum pumps off. The discharge pumps are then used to pump the collection tank down to the normal operating level. The line valves can then be opened and the vacuum pumps returned to their automatic mode. Good design will include electrical provisions to prevent overriding the automatic mode without these steps first being taken.

3.7.4.4 Construction Related

a. Line Break

Line breaks, caused by a trench settlement, were most likely the result of inadequate bedding materials or poor compaction during construction.

b. Broken Fittings

There have been cases of loss of system vacuum due to broken fittings. In all but a few cases, the failures have occurred at fittings at or near the valve pit. This is most likely due to insufficient compaction around the valve pit coupled with system rigidity due to solvent welded fittings.

c. Construction Debris-Valve Failure in Open Position

These systems experienced more problems than others on startup. Construction debris (stones, small pieces of pipe, etc.) in the homeowner's building sewer causes the vacuum valve to hang open until manually cleared. These problems usually disappear within a few weeks of startup. Problems of this nature are easily discovered by the operator simply by listening to the auxiliary vent. Hearing the constant rushing of air is a good indication that the valve is hung open. Opening the valve pit, unscrewing the valve body, and clearing the obstruction is a 10-minute procedure.

d. Extreme Heat in the Station

Temperature approaching 70°C (175°F) were reported in one system shortly after startup. The hot air from the vacuum pumps was blown directly at the motor control

center (MCC). The extreme heat caused relay and starter problems in the MCC, which resulted in pump and telephone dialer malfunctions.

An analysis of the situation revealed that the vacuum pumps were wired incorrectly. Rather than the pump fans coming on when the temperature reached 65°C (150°F) and remaining on until the pumps turned off, the fans came on at the same time the pumps did and ran for a timed 10 minutes. This has been corrected and the result is a much cooler vacuum station. Future plans call for the hot air to be directed away from the MCC through duct work.

e. Broken Cleanouts

A few cases of broken cleanouts have occurred. Breaks in fittings adjacent to the cleanouts were believed to be caused by pit settlement due to poor compaction during construction.

3.7.4.5 Equipment Malfunction

a. Faulty Level Control Transmitter

At one system, a problem with one of the level probes occurred. The probe failed to send the proper signal to the motor control center to turn the vacuum pumps off during periods when high wastewater levels existed in the collection tank. This resulted in wastewater being pulled into the vacuum pumps causing damage. Another time the probe failed to send the proper signal to the motor control center to turn off a discharge pump. This resulted in the pump continuing to run until the tank was dry. The problem was traced to a faulty transmitter which was replaced.

Since failure of the probe can lead to the ruining of a vacuum and/or a wastewater pump, the operator developed a simple inexpensive backup system, involving the use of magnets strapped to the site glass above and below the highest and lowest set point of the probe. A float-mounted magnet located inside the site glass and, held inside a plastic tube, moves with the level of the tank. Should the probes fail, the floating magnets and one of the fixed magnets will meet, causing a circuit to close and the appropriate pumps to either start or stop.

b. Telephone Dialer Malfunctions-Interference

At one system, the automatic telephone dialer malfunctioned by calling the operator only to report that the system "was all clear." Investigation of this problem revealed that interference from the motor control center, caused by electrical spikes, was sending false signals to the dialer. Shielded cable added to the dialer wiring did not help. The dialer was taken out of the MCC and mounted on a nearby wall. This corrected the problem.

It is now known that the microprocessor-based equipment is very sensitive to power spikes. Provisions should be made during design to filter the power supply or to provide a separate smooth power supply to this kind of equipment.

c. Telephone Dialer Malfunction-Undetermined

A big problem in one of the earlier systems has been the inability of the telephone dialers to function properly. Without a dialer, which provides 24-hr/d coverage, problems go unnoticed until the next work day. While this has reduced the amount of overtime significantly, it has also resulted in increased pump run-times. The operating personnel apparently feel that the system is reliable enough (i.e., oversized vacuum pumps can keep up with a valve failure) and valve failures are so infrequent that replacing the dialers cannot be economically justified.

The above rationale may be a case of false economy. Allowing a low vacuum situation to go undetected for hours will result in unnecessary additional run-time of the vacuum pumps. This will result in increased power costs as well as increased wear on major equipment. This increased wear leads to decreased equipment life. A high-wastewater level in the collection tank typically results in total system shutdown until the operator corrects whatever is wrong. With no dialer to notify the operator of this situation, the system may be down for hours at a time. This will lead to waterlogging, which will require a significant labor effort to correct.

Even more serious is the liability potential that exists as a result of damage done by system backups into the customer's homes. For these reasons, telephone dialers are considered to be a necessity in the vacuum station.

3.7.4.6 Extraneous Water Related

a. System Waterlogging

One of the most severe problems that can occur with the collection system is loss of vacuum due to "waterlogging." This occurs when wastewater is admitted to the system with insufficient atmospheric air behind it. This results in ever-decreasing vacuum levels beyond the waterlogged section. This may lead to insufficient vacuum to open the vacuum valves and ultimately to wastewater backup in the home. In most cases, waterlogging is caused by too much liquid (extraneous water) entering the system at one time. This is a very difficult problem to address since it typically is related to illegal, and difficult to find, storm water connections by the customer. An aggressive I/I program during the hookup stage will keep problems such as these to a minimum.

b. Water in Controller-Valve Failure in Open Position
Component defects have been responsible for many of the valve failures in the past. With these failures being drastically reduced by component improvements, one of the remaining ways for a valve to fail is through water in the controller. Water in the controller will prevent it from completing its cycle and the valve will remain open. This problem is more likely to occur with the Model "S" valve than with the model "D" valve.

In either the Model "S" or Model "D" valve, water can enter the controller in two general ways. In the first way, water that is present in the upper valve chamber enters directly into the controller as a result of the controller not being air and/or vacuum tight. A tightness test is normally performed at installation, during the annual preventive maintenance visit, and anytime emergency maintenance is performed on the valve. The other possibility is through condensation in the breather tubing. A properly installed breather line, with a drain leading to the valve, will prevent this second case from occurring.

With the Model "S" valve, a third possibility exists. In this case, water comes directly from the lower sump to the controller. The Model "S" valve requires a watertight seal between the upper and lower sections of the valve pit so that a bubble of air can be trapped for use by the valve controller during its cycle. Should the seal be broken and water take the place of air, it will be drawn into the controller by vacuum when the valve cycles.

3.8 System Costs

3.8.1 Construction Costs

3.8.1.1 General

Certain site conditions contribute to the high cost of conventional sewer installation. These include unstable soils, rock, and a high water table. In addition, restricted construction zones or areas that are flat may also result in high construction costs. By using vacuum sewers, the construction costs for these difficult conditions can be reduced. Smaller pipe sizes installed at shallower depths are the prime reasons for this. The uphill transport capability, even when used only to a very small degree, may save many dollars in installation costs. One other major advantage is the extent to which unforeseen subsurface obstacles can be avoided. Each of these considered individually results in lower costs. Considered collectively, they may result in substantial cost savings.

It is not uncommon for a wide range of bids to be received on an engineer's first vacuum project. Contractors unfamiliar with vacuum sewers may bid high simply because of the fear of the unknown (e.g., bid as if the

project were a gravity sewer). Equally possible is a contractor who bid too low because of an underestimation of the effort required (e.g., bid as if it were a water line). Usually the cost is somewhere between these two extremes. Once the contractors have experience constructing vacuum sewers, the spread between low and high bid narrows. It then becomes much easier for the engineer to estimate the construction costs of future projects.

Many factors affect construction cost bids. Material surpluses or shortages, prevailing wage rates, the local bidding climate, geographic area, time of year, soundness of the design documents, and the design engineer's reputation are examples of these. Funding and regulatory requirements also play a part in project cost estimating to the extent that the regulations may be a help or hindrance to the contractor, the client, and the engineer.

Because of the many variables, accurate cost-estimating guidelines are beyond the scope of this manual. The following general guidelines, however, will be of help to the estimator.

3.8.1.2 Piping System

Pipe installation prices are a function of pipe diameter, pipe material, trench depth, and soil conditions. Other factors, such as shoring, dewatering, and restricted construction area conditions will have a large effect on the price.

Piping systems are best estimated using guidance from water system projects built in the same area, if similar materials and specifications are used. The best situation is one where the water line project was designed and construction managed by the same engineering firm as is producing the sewer cost estimate. In this way, projects similarities and differences can be factored into the comparison. If the estimating engineers are not familiar with the project they are obtaining guidance from, they should become familiar with the specifications for that project to rationalize differences between the projects. In some cases, the Associated General Contractors (AGC) can provide helpful insight.

In the absence of better information, Table 3-25 provides estimating data for planning purposes only. This table was prepared by reviewing bid tabulations from numerous projects throughout the United States. Some projects were known to have been built so cheaply that long term performance was questionable. Other projects had unusually stringent specifications or other features that resulted in particularly high costs. Both the high cost and low cost bid tabulations were discarded, leaving mid range averages to produce the table.

Table 3-25. Average Installed Unit Costs (Mid-1990) for Vacuum Sewer Mains and Appurtenances

Item	Unit Cost (\$)
4-in Mains	11.00/LF
6-in Mains	14.00/LF
8-in Mains	17.00/LF
Extra for Mains in A.C. Pavement	5.00/LF
4-in Division Valve	350/ea.
6-in Division Valve	400/ea.
8-in Division Valve	550/ea.
Gauge Tap	50/ea.
Lifts	50/ea.

Table 3-26. Average Installed Unit Costs (Mid-1990) for Valve Pits and Appurtenances

Item	Unit Cost (\$)
Standard Setting	2,300/ea.
Deep Setting	2,500/ea.
Single Buffer Tank	3,000/ea.
Dual Buffer Tank	4,000/ea.
Extra for Anti-Flotation Collar	100/ea.
4-in Auxiliary Vent	50/ea.
External Breather	50/ea.
Optional Cycle Counter	125/ea.

Pipe prices include furnishing and installing the pipe, excavation, bedding, backfilling, compaction, vacuum testing, cleanup, and similar requirements. Not included are allowances for such items as rock excavation, engineering, and administration.

3.8.1.3 Valve Pits

Valve pit prices will vary depending on the type of valve, type of pit, and depth of the pit.

The most common valve pit setting (standard setting) consists of the following:

- Model D-3-in vacuum valve w/controller
- 16 in x 30 in fiberglass tapered sump - 30-in deep
- 27 in x 36 in fiberglass valve pit - 42-in deep
- Pit bottom
- Cast iron frame and cover
- 3-in suction line
- 2-in sensor line
- All piping/tubing hardware
- Grommets for openings
- 4-in gravity stub-out - 6-ft long

Table 3-27. Average Installed Cost (mid-1990) for Vacuum Station

Item	No. Customers	Equipment Cost* (\$)	Building Cost (\$)	Installed Cost (\$)	Total Cost (\$)
Package Station	10-25	50,000	25,000	20,000	95,000
Package Station	25-50	75,000	30,000	25,000	130,000
Package Station	50-150	90,000	40,000	30,000	160,000
Custom Station	100-300	120,000	50,000	40,000	210,000
Custom Station	300-500	140,000	60,000	50,000	250,000
Custom Station	>500	170,000	75,000	75,000	320,000

* Includes Generator

Deeper settings contain the same items, except the 30-in deep sump is replaced by a 54-in deep sump.

Single buffer tanks consist of the following:

- Model D-3-in vacuum valve w/controller
- 4-in diameter concrete manhole - variable depth
- Cast iron frame and cover
- 3-in suction line
- 2-in sensor line
- All piping/tubing hardware
- All pipe support hardware
- 4-in gravity stub-out - 6-ft long

Table 3-26 gives average installed unit prices for the various valve pit settings and appurtenances. The prices include furnishing and installing the valve pit, excavation, bedding, backfill, compaction, vacuum testing, and surface restoration.

3.8.1.4 Vacuum Stations

The price of a custom-designed vacuum station depends very much on the equipment selected, the type of structure it is housed in, and the amount of excavation required.

Equipment cost varies with the capacity required for each component. Equipment for a typical vacuum station includes:

- Vacuum pumps (2)
- Wastewater Pumps (2)
- Generator
- Collection tank
- Reservoir Tank
- Level controls
- Motor control center

A package vacuum station, used for smaller (<250 gpm) projects, includes the above equipment, with the exception of the generator and reservoir tank. This equipment is

assembled, painted and tested at the factory and then shipped on a skid for placement in the building.

Table 3-27 gives average installed prices for both custom-designed stations as well as for package stations. The prices include the equipment (including the generator for all stations), station piping, electrical, excavation, site restoration, and labor.

3.8.2 Estimating Techniques

Most engineers are capable of estimating capital costs in their geographic area of practice once major material component costs are known. Installation cost can be developed by analyzing the effort required to install conventional technology and applying the appropriate modifications to the unit prices to correct for the local site conditions. Using sound engineering practices the engineer should be able to make a fairly accurate estimate of the construction costs. The following steps may be of some value for engineers considering vacuum sewers for the first time:

- Analyze bid tabulations of other vacuum projects. It is desirable to use a project that is in the same geographical area and has similar site conditions.
- Request a set of plans and specifications in order to gain a full understanding of what each bid item includes. Ask about any peculiar or unusual bidding conditions.
- Estimate the cost of the system by applying modified unit prices that take into consideration the locale and site conditions.
- Correct for inflation by applying the appropriate cost index.

Because of the many factors that influence a bid, it is difficult to say if the above procedure will yield information of quantitative value, although qualitative assistance is likely.

Table 3-28. Typical O&M Cost Components

Labor	Normal, preventive, emergency maintenance
Clerical	Billing
Power	Vacuum and sewage pumps
Utilities	Water, phone, fuel
Transportation	Vehicle amortization, fuel, ins.
Supplies/Maintenance	Maintenance contracts
Misc. Expenses	Insurance, professional fees
Equipment	Renewal and replacement (sinking fund)
Future Connections	Set-aside amount (if required)

3.8.3 Operation and Maintenance Costs

The obvious advantage to utilizing vacuum sewers is a savings of capital costs. This savings, however, may come at the expense of higher O&M costs. The question then becomes, "Is the savings of capital cost enough to offset the increase in O&M expenses?" A present worth analysis, where life cycle costs are converted to present values, will answer this question. This analysis, however, is only valid if reasonable capital and O&M cost figures are used.

Because of the relatively new nature of the vacuum sewers, very little historical cost data exist. This is especially true for operation and maintenance costs. This lack of data has led many to the conclusion that vacuum sewers must be O&M intensive. A review of operating records of systems discussed in this chapter suggests that previously published O&M figures may no longer apply. Reasons for this are twofold. First, the previous figures were based on very limited data on a few early systems. Second, component improvements have resulted in significantly fewer service calls and lower O&M costs. These factors require that the previously published data be used only as a knowingly conservative estimate of the state of the art.

Information gathered from the systems that were visited in 1989 was used in the formation of the estimating tables that follow. Data from the Ocean Pines system was not included since this system is not representative of the current state of vacuum technology.

Table 3-28 shows typical O&M cost components.

3.8.3.1 Labor

Labor costs are estimated by multiplying the number of person-hours required by the hourly rate, and adding fringe benefits. The annual person-hour requirements are made up of normal, preventive, and emergency maintenance.

Table 3-29. Person-Hour Estimating Factors

	Low	High	Average
	(Person-Hour/Yr/Valve)		
Normal	0.4	3.9	1.7
Preventive	0.5	1.1	0.7
Emergency	0.2	1.2	0.8
Total	1.6	4.8	3.2

For normal maintenance, an operator is not required 24 hours a day to monitor the system, as the telephone dialer does this for him. However, someone must be available around the clock in case the telephone dialer calls with a problem. In this respect, vacuum systems are unique. Very few problems in a vacuum system can go uncorrected for any length of time without causing a cumulative effect.

The operating entity's overall responsibilities should be considered when estimating the labor costs. For example, the entity may also be responsible for other sewer facilities, or possibly even water facilities. In these cases, operating personnel are usually shared. At the end of the year, the time charged to the operation of the vacuum system most likely will relate exactly to the effort required (e.g., 1 hr/d plus some hours charged to emergency maintenance). If the overall facilities are large enough to warrant different shifts, emergency work most likely will be done without overtime being required.

An entirely different situation exists for the entity operating nothing but a similarly sized vacuum system. Typically, a full-time operator is hired. This person charges 8 hr/d to the maintenance of the system although most days he will spend much less than this. Should a problem develop after normal working hours, he most likely will be paid overtime. Even though both operators will spend the same amount of actual maintenance time, the amount of billed time will be entirely different. The engineer should carefully analyze the client's overall operation, taking into consideration the possibility of shared duties, prior to making an estimate of the labor costs.

Preventive maintenance is usually scheduled to be done by the normal workforce during off-peak working hours. Because of this, preventive maintenance is usually reported as normal maintenance.

Emergency maintenance many times requires personnel after normal working hours. The result is overtime pay. Emergency maintenance typically requires two operators or one plus an assistant.

Table 3-29 presents a range of person-hours required per year as a function of the number of vacuum valves. As such, the values shown should be considered as realistic values for new systems with proper design, construction, and operation.

When a full-time operator is to be hired, regardless of anticipated workload, the values in Table 3-20 should not be used. In this case, the estimated annual person-hour requirements should include the full-time hours of employment plus an estimate of the overtime (emergency maintenance) hours, taking into consideration overtime work generally requires two people. No allowance is needed for normal or preventive maintenance since these can be performed during normal working hours.

The following equation can be used to estimate annual labor hours for the case of a full-time operator. This equation assumes a 40-hr workweek and that 50 percent of the emergency maintenance will occur during normal working hours.

$$2080 \text{ hr/yr} + (0.5 \times \text{EMF} \times \# \text{ valves} \times 2)$$

Where,

EMF = Emergency Maintenance Factor from Table 3-29

As an example, a system with 200 valves and an average EMF (0.8 hr/yr/valve) would yield an annual labor requirement of $2,080 + 160$, or 2,240 hr. Given the range of EMF from Table 3-29, this requirement could vary from 2,120 hr to 2,320 hr.

3.8.3.2 Clerical

This item includes wages for the clerical staff. Also included would be the billing costs such as envelopes and stamps. Like labor costs, the value of this item most likely will depend on whether the operating entity has an existing, ongoing operation which requires office staff. If so, the costs would be limited to the direct billing expenses only.

3.8.3.3 Power

Power is required for the vacuum pumps, the wastewater pumps, and the heating and lighting of the vacuum station. Once the design is completed, it is possible to accurately estimate the annual power consumption.

Power costs for both the vacuum and wastewater pumps are estimated by using the following general equation:

$$P = 0.746 T H C$$

Table 3-30. Vacuum Station Power Consumption Estimating Factors

Low	High	Average
(kWh/Yr/Customer)		
160	460	250

where:

P = Annual power cost (\$)
T = Time of operation (hr/yr)
H = Horsepower
C = Cost of electricity (\$/kWh)

This equation does not include any surcharge the power company may assess on peak demands. The local rate structure of the power company should be analyzed and an appropriate surcharge estimated.

The capacity of the vacuum pumps, and the resulting horsepower requirements, can be determined by using the equations in Section 3.4. Likewise, the run-time of the vacuum pumps can also be determined. An allowance, typically an additional 10-20 percent should be made in the run-time to account for leaks, breaks, and valve failures.

The capacity of the wastewater pumps and the resulting horsepower requirements were discussed previously. Daily run-time can be estimated by dividing the average flow (gpd) by the normal discharge rate (gpm) and again by 60 to convert the units. Annual run time is then computed by multiplying the result by 365.

There are also power costs for heating, ventilation, and lighting at the vacuum station, which generally amount to less than \$50/month.

For planning purposes, values shown in Table 3-30 can be used to estimate the annual power consumption for the entire vacuum station.

It should be noted that the high factor shown in Table 3-30 was for a early vacuum system. The average figure is a more accurate representation of the power requirements of recent vacuum systems.

3.8.3.4 Utilities

Utilities at the vacuum station generally include water, telephone, and fuel. Water may be required for sinks, hose bibs, or toilets. A telephone is required for the fault monitoring system. Some systems make use of cellular phones, while others use radio communications rather than a telephone. Fuel may be required for the standby

generator. The cost of these utilities generally is less than \$50/month.

3.8.3.5 Transportation

Vehicle expenses to maintain the system will be incurred. For estimating purposes, a mileage rate multiplied by the estimated annual miles will suffice. This rate should include vehicle amortization, depreciation, taxes, and similar expenses. Mileage will be required for the following tasks:

- Daily visits to the vacuum station
- Annual visits to valve pits for preventive maintenance
- Periodic emergency maintenance

3.8.3.6 Supplies/Maintenance

As with a conventional system, certain supplies will be required. Restocking of spare parts and inventory is included in this item, as are oil, fuses, charts, and chart pens. Initial purchase of items on quantity discount should be maximized to take advantage of the lower unit costs when compared to subsequent prices for replacement.

Service contracts for emergency generators, as well as fuel for the generators, may also be included in this item.

3.8.3.7 Miscellaneous Expenses

Miscellaneous expenses include insurance and maintenance on the system structures as well as professional services (engineering, accounting, legal) that may be required during the year.

3.8.3.8 Equipment Renewal and Replacement

An annual set-aside account should be established to generate sufficient funds for major equipment renewal and replacement. The annual cost is estimated by dividing the replacement cost by the useful life. This amount is generally set aside in an interest bearing account until needed. Present dollars can be used in the estimate since the interest earnings most likely will offset inflation. Alternative methods dictated by regulatory agencies also can be employed.

Table 3-31 lists the major equipment items and their useful life.

3.8.3.9 Future Service Connections

The costs of future service connections may have to be included in the O&M budget. Unlike conventional systems, where a future connection may be relatively inexpensive, a future vacuum connection can be quite costly. The costs of a valve, valve pit/sump, fittings, pipe, and labor may exceed \$2,000.

Table 3-31. Typical Renewal and Replacement Factors for major Equipment

Item	Useful Life (yr)
Vacuum Pumps	10
Sewage Pumps	10
Vacuum Valve rebuild	6
Misc. Station Equipment	10

Most systems that were visited simply charge the future customer the cost of the connection. This does not appear to be a problem, since most new houses would have a similar expense for an on-lot system. In this case, the annual operating budget does not have to include a line item for future service connections.

In West Virginia, however, this is not the case.⁶ Sewer utilities are regulated by a Public Service Commission. This agency hesitates to approve a tap fee greater than \$250, regardless of the type of system. For this reason, the operating entity must include the cost of future connections in their rate package as an annual set-aside. The total installation cost is discounted by the \$250 tap fee and multiplied by the number of estimated annual future connections. Since some future customers may be able to connect to an existing valve pit, a sharing factor may be applied. This method requires present customers to subsidize the cost of future connections.

A modification of this concept includes prefinancing a set amount of future connections in the construction capital budget, and adjusting the annual set-aside amount accordingly. An example calculation of this set-aside amount follows:

No. vacuum customers	140
No. vacuum valves	110
Sharing factor, percent	78
20-year growth rate, percent	15
Cost of new service, \$	2,000/ea
Tap fee, \$	250/ea
No. prefinanced connections	8
Net cost of connection, \$	$2,000 - 250 = 1,750$
Total set-aside required, \$	$1,750 \times 8 = 14,000$
Annual set-aside required, \$	$14,000/20 = 700$

3.8.4 User Charge Assessments

To generate sufficient revenues to offset expenses, the operating entity must develop a user charge system. Components of the annual budget are:

- O&M expenses
 - Labor
 - Clerical

Table 3-32. Annual Budget Example

	Vacuum	Pressure/Gravity	Treatment Plant	Total
O&M				
Labor	3,500	2,000	14,300	19,800
Clerical	460	540	0	1,000
Power	2,200	2,000	6,900	11,100
Utilities	750	500	750	2,000
Transportation	1,400	200	400	2,000
Supplies/Maintenance	1,500	200	1,630	3,330
Miscellaneous Expenses	1,000	500	2,000	3,500
Chemicals	0	0	1,200	1,200
Equipment Replacement/Repair	1,600	3,100	2,200	6,900
Future Service Connection	700	65	0	1,350
Total O&M	13,110	9,690	29,380	52,180
Debt Service	16,655	16,655	11,710	45,020
Total Annual Budget	\$29,765	\$26,345	\$41,090	\$97,200

- Power
- Utilities
- Transportation
- Supplies/Maintenance
- Miscellaneous Expenses
- Equipment Renewal and Replacement
- Future Service Connection
- Debt Service

There are different methods of developing rates. A common method includes a charge based on metered water consumption, with a flat rate for nonmetered users. The rate structure may be the same for all levels of usage, or may decline as water use increases. Others simply charge a flat rate for all users. No matter what system is used, the rates must be sufficient to generate the required revenue.

Most tariffs include provisions for tap fees. These generally cover initial users of the system as well as future users. The initial tap fees are generally used to cover startup expenses. Tap fees for future connections are used to offset all or part of the actual cost to make the connection.

As an example, the projected annual operating budget of a project in West Virginia¹ is presented in Table 3-32. This project is scheduled for construction in 1991, with

operation to begin in 1992. The project consists of a hybrid collection system (vacuum, pressure, and gravity) and a treatment plant.

General Project Information for Annual Budget Example:

	Vacuum	Pressure/ Gravity	Treatment Plant	Total
Const. Costs, \$	1,000,000	1,000,000	750,000	2,750,000
No. Connections	140	160	300	300

3.9 System Management Considerations

3.9.1 Homeowner Responsibilities

Use of the system should comply with requirements of the user ordinance. Typical requirements include that the homeowner should not drive or build over the tank, and should protect the facilities from damage. Discharge of flammables, acids, excessive amounts of grease, sanitary napkins, or other non-wastewater items is discouraged. This requirement differs little from user ordinance requirements for conventional sewers. Proper use of the system results in lower user charges and improved reliability.

3.9.2 Sewer Authority Responsibilities

Once all customers are connected, the Authority is focused on providing reliable, efficient service to their

customers. To achieve this, the operating personnel must be capable, dependable, and knowledgeable. Of utmost importance is attitude. An operator that does not believe in the system will ultimately cause the system to operate below its potential, in terms of reliability and costs. Conversely, one with a good attitude uses creativity to get more out of the system than was originally planned.

To operate any system at a high level of efficiency requires a Sewer Use Ordinance. This document sets consistent rules for all users to follow. Included are material specifications for the building sewer, minimum slope requirements, and vent locations. Of extreme importance to the Authority is a limitation of use of the vacuum sewer to sanitary wastes only, as extraneous water will cause operational problems.

An active program for the identification of extraneous water sources should be developed. This may include smoke testing and dye testing. To identify and quantify sources of extraneous water, the Authority can take advantage of an integral feature of a vacuum system: the cycle counter. This device, when connected to the valve, will record the number of times the valve opens in a given period. Knowing that each cycle is approximately 38 L (10 gal), the Authority can estimate, based on water consumption records, the minimum number of cycles expected over that period. A count much in excess of the expected may be a sign of extraneous water. To quantify the amount, the number of cycles is multiplied by 38 L (10 gal) and compared to the water consumption. Listening to the auxiliary vent for sounds of running water when no wastewater-generating activity is taking place may also provide clues for sources of extraneous water.

The Authority also is responsible for future extensions of the system. This includes proper planning, design, and construction of such extensions. Finally, future connections to the existing system are made by the Authority in accordance with the provisions of the Sewer Use Ordinance.

3.9.3 Other Entities

During the planning, design, and construction of sewer systems, there are many different entities involved. Two of these are regulatory agencies and the engineer. It is during these times that many decisions are made and details finalized. Often, these entities view the startup of a system as their final involvement. While this attitude is understandable, it is not acceptable. Continuing involvement is needed to help develop an experience base with newer systems which permits intelligent applications in the future.

The engineer should spend a significant amount of time during the startup of the system. Tests should be run and problems simulated to see if the system is operating as designed. Periodically, the operating records should be analyzed for budget sufficiency purposes. Problems and their solutions should be recorded. In short, the engineer should use the operating experience of the system to help develop improvements in future designs.

Likewise, regulatory agencies should follow up on the operation of a new system. Information on problems, including causes and the remedies, should be gathered. Cost data should be obtained. This type of information can then be used for future projects.

It is this present lack of information that causes many engineers and regulatory agencies to shy away from a new technology. It has become easier to be conservative, and hence unduly critical, rather than to learn the details of a new technology, no matter how cost-effective.

3.10 References

When an NTIS number is cited in a reference, that reference is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

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CHAPTER 4

Small Diameter Gravity Sewers

4.1 Introduction

Small diameter gravity sewers (SDGS) 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 (septic tank effluent pumping [STEP] unit) into the gravity collector mains usually located in the public right-of-way. The mains transport the tank effluent to a treatment facility or connection with a conventional gravity sewer interceptor.

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 gradient needed and, as a result, the depth 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 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 and operation and maintenance (O&M) 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. Also, effluent sewer termination into vacuum systems could have odor potential at the central vacuum station.

4.2 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 4-1). Other appurtenances may be added as necessary

4.2.1 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 10-15 cm (4-6 in) diameter pipe laid at a prescribed slope, usually no less than 1 percent, made of cast iron, vitrified clay, acrylonitrile butadiene styrene (ABS) or polyvinyl chloride (PVC).

4.2.2 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 greater than 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 be removed, typically on 1-10 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 percent.^{1,2}

Septic tanks are typically used as interceptor tanks (Figure 4-2). 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

Figure 4-1. Components of a small diameter gravity sewer (SDGS) system.

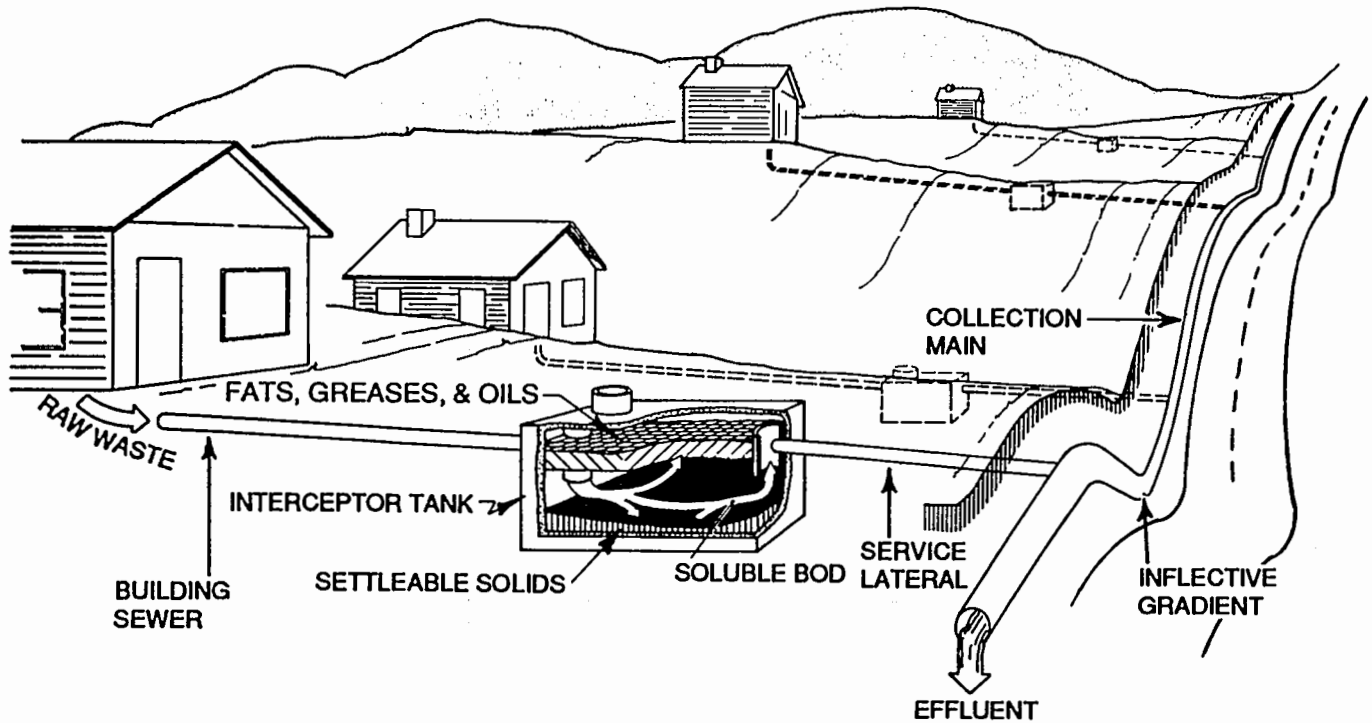
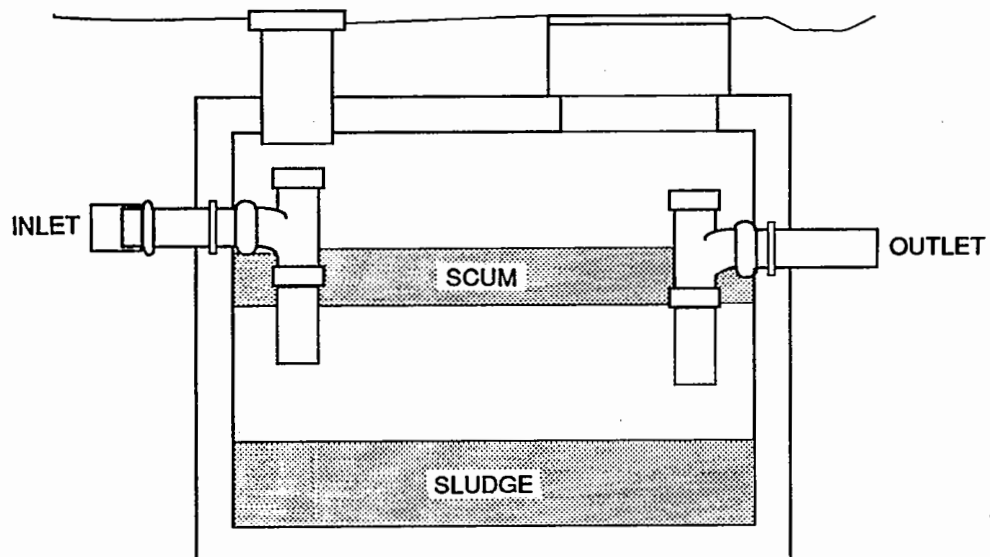


Figure 4-2. Typical pre-cast concrete interceptor tank.



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.

4.2.3 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 4-3).

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 retrofitted 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.

4.2.4 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. However, flexible, high density polyethylene pipe with heat fused joints has also been used successfully.

4.2.5 Manholes and Cleanouts

Manholes and cleanouts provide access to the collector main for various maintenance tasks. 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 120-300 m (400-1,000 ft).

4.2.6 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 4-4). Individual connections located at a summit can also serve as a vent if the service is neither trapped nor fitted with a check valve.

4.2.7 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 lift stations are essentially STEP systems and 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 4-5). 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 effluent is screened prior to pumping to eliminate any solids that might clog the turbines. Mainline lift stations were originally similar in design to the "residential" lift stations, but because of corrosion problems which commonly occur in the wet well, the use of dry wells is becoming more common to reduce corrosion problems and to facilitate maintenance.

4.3 System Design Considerations

4.3.1 Hydraulic Design

A small diameter gravity sewer system conveys settled wastewater to its outlet by utilizing the difference in elevation between its upstream connections and its downstream terminus. It must be set deep enough to receive flows by gravity 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 hydraulic head 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 Chapter 2). The number and location of individual lift stations or STEP units are usually determined from 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 common.

4.3.1.1 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/cap/d (100 gpcd) 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 greatly exceed actual

Figure 4-3. Service lateral installation using a trenching machine.



Figure 4-4. Typical combination cleanout and air release valve detail.

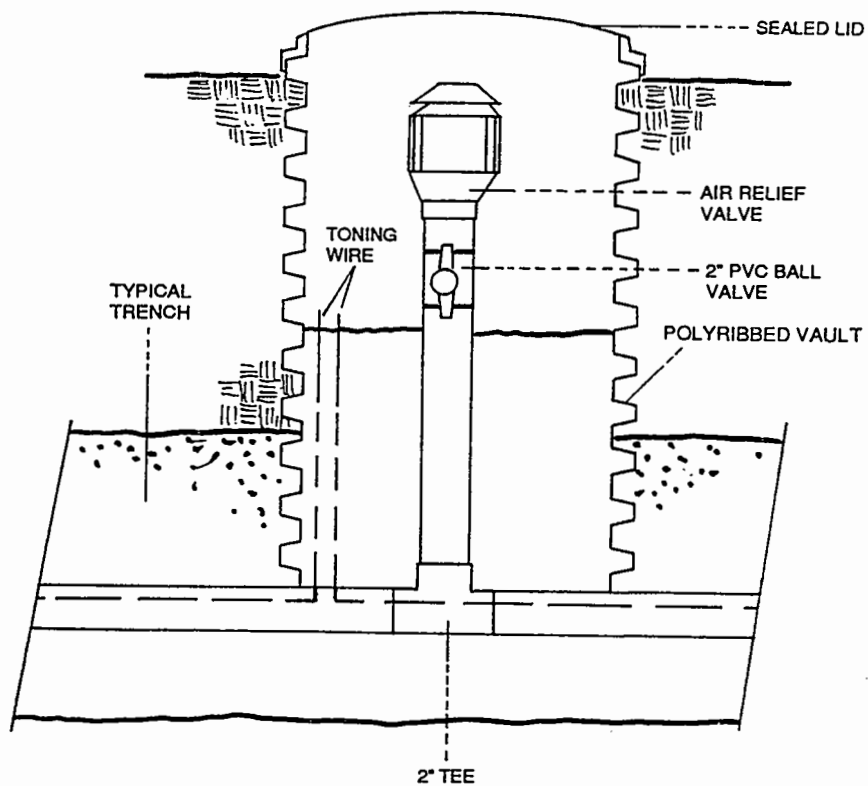
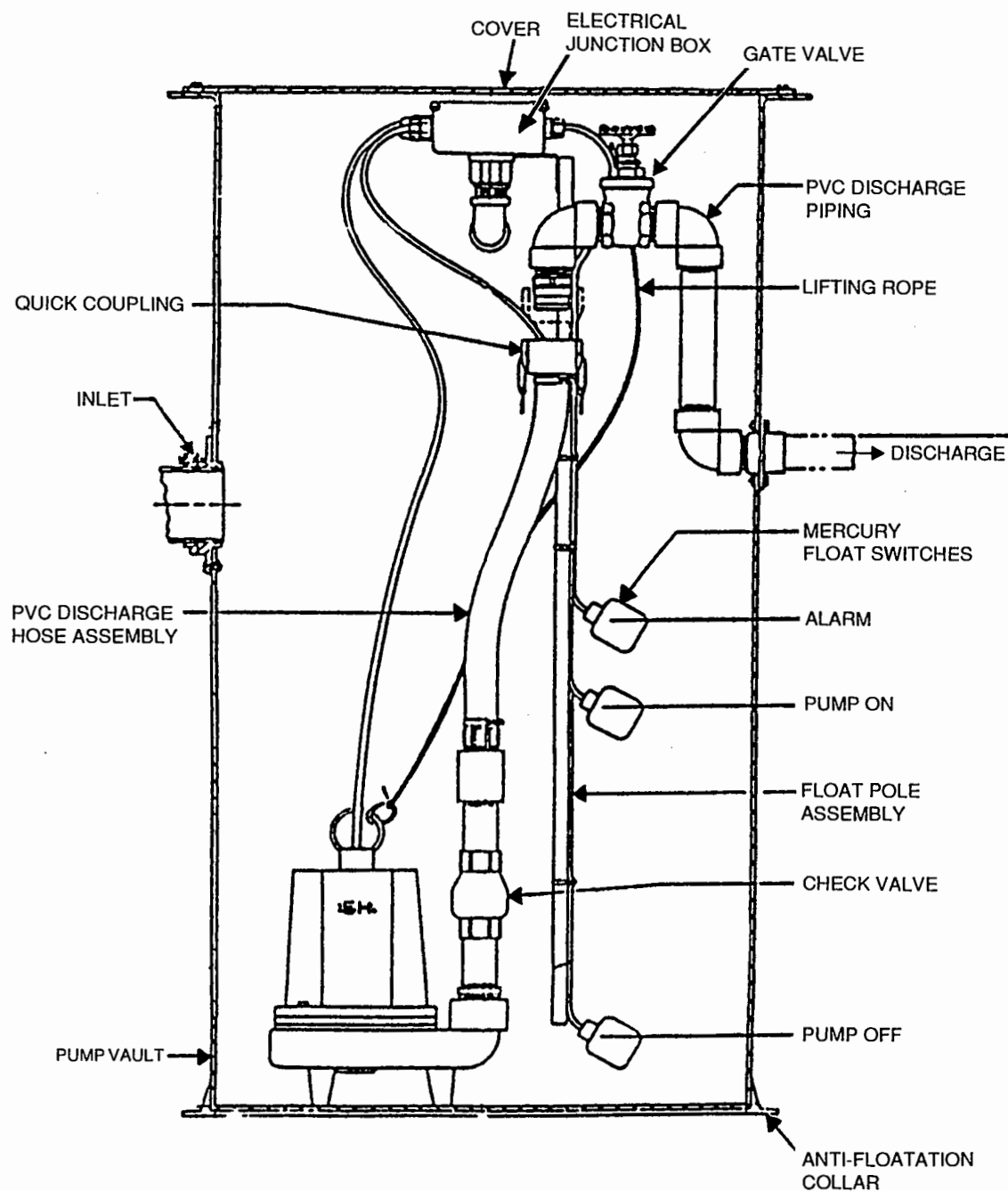


Figure 4-5. Typical STEP lift station detail.



flows because most SDGS serve residential areas where daily per capita flows are far less than 380 L/cap/d (100 gpcd); the peak to average flow ratio is also less than 4 because the interceptor tanks attenuate peak flows markedly.²

Measured average daily wastewater flow per capita is approximately 170 L/d (45 gpd).³⁻⁵ 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 percent less.⁶ Household wastewater flow can vary considerably between homes but it is usually less than 227 L/d (60 gpd) and seldom exceeds 284 L/cap/d (75 gpcd).⁷ Typically, 190 L/cap/d (50 gpcd) is assumed for wastewater flows in residential areas where actual water use data are not available. Commercial flows are estimated individually using established criteria.⁷

The collector mains are sized to carry the maximum daily peak flows rather than the average flow. In residential dwellings, the rate of wastewater discharged from the building depends on its water use appliances and fixtures used. Instantaneous peak flows are typically 0.3-0.6 L/s (5-10 gpm).⁷ Maximum flows of 0.1 L/s (1.7 gpm) may occur.^{8,9} However, the interceptor tank in SDGS systems attenuates these peaks dramatically. Monitoring of individual interceptor tanks shows that outlet flows seldom exceeded 0.06 L/s (1 gpm) and most peaks ranged between 0.03 and 0.06 L/s (0.5-0.9 gpm) over periods of 30-60 minutes. There were long periods of zero flow.² The degree of attenuation depends on the design of the interceptor tank and/or its outlet.

In addition to wastewater flows, allowance must be made for potential clear water infiltration/inflow (I/I). Common sources of infiltration in SDGS systems are 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.²

In all systems, foundation drains and roof leaders may be significant sources of inflow and SDGS projects should attempt to eliminate them during construction. Despite these attempts, the designer may wish to allow for some degree of unavoidable I/I; but this allowance should be significantly lower than typical conventional gravity systems due to their higher elevation and smaller diameter.

Experience with SDGS systems has shown that the criteria used to estimate design flows have been conservatively high. Design flows have generally been 190-380 L/capita/d (50-100 gpcd) with peaking factors of 1 to 4. More recent designs have been based on flows per connection of 545-1,635 L/d (0.1-0.3 gpm). 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.

4.3.1.2 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 15 cm/s (0.5 fps) are achieved.²

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 30-45 cm/s (1.0-1.5 fps) be maintained during daily peak flow periods.

Maximum velocities should not exceed 4-5 m/s (13-16 fps). 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.

4.3.1.3 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 segment of the 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 "n" and "C" values are 0.013 and

140 respectively.² Nomographs and hydraulic elements graphs may be found elsewhere.¹⁰

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 grade 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 valves on the individual service lateral may suffice to prevent backflow.

4.3.2 Collector Mains

4.3.2.1 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 alongside 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 redirected to the front.

4.3.2.2 Alignment and Grade

The horizontal alignment of SDGS need not be straight. Obvious obstacles such as utilities, large trees, rock outcrops, etc. should be avoided with careful planning, but unforeseen obstacles can often be avoided by bending

the pipe. The radius of the bend should not exceed that recommended by the pipe manufacturer for the conditions under which it is to be installed.

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.

4.3.2.3 Pipe Diameter

The pipe diameter is determined through hydraulic analysis. It varies according to the number of connections and the available slope. The minimum diameter used is typically 10 cm (4 in), but 5-cm (2-in) diameter pipe has been used successfully in recent projects. Where the 5-cm (2-in) diameter pipe is used, the interceptor outlets have used flow control devices to limit peak flows, and check valves to prevent flooding of service connections during peak flow periods. The costs of the flow control devices and check valves generally cancel savings realized from the smaller pipe; 10-cm (4-in) diameter pipe, therefore, is most commonly used as a minimum size.

4.3.2.4 Depth

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. Any of these conditions may control. In most cases, designers do not attempt to set the depth such that all connections can drain by gravity. Where gravity drainage from a residential connection is not possible, STEP lift stations are used. An optimum depth is selected to minimize the total construction costs due to mainline 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 75 cm (30 in); however, a depth of 60 cm (24 in) is considered minimum for conventional pipe. 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.

4.3.2.5 Pipe Materials

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 affected segment of collector mains because of pressurizing requirements and the compatibility of pipe fittings. Typically, elastomeric (rubber ring) joints are used, however, for pipe smaller than 7.5 cm (3 in) in diameter, only solvent weld joints may be available.

HDPE has been used infrequently, but successfully. Pipe joining is by heat fusion.

4.3.3 Service Laterals

Typical service laterals between the tank and the sewer line are 10-cm (4-in) diameter PVC pipe, although laterals as small as 3 cm (1-1/4 in) in diameter have been used; they are not recommended. 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 on the service lateral upstream of the connection to the main to prevent backflooding of the service connection during peak flows. If used, it is important that the valve be located very close to the collector main connection. Air binding of the service lateral can occur if the valve is located near the interceptor tank outlet.

4.3.4 Interceptor Tanks

4.3.4.1 Location

The interceptor tanks should be located where they are easily accessible for periodic removal of accumulated solids. Typically, they serve a single home and are located near the house between the foundation and the collector main adjacent to or in place of the existing septic tank. Single tanks serving a group of homes have not been accepted by users because of fear of backups; therefore, tanks at each connection are recommended. 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 4-6).

4.3.4.2 Design

Prefabricated, single-compartment septic tanks are typically used for interceptor tanks in SDGS systems. Most projects standardize the use of 3,785-L (1,000-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. 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 4-7). These devices are not necessary, however, since these solids have not been shown to cause problems in SDGS systems.

Flow control devices have been used on interceptor outlets to limit peak flow rates to a predetermined maximum. Surge chambers were added to interceptor tanks in early projects.¹¹ The surge chamber contained a standpipe with a small orifice drilled near the bottom (Figure 4-8). 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. They also require about 30-45 cm (1.0-1.5 ft) of headloss which may require deeper burial of the collectors and, as a result, higher construction costs. Also, odor problems have resulted due to the free fall of available interceptor tank effluent. Flow control devices are now available that are placed within the interceptor tank and use the freeboard provided in the tank for storage (Figure 4-9).

Water-tightness is a critical criterion in selection of an interceptor tank. For that reason, existing septic tanks are infrequently 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 reviewed which had significant numbers of old tanks all had high ratios of wet weather to dry weather flows.² Common practice now is to replace all tanks. Currently, there is no standard procedure for existing tank leakage inspection. This practice has the added advantage of requiring the property owner to replace the building sewer to ensure greater

Figure 4-6. Alternative locations for interceptor tanks.

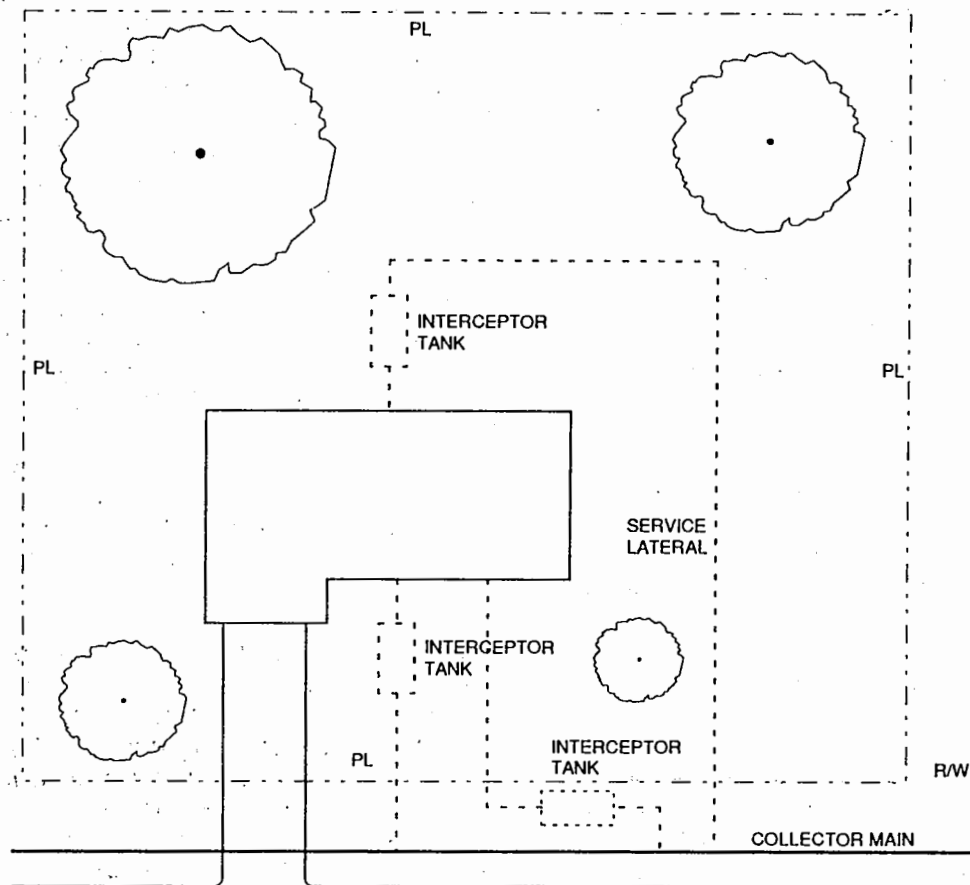


Figure 4-7. Typical interceptor tank outlet baffles.

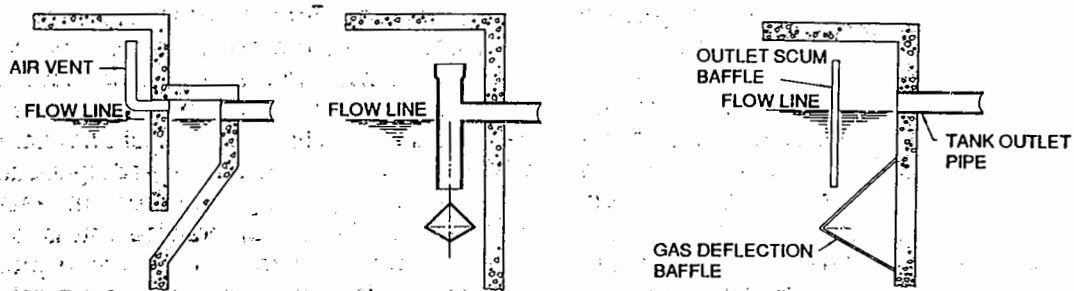


Figure 4-8. Typical surge chamber detail. (Courtesy Orenco Systems)

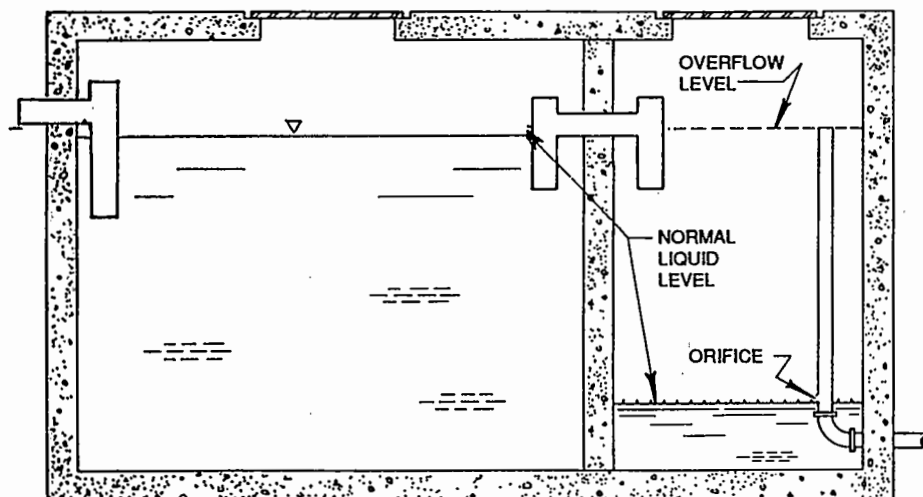
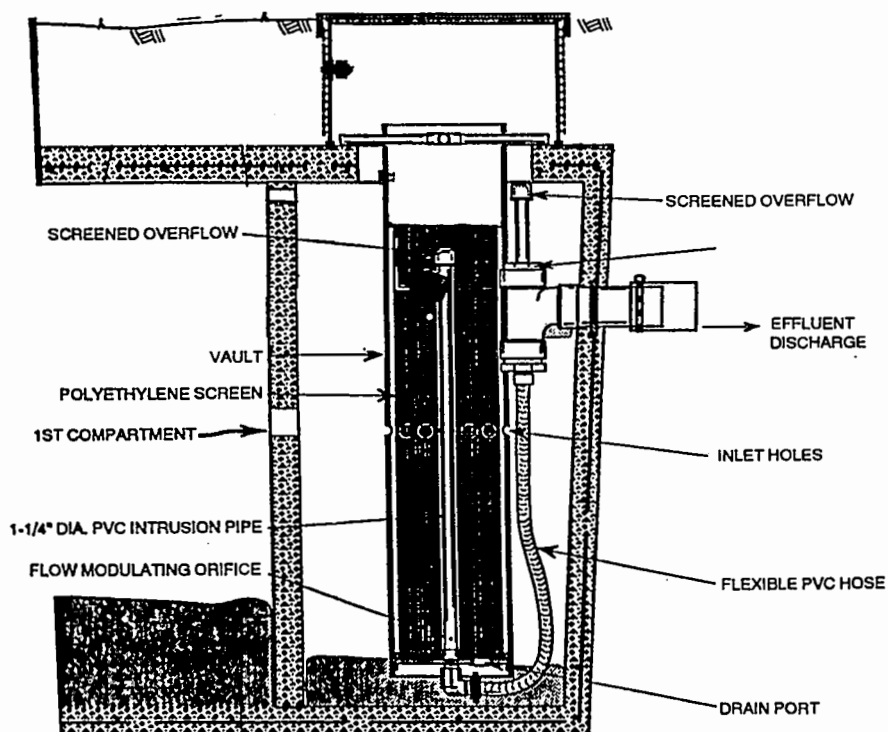


Figure 4-9. Interceptor outlet flow control device.



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 tank's septic conditions, unsupervised or unaccompanied personnel must not enter the tank. All applicable safety codes must be followed in the design of these facilities. 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.

4.3.4.3 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 during storage and installation, 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.

4.3.5 Manholes and Cleanouts

In most SDGS systems, cleanouts are used instead of 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. Manholes represent a potential source of odors and of grit and other solids in SDGS systems.

Cleanouts are typically located at upstream termini of mains, junctions of mains, changes in main diameter and at intervals of 120-300 m (400-1,000 ft) (Figure 4-10). Cleanouts may also be used in place of drop manholes. 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 4-4) or an open vent cleanout installed (Figure 4-11).

4.3.6 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 wastewater applications with working mechanisms made of type 316 stainless steel or of a plastic proven to be suitable. The valves are installed within meter or valve boxes set flush to grade and covered with a water tight lid (Figure 4-4). If odors are detected from the valve boxes, the boxes may be vented into a small buried gravel trench beside the boxes (see Section 2.4.8).

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 5-cm (2-in) diameter mains. Many types of check valves are manufactured, but those with large, unobstructed passageways and resilient seats have performed best. Wye pattern swing check valves are preferred over tee pattern valves when installed horizontally. Although the systems with 10-cm (4-in) diameter mains have operated well without check valves, their use can provide an inexpensive factor of safety for these applications as well. 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. Care must be exercised to prevent backflow through such connections in areas with high groundwater. In Australia, a "boundary trap" is included at every connection which provides an overflow to the ground surface if backups occur (Figure 4-12).¹²

4.3.7 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

Figure 4-10a. Typical cleanout detail.

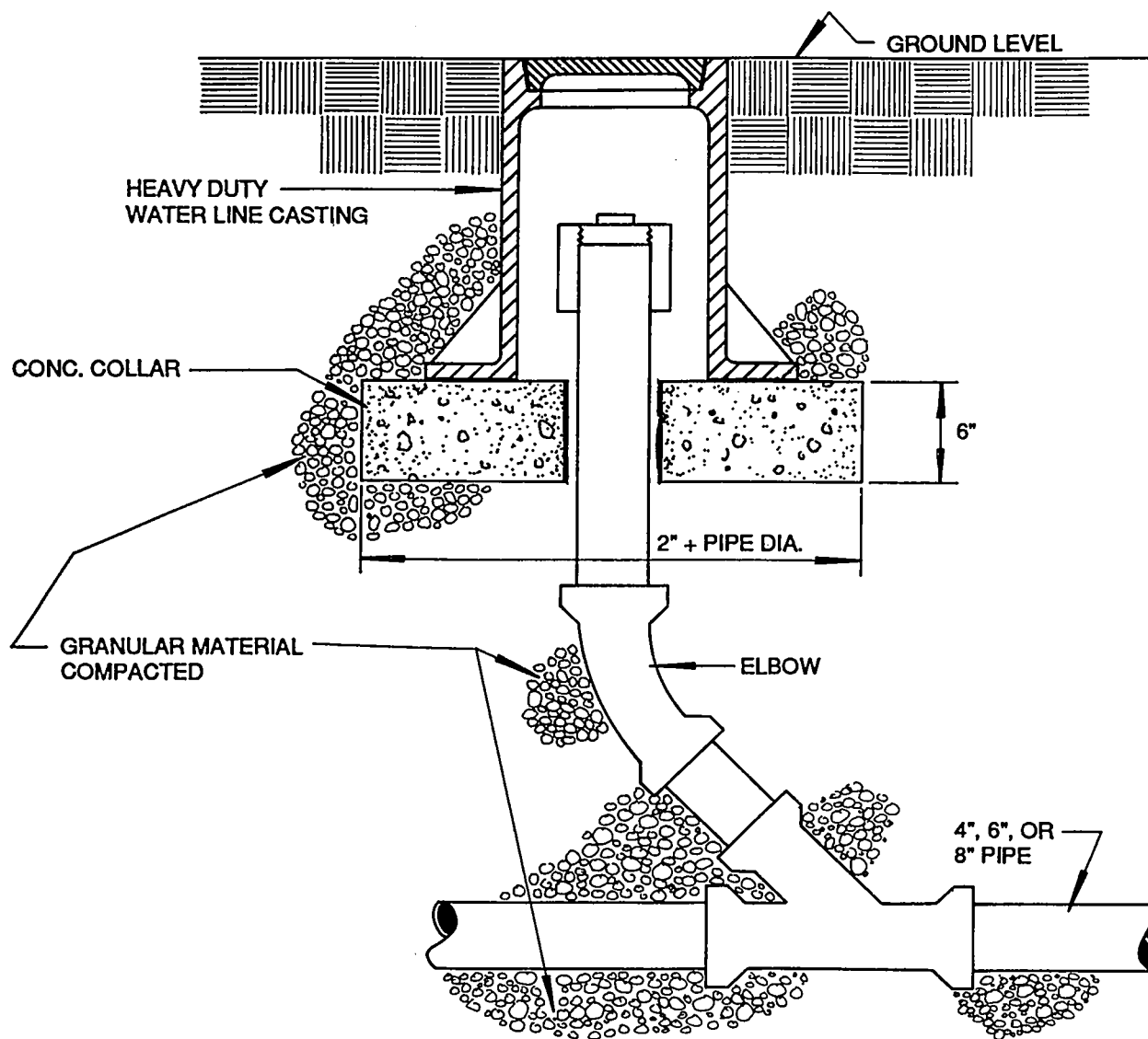


Figure 4-10b. Typical cleanout detail.

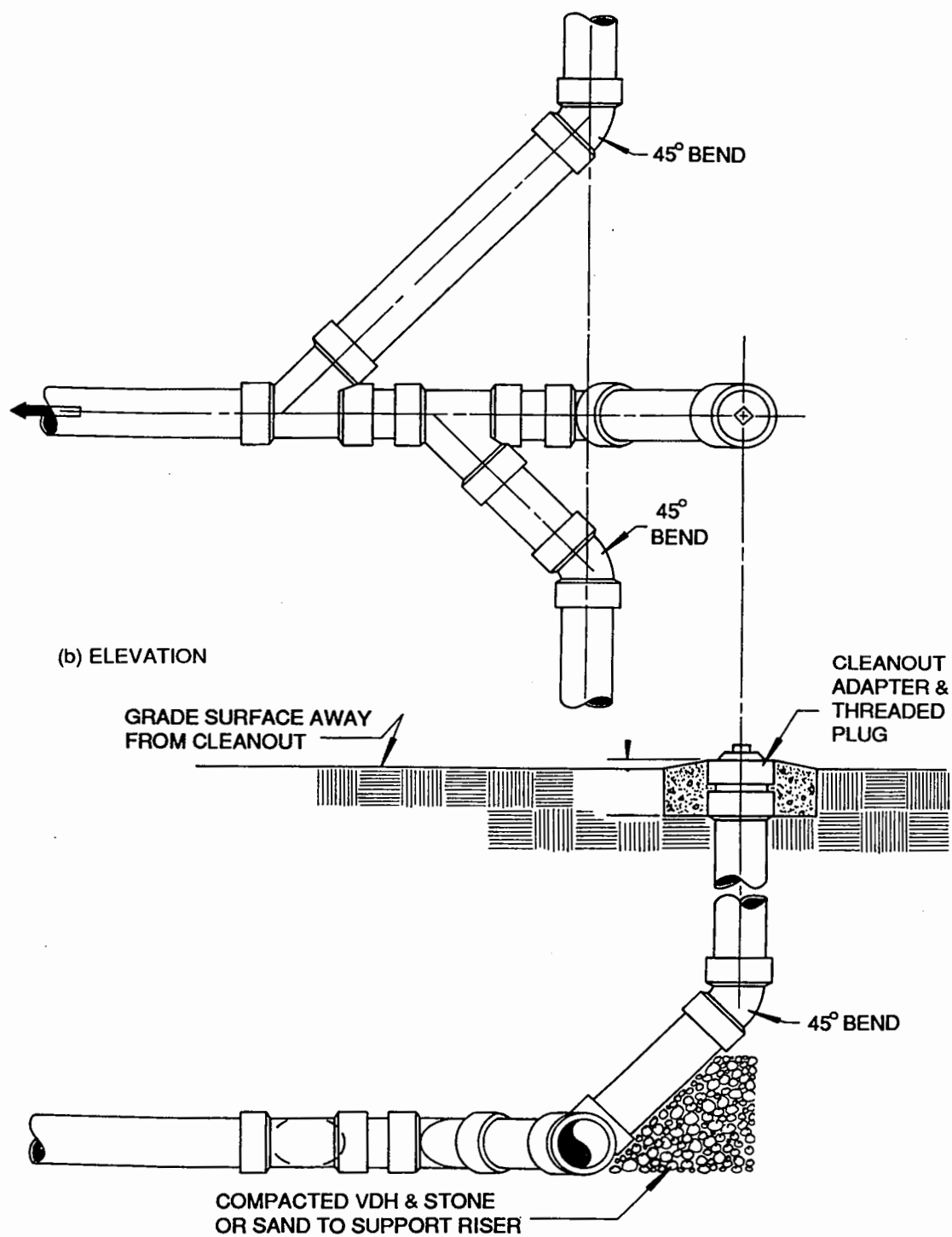


Figure 4-11. Ventilated cleanout detail.

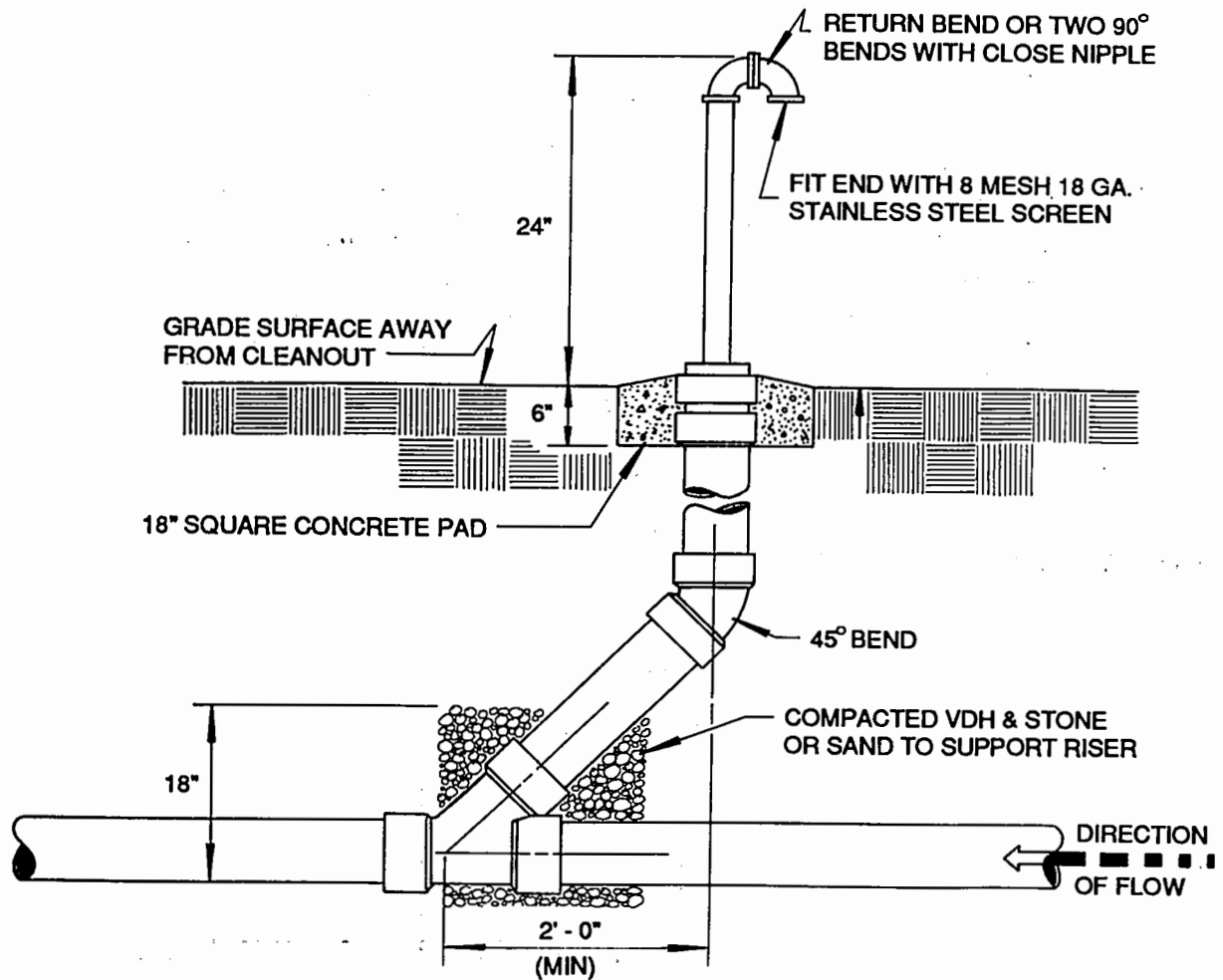
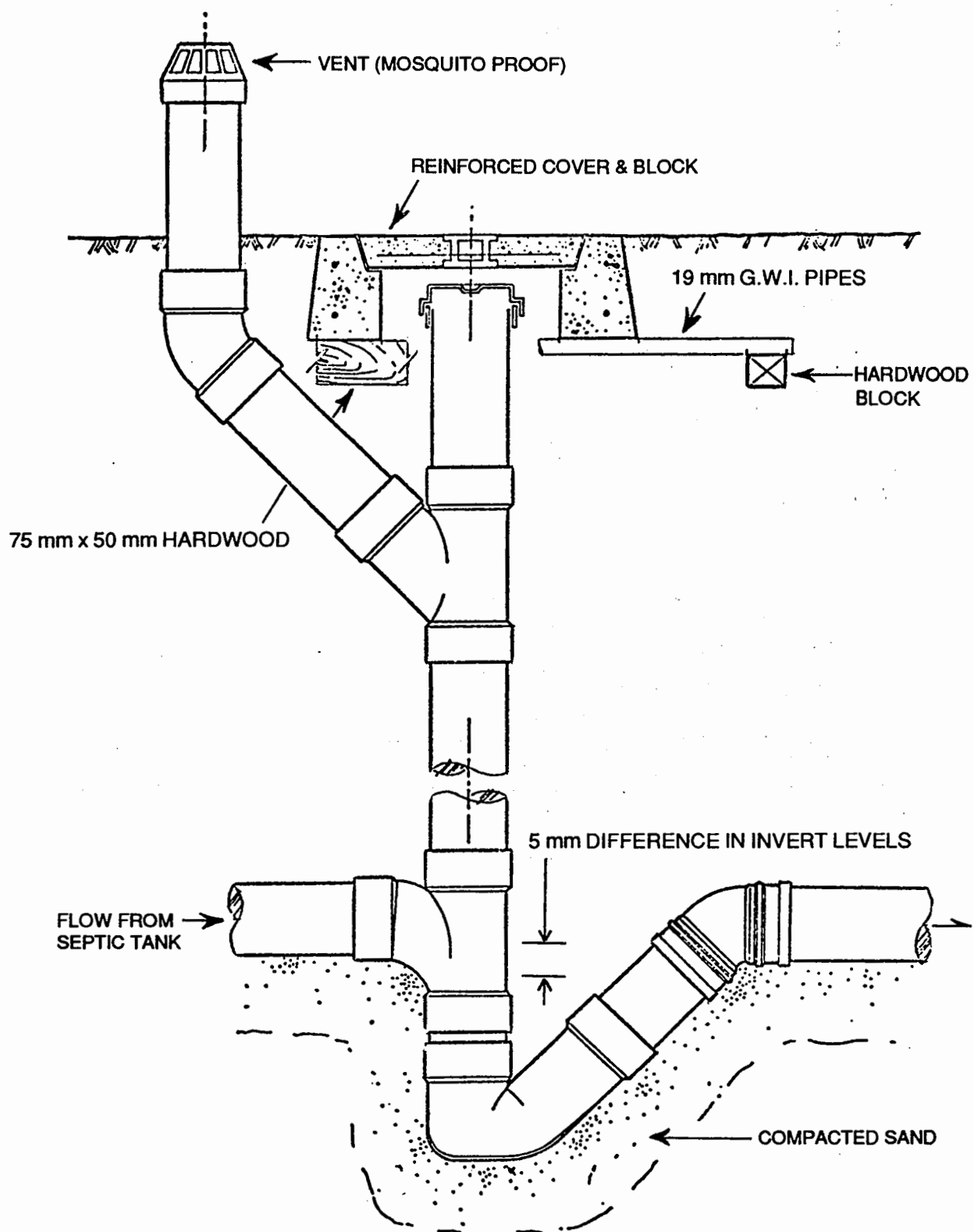


Figure 4-12. Australian boundary trap detail.



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 controlled by minimizing turbulence and sealing uncontrolled air outlets. Drop inlets have been effective in eliminating odors at lift stations (Figure 4-13). 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 4-14). Carbon filters have been used successfully, but require regular maintenance. Manholes should be replaced with cleanouts; however, if used, the manholes should have gas-tight covers. Odors from improperly designed house plumbing vents have been controlled most easily by sealing the vent on top of the interceptor tank outlet tee 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 Section 2.4.8). More recent SDGS systems have used wet well/dry well design for lift stations to reduce the exposure of mechanical components to the corrosive atmosphere.

4.4 Construction Considerations

4.4.1 General

Construction of small diameter gravity sewers is similar to construction of conventional gravity sewers except that strict horizontal and vertical control of main alignment is not required. As a result, construction can proceed much more quickly and be less costly. However, SDGS systems require that a significant portion of the work be performed on private property to install the interceptor tank and service lateral. Because the property owner can be very demanding in surface restoration, many general contractors are uncomfortable with such work. As a result, the bids received for construction may be few and inflated to account for the work on the service connections. To maximize the potential for cost savings, consideration should be given to letting two construction contracts, one to install the mains and the other to perform all work on private property. The contractor for the private work should be a contractor who is experienced in working with property owners such as a local septic tank system installer.

4.4.2 Mainline Construction

4.4.2.1 Line Changes

Setting the line of the collector main should be performed with the objective of minimizing site restoration costs. Detailed surveys during the design phase may not have

been performed because of cost considerations. As a result, all obstacles in the intended path of the main may not have been identified on the plan sheets. Since straight alignment is not required for SDGS, changes in the alignment within maximum pipe deflection limits can be made in the field to avoid large trees, fences, pavement, etc. that could increase restoration costs. Most changes can be made by the construction manager, but major changes in alignment should be evaluated by the design engineer. Any changes made should be documented and shown on the as-built drawings.

4.4.2.2 Grade Control

Strict vertical control of SDGS during mainline construction is not necessary. In most cases, the pipe may be joined above ground and laid in the trench. However, the pipe should be laid as uniformly as is reasonable to minimize headlosses and potential points where gas can collect. If significant changes in the pipe profile are required to avoid utilities or at various crossings, they must be evaluated by the design engineer for air release valves. All changes must be documented and recorded on the as-built drawings.

4.4.2.3 Trench Construction

Trenching may be done by backhoe or trenching equipment. Over-excavation is not a critical concern if the change in the pipe invert elevation is not greater than one pipe diameter nor so sudden that the integrity of the pipe is threatened.

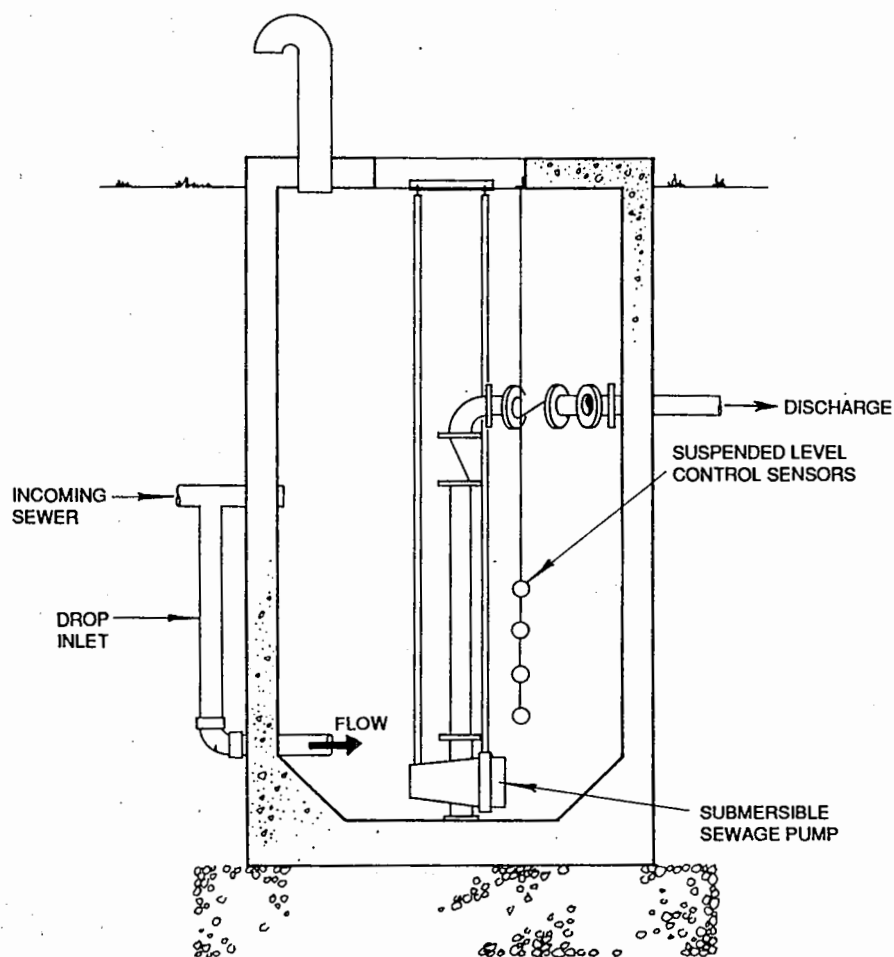
Select backfill for bedding and surrounding the pipe is necessary if the native trench spoil contains cobble or does not fill around the pipe snugly. Granular materials such as medium or coarse sand or pea gravel is usually used. Local requirements may control. To help locate the pipe or warn excavators working in the area, color coded warning tape should be buried in the backfill 10-20 cm (4-8 in) below grade directly over the main. Pipeline markers which relate the pipe to existing permanent above ground structures should also be used.

4.4.3 Service Connections

Service connections include the building sewer, interceptor tank and service lateral to the collector main. Usually, the utility district is responsible for installation of the interceptor tank and service lateral while the user is responsible for installing the building sewer and its connection to the interceptor tank. However, in some cases, the utility district has also taken responsibility for installing the building sewer to help ensure a watertight connection and minimal inflow from illegal connections.

In laying out the service connection, the property owner should be involved. The owner should be consulted

Figure 4-13. Examples of drop inlets, external (a) and internal (b).



a) OUTSIDE DROP INLET

b) INSIDE DROP INLET

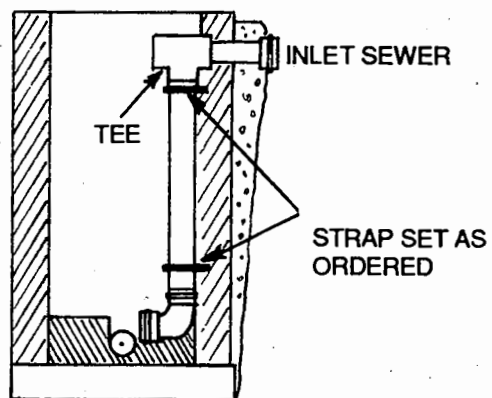
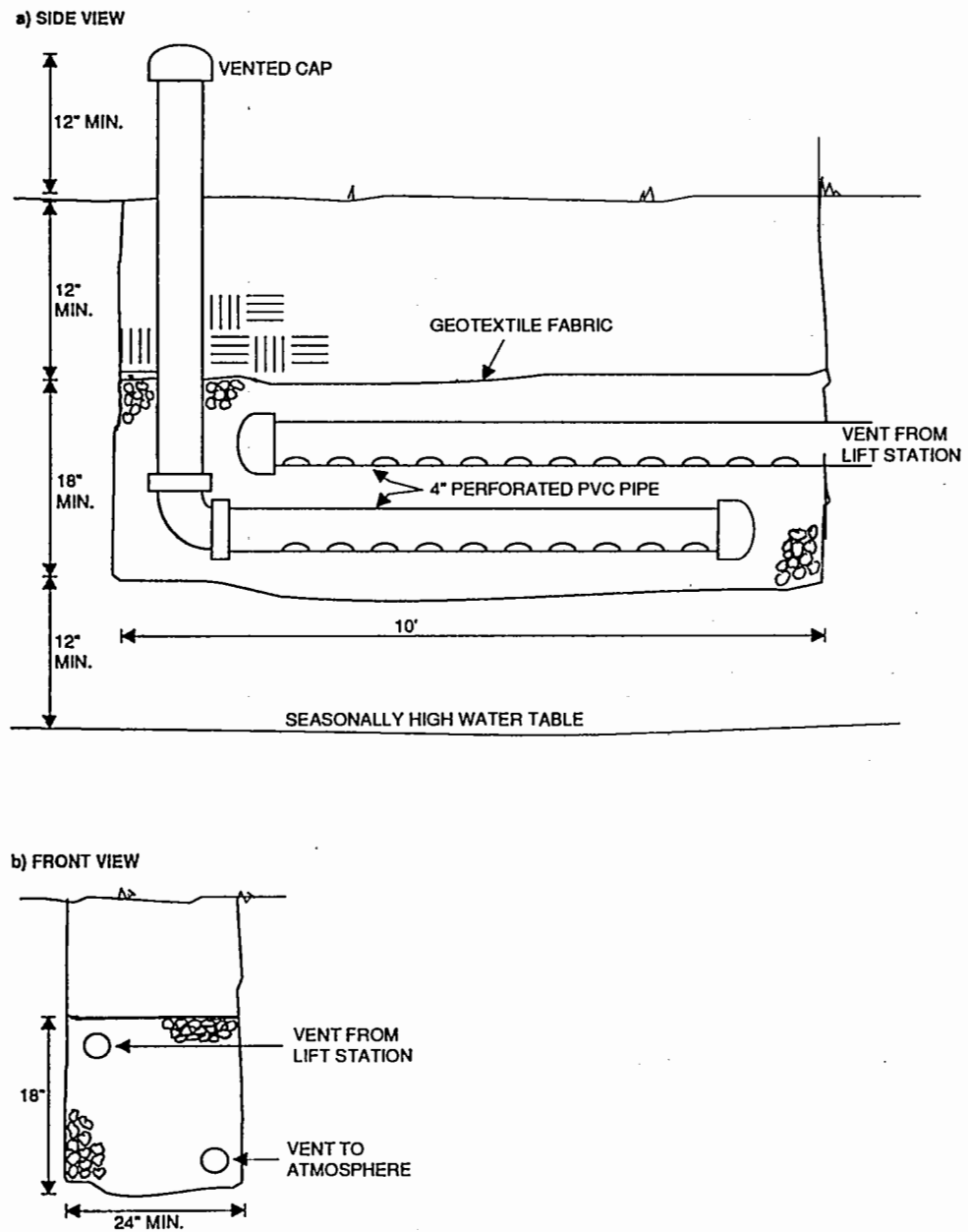


Figure 4-14. Soil odor filter detail



concerning the preferred location of the tank and service lateral, existing utilities and other areas of the property to be avoided. The proposed route and any areas to be affected by the construction activities should be video taped to provide a reference during restoration work.

Early SDGS systems attempted to utilize existing septic tanks at each connection as interceptor tanks to minimize construction costs. In such instances, the existing tanks were pumped and inspected prior to being accepted by the utility. However, where a significant number of existing tanks were included, clear water infiltration and inflow has been a problem. Current practice is to install all new interceptor tanks to limit infiltration and inflow. To provide the tightest system as possible, the user should be required to install a new building sewer subject to a leak test by the utility district. The existing tank must be pumped and abandoned by removal or by destruction and filling with inert solid material.

The interceptor tanks should be located where they can be reached easily for routine pumping by vacuum trucks. However, the tanks should be clear of any area subject to vehicular traffic. To facilitate maintenance, the interceptor tanks have been located in the public right-of-way in some projects. This approach avoids many of the problems associated with construction on private property, but does increase the hookup cost to the property owner since the owner is usually responsible for the building sewer to the interceptor tank.

Tank installation must follow the manufacturer's specifications. Proper bedding and flexible, water-tight inlet and outlet connections must be used. Flotation collars may be required to prevent flotation when the tank is pumped in areas that experience high water conditions.

As-built site plans should be prepared after the service connection is made. The plans should show the location of all elements of the service and referenced to permanent structures on-site. Where possible, photographs should be included in the record for the utility district.

4.4.4 Testing

Water-tightness testing of the collection mains, interceptor tanks, service connections and building sewers should be performed during construction. Testing procedures and criteria appropriate for conventional gravity sewers are used for testing the mains, service connections and building sewers. Both vacuum and hydrostatic tests are used for interceptor tanks. Typical acceptance criteria are less than 2.5 cm (1 in) loss of Hg vacuum after 5 minutes with an initial vacuum of 10 cm (4 in) of Hg or a drop in water level of 2.5 cm (1 in) after 24 hours in an overfilled tank. With the hydrostatic test, it is necessary

that the tank be filled to at least 60 cm (2 ft) above the top of the tank to check covers and manhole riser connections. Typically, the property owner is responsible for testing of the building sewer to the satisfaction of the utility district before connection.

4.5 Operation and Maintenance Considerations

4.5.1 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 avoids 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 or equivalent responsibility for 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 some cases, the easements are obtained without compensation to the owner, while, in others, a nominal charge is provided. In all cases, property owners are entitled to some compensation under the Uniform Relocation act; but waiver thereof implies their support for the community's endeavor. 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 is presented in Figure 4-15

4.5.2 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

Figure 4-15. Example of general easement.

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.
------	-----------	----------------	-----------

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 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, methods, and schedule 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 extremely helpful to O&M personnel.
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.

4.5.3 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.

Maintenance equipment is also limited. A truck mounted centrifugal suction pump can be used to provide most emergency operation equipment needs. Sufficient hose should be purchased to reach between cleanouts. Other equipment can be provided by outside contractors as needed.

For STEP installations (including lift stations), O&M requirements are described in Section 2.6.

4.5.4 Operator Training

Specialized training for SDGS maintenance personnel is not necessary. Basic plumbing skills, however, are desirable. If a significant number of service connections include STEP units, an understanding of pumps and electrical controls is also helpful. (For a small number of such units, it is common for the utility district to retain local plumbing and electrical contractors to be available for any necessary repairs.)

The staff should be aware of the dangers of exposure to sewer gases and to avoid entry into confined spaces unless properly protected. Since a significant portion of the system is located on private property, it is important that the staff have good communication skills and a willingness to work with residents.

4.5.5 Spare Parts Inventory

Because SDGS systems have few mechanical parts, the need to maintain a spare parts inventory is limited. However, if individual STEP units are included in the system requiring that spare pumps and controls must be available for emergency repairs. A minimum of two spare pumps and the associated float switches and controls should be maintained for small systems (see Section 2.6.4 for further discussion). Pipe and pipe fittings should be kept on hand to repair any pipeline breaks that may occur. Spare interceptor lids and riser rings should also be kept.

4.5.6 As-Built Drawings

As-built drawings of the entire SDGS system including all on-lot facilities are 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.

4.5.7 Maintenance

4.5.7.1 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.

4.5.7.2 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.

a. Interceptor Tanks

The interceptor tanks must be evacuated periodically to prevent solids from entering the collector mains. Prescribed pumping frequencies are typically 3-5 years, but operating experience indicates that a longer time between pumpings, of 7-10 years, is usually adequate (see Section 2.4.4). Restaurants and other high use

facilities, such as taverns, require more frequent pumping. Common practice is to require additional grease removal and pump tanks serving these facilities every 6-12 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.

A preliminary septage handling and disposal plan must be developed which complies with existing State and Federal regulations. However, 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 utility is responsible for the conduct of its contractors and must provide oversight to ensure compliance. The septage removed is usually land spread or discharged into a regional treatment plant.¹³ 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 actual accumulation rates.

b. Collector Mains

Periodic inspection and cleaning of the collector mains are the usually recommended maintenance functions. Hydraulic flushing is most often recommended for cleaning. Pressure hoses to push "pigs" through the mains have also been suggested as a cleaning method, but are 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 inspection and flushing is still recommended for long flat sections in which daily peak flow velocities are less than 15 cm/s (0.5 fps).

c. Lift Stations

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

4.5.7.3 Emergency Calls

Mainline or service lateral obstructions and lift station failures require that emergency actions be taken to limit the time the system is out of service to prevent

environmental or property damage that might occur. It requires that the utilities have defined emergency operation procedures.

a. Obstructions

If an obstruction occurs, the utility must be able to respond quickly such that backups do not occur at upstream service connections. Experience has shown that most obstructions are 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 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 an improperly inspected service connection was made. Construction debris has been the cause. Obstructions from other causes have not been reported.

b. 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 4-16) and/or truck mounted pumps that can pump from the wet well to a downstream hose connection on the force main (Figure 4-17). This latter method also works well for mechanical failures.

4.5.8 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 just prior to responding to a service call out.

4.5.9 Troubleshooting

4.5.9.1 Odors

Odors are the most frequently reported problem with SDGS systems. Odors typically occur at lift stations and

Figure 4-16. Mainline lift station with emergency storage.

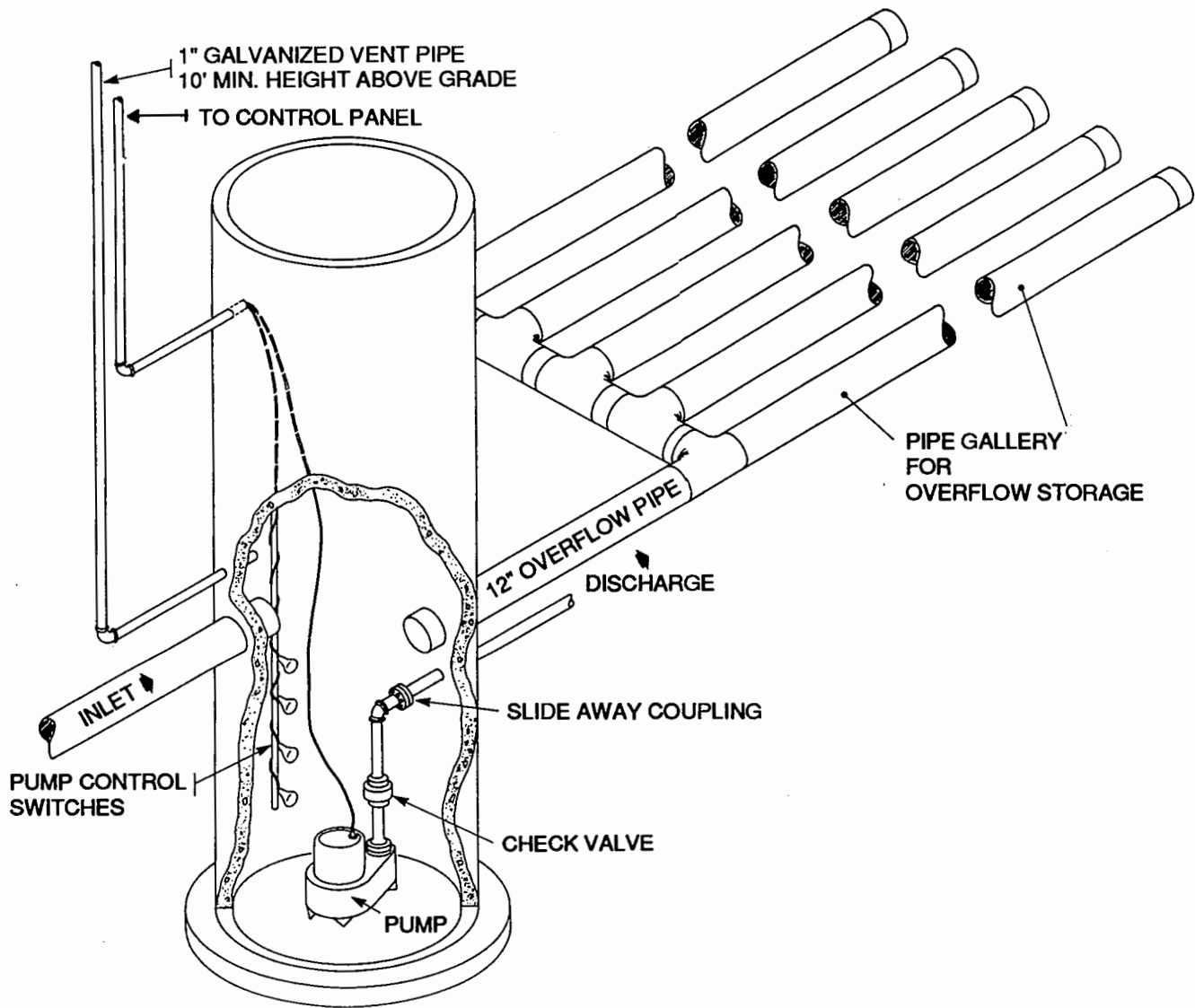
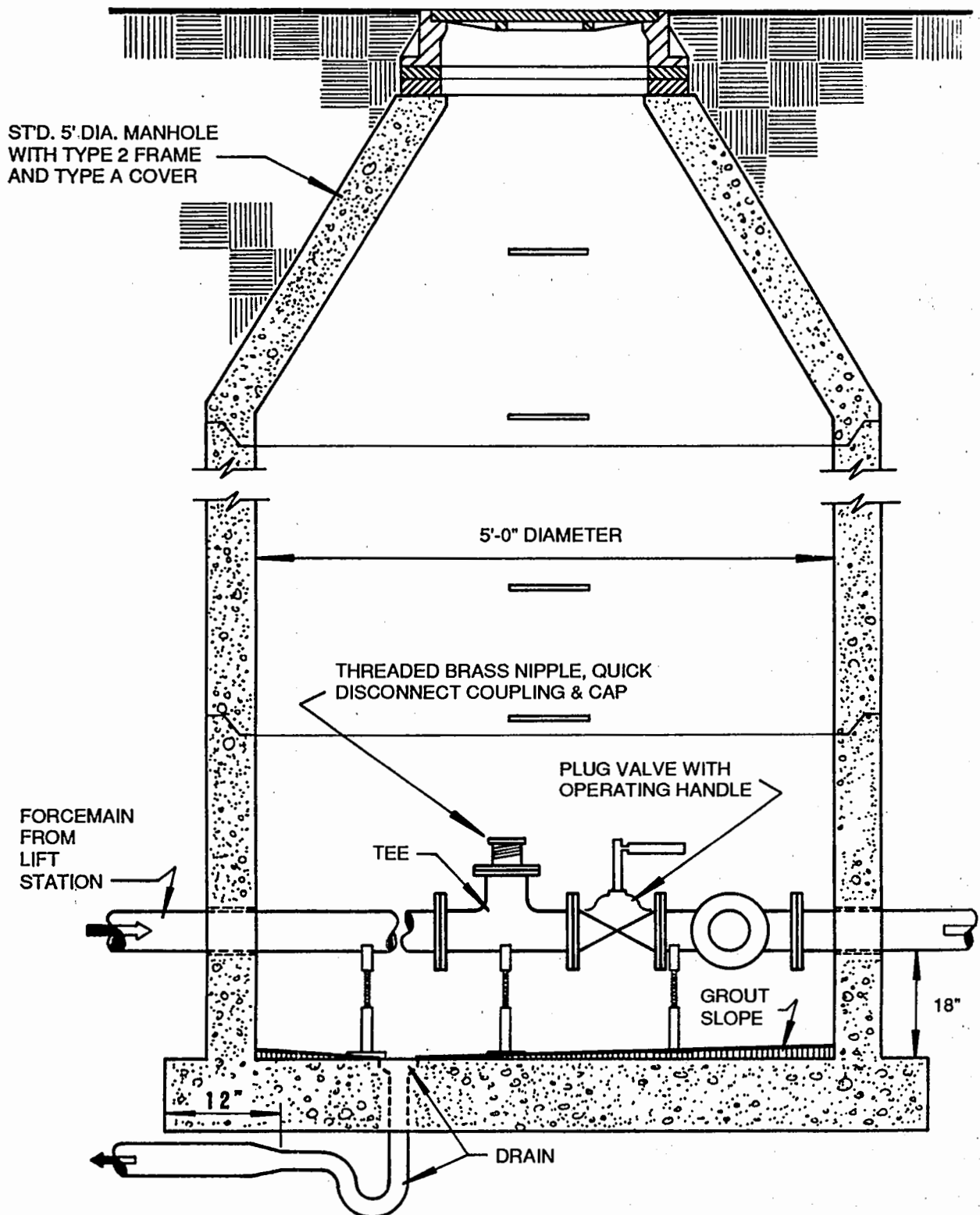


Figure 4-17. Emergency pumping manhole.



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 4-14), air tight wet well covers and vents that extend 3-5 m (10-15 ft) above grade.

Odors at individual connections often originate in 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 4-12). 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.

4.5.9.2 Corrosion

Corrosion is a problem that is usually most evident at 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.

4.5.9.3 Infiltration/Inflow

Clear water I/I 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 I/I problems.

4.6 Review of Operating Systems

Because knowledge of the performance of operating small diameter sewer systems in the United States is relatively sparse, twelve operating systems were selected for review. The systems selected were based on size, date on-line, type of design (uniform grade versus variable grade), and local terrain. A summary of the projects selected for detailed review is presented in Table 4-1. Summaries of the interceptor tank and collector main designs are presented in Tables 4-2 and 4-3. Comparisons of system component use as a function of total feet of collector main installed are presented in Table 4-4.

All the systems reviewed have performed well. Obstructions have not occurred in any of the systems despite the fact that mainline flushing has not been performed. Odors have created nuisance problems in several systems, but control measures have been effective. Corrosion is a common problem in lift stations because the corrosive atmosphere created by the septic waste was not anticipated. In the systems where existing septic tanks and building sewers were retained, infiltration has been a significant problem. This has not been the case where new tanks and building sewers were installed.

Routine maintenance is limited to weekly inspection of mechanical equipment and pumping of the interceptor tanks every 5-7 years. Call outs have been infrequent and usually due to problems in the building sewer rather than the systems themselves.

4.7 System Costs

4.7.1 Construction

Construction costs were obtained from the twelve SDGS systems reviewed. Total construction costs adjusted to January, 1991 are presented in Table 4-5. Unit costs of components and their averages adjusted to January, 1991 are presented in Table 4-6. The costs of the components per foot of pipe installed and their adjusted averages for the various projects are presented in Table 4-7. Table 4-8 presents the component costs as a percent of the total construction costs.

Based on the costs from the twelve systems, the components were ranked from most to least costly:²

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. Miscellaneous

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

Costs of installing the collector mains and the interceptor tanks and service laterals typically account for over 50 percent of the total cost of construction. The exact order of the other construction cost categories will depend on the characteristics of the individual project. Therefore,

Table 4-1. Summary of SDGS Projects Reviewed

Community	Pop.	Features	No. Connections	Length					Pressure	Length/ Connection (ft)	Comments	Date On-Line
				Total (ft)	3-in	4-in	6-in (%)	8-in				
Mt. Andrew, AL	100	Gently sloping.	31	2,500	50 (3-in) 50 (2-in)	-	-	-	-	81	<ul style="list-style-type: none"> • Infective gradient with sections depressed below HGL. • 2-in minimum diameter drains. • No manholes or cleanouts. • Some pressure inlets. 	July 1975
Westboro, WI	200	Gently sloping. Deep well-drained soils.	87	18,846	-	77	-	5	18	217	<ul style="list-style-type: none"> • Uniform gradient. • Curvilinear alignment between manholes. • Hybrid gravity/pressure system. 	Sept 1977
Badger, SD	105	Flat to gently rolling.	53	6,616	-	77	23	-	-	125	<ul style="list-style-type: none"> • Uniform gradient. 	Nov. 1980
Avery, ID	90	Narrow, steep-sided mountain valley bottom. Moderately deep soils.	55	6,690	-	100	-	-	-	122	<ul style="list-style-type: none"> • Uniform gradient. • No horizontal control maintained during construction. • Pipe gallery reserve storage in lift stations. 	Sept 1981
Maplewood, WI	150	Flat. Very shallow creviced bedrock.	61	5,800	-	-	100	-	-	95	<ul style="list-style-type: none"> • Uniform gradient • Emergency pump manholes below each lift station. 	Nov. 1981
S. Corning, NY	2,000	Flat valley bottom. Steep side slopes. Poorly-drained soils.	606	45,525	-	77	23	-	-	70	<ul style="list-style-type: none"> • Uniform gradient. • "Sump manholes" isolate sections of network. 	July 1983
New Castle, VA	190	Gently sloping. High seasonal water table. Boulderly soil.	64	6,955	-	64	-	36	-	109	<ul style="list-style-type: none"> • Uniform gradient. 	May 1982
Miranda, CA	300	High, moderately to steeply sloping river terrace. Deep alluvial soils.	100	9,617	9	91	-	-	-	96	<ul style="list-style-type: none"> • Uniform gradient. 	Nov. 1982
Gardiner, NY	500	Gently sloping.	109	19,330	-	71	19	10	-	177	<ul style="list-style-type: none"> • Uniform gradient. • Curvilinear alignment between manholes and cleanouts. 	Dec. 1982
Lafayette, TN	1,500	Top of plateau and steep side slopes.	510	45,310	-	47	53	-	-	89	<ul style="list-style-type: none"> • Uniform gradient. • Curvilinear alignment between manholes and cleanouts. • Aerated lift stations for odor control. 	Sept. 1983

Table 4-1. Summary of SDGS Projects Reviewed (continued)

Community	Pop.	Features	No. Connections	Length					Pressure	Length/ Connection (ft)	Comments	Date On-Line
				Total (ft)	3-in	4-in	6-in (%)	8-in				
West Point, CA	430	Very hilly with steep slopes. Shallow bedrock.	155	18,000	100 (2-in)	-	-	-	-	116	<ul style="list-style-type: none"> • Inflective gradient with sections depressed below HGL. • 2-in minimum diameter mains. 	Nov. 1985
Zanesville, OH	1,880	Very hilly with steep slopes. Shallow bedrock.	711	61,362	18 (2-in) 10 (3-in)	2	-	-	70	86	<ul style="list-style-type: none"> • Buried at constant depth, but no sections depressed below HGL. • 2-in minimum diameter mains. 	Oct. 1986
Muskingham Co., OH	2,150	Very hilly with steep slopes. Shallow bedrock.	767	89,748	79 (2-in) 16 (3-in)	3	2	-	-	117	<ul style="list-style-type: none"> • Inflective gradient with sections • 2-in minimum diameter mains. • Surge tanks installed following interceptor tanks. 	Nov. 1986

Table 4-2. Summary of Interceptor Tank Characteristics Used In Selected Projects

Community	Sizing Criteria	Min. Size (gal)	Access	Special Features	Replacement Rate (%)	
					Estimated	Actual
Mt. Andrew, AL	508-gal tank for all connections.	508	• Buried manhole	• Precast concrete • Outlet consists of 6 2-in clarifier tubes @ 60 degrees	100	100
Westboro, WI	Wisconsin Administrative Code	1,000	• Buried manholes • 4-in inspection port to grade	• Precast concrete	90	95
Badger, SD	1,000-gal tank for all connections	1,000		• Precast concrete	25	50
Avery, ID	1,000-gal single residence 1,500-gal double residence	1,000	• Buried manhole • 6-in inspection port to grade	• Precast concrete • Double layer mastic on risers	100	100
Maplewood, WI	Wisconsin Administrative Code	1,000	• Buried manhole • 4-in inspection port to grade	• Precast concrete • Located near road to minimize length of connection	100	100
S. Corning, NY	1,000-gal tank for all connections	1,000	• Buried manhole with O-ring gaskets • 4-in inspection port to grade	• Precast concrete with waterproof coating • Wall baffles with horizontal tee section on outlet • 2 outlets: upper one to existing dry well to act as overflow	75	83
New Castle, VA	2.5-day detention time based on metered flow	1,000	• Buried manhole • 6-in inspection port to grade	• Precast concrete	46	58
Miranda, CA	2-day detention time based on metered flow	750	• Manhole to grade	• Fiberglass tanks <1,500-gal capacity • Precast concrete 2-chambers >1,500-gal capacity • Coated and water tested • Structural specification	75	90
Gardiner, NY	New York Administrative Code	750	• Buried manhole • 4-in inspection port to grade	• Precast concrete • Structural specification	65	20
Lafayette, TN	Tennessee Administrative Code	750	• Buried manhole	• Precast concrete	5	23
West Point, CA	1,000-gal tank for all residential applications	1,000	• Manhole to grade	• High-density polyethylene • Screened outlet • Flow controlled outlet	100	100
Zanesville OH	1,000-gal tank for all applications	1,000	• Manhole to grade	• High-density polyethylene • Spherical shape • 2-in diameter outlet • Gas deflection baffle	100	100
Muskingham Co., OH	1,000-gal tank for all applications	1,000	• Manhole to grade	• High-density polyethylene or concrete • 2-in diameter outlet • Separate surge tank	-	60

Table 4-3. Summary of Collector Main Design Criteria Used in Selected projects

Community	Design Flow	Min. Pipe Diameter (in)	Min. Design Velocity (fps)	Minimum Slope				Roughness* Coefficient	Pipe Material	Alignment	Depth (ft)	
				3-in	4-in	6-in	8-in				Min.	Avg.
				Minimum Slope (%)								
Mt. Andrew, AL	0.4 gpm/connection	2	N/A	Inflective gradients				C = 150	PVC SDR 26	Curvilinear	1	1
Westboro, WI	72 gpcd	4	1.5 (0.5 full)	-	0.67	-	0.67	n = 0.013	PVC SCH 40	Curvilinear	7	7.5
Badger, SD	50 gpcd, min. pipe size based on fixtures	4	1.0 (full)	-	0.60	0.28	0.19	n = 0.011	PVC SDR 35	Straight	5	7.5
Avery, ID	70 gpcd peaking factor = 3	4	1.5 (0.5 full)	-	0.40	-	-	n = 0.010	PVC SDR 35	Curvilinear in horiz. plane	5	5
Maplewood, WI	75 gpcd peaking factor = 4	6	1.5 (0.5 full)	-	-	0.27	-	n = 0.013	PVC SDR 35	Straight	6	6
S. Corning, NY	200 gpd/connection peaking factor = 4	4	1.5 (full)	-	0.40	0.20	0.15	n = 0.011 (Kutter's)	ABS & PVC SDR 35	Curvilinear	4.5	7
New Castle, VA	50 gpcd peaking factor = 4	4	1.0 (0.5 full)	-	0.50	0.50	-	n = 0.013	PVC SDR 35	Straight	3	5.5
Miranda, CA	175 gpd/connection peaking factor = 2	3	1.5 (0.5 full)	0.94	0.67	-	-	n = 0.013	PVC SDR 35	Straight	4	8
Gardiner, NY	80 gpcd peaking factor = 4	4	1.5 (0.5 full)	-	0.67	0.40	0.40	n = 0.013	PVC SDR 26	Curvilinear	4	7.5
Lafayette, TN	350 gpd/connection	4	1.0 (0.5 full)	-	0.36	0.36	-	C = 100	PVC SDR 35	Curvilinear	2.5	4
West Point, CA	225 gpd/connection peaking factor = 2	2	0	Inflective gradients				n = 0.012	PVC SDR 26	Curvilinear	3	3.5
Zanesville, OH	0.5 gpm/connection	2	0	Inflective gradients (constant buried depth)				C = 150	PVC SCH 40 & SDR 35	Curvilinear	3.5	3.5
Muskingham Co., OH	0.5 gpm/connection	2	0	Inflective gradients				C = 150	PVC SDR 35 & SDR 26	Curvilinear	4.5	4.5

* C = Hazen-Williams; n = Manning's (except as noted)

Table 4-4. Comparison of System Component Use as a Function of Number of Connections or Feet of Collection Main Installed in Selected Projects

Community	Feet of Category/Connection			Feet of Main/Category					
	Mainline	Service Laterals	Septic Tanks	Manholes	Cleanouts	Category Manholes & Cleanouts	Residential Lift Stations	Mainline Lift Stations	Force Main, ft
Westboro, WI	217	217	0.90	571	-	571	1,450	5,143	8.2
Badger, SD	125	125	0.38	348	-	348	6,616	3,308	10.3
Avery, ID	122	122	1.02	3,345	394	352	-	1,673	2.4
Maplewood, WI	95	95	0.80	1,450	112	104	-	1,933	1.7
S. Corning, NY #1	63	63	0.88	3,096	310	281	3,715	-	-
S. Corning, NY #2	77	77	0.81	2,994	342	307	2,395	-	-
New Castle, VA	109	109	0.30	541	104	84	-	6,955	3.1
Miranda, CA	96	96	0.72	1,374	163	146	962	-	46.7
Gardiner, NY	177	98	0.94	716	805	379	2,761	19,330	6.6
Lafayette, TN	89	89	0.05	1,678	781	533	22,655	5,034	4.6
West Point, CA	116	94	1.03	-	857	857	-	18,000	3.6
Zanesville, OH	83	123	0.43	2,609	272	246	163	-	-
Average	114	109	0.67	1,702	414	351	5,090	7,672	9.3

Table 4-5. Comparison of SDGS Construction Costs (\$) from Selected Projects

Community (Bid Date)	Construction Costs	Cost/Connection		Cost/ft of Main	
		Bid	Adjusted to January 1991	Bid	Adjusted to January 1991
Westboro, WI (Jan. 1977)	245,635	2,959	5,668	13.03	24.96
Badger, SD (July 1980)	103,281	1,949	2,856	15.61	22.87
Avery, ID (Aug 1980)	290,280	5,278	7,632	43.39	62.74
Maplewood, WI (Dec. 1980)	265,903	4,359	6,168	45.85	64.88
S. Corning, NY #1 (April 1981)	810,345	2,738	3,789	43.63	60.38
S. Corning, NY #2 (April 1981)	1,218,301	3,930	5,438	50.87	70.40
New Castle, VA (April 1981)	212,696	3,623	5,014	30.58	42.32
Miranda, CA July 1981	666,703	6,667	8,909	69.33	92.64
Gardiner, NY (Aug 1981)	596,246	5,470	7,309	30.84	41.22
Lafayette, TN (May 1982)	737,844	1,447	1,823	16.29	20.52
West Point, CA (March 1985)	695,432	4,487	5,164	38.64	48.67
Zanesville, OH (Feb. 1985)	2,798,913	3,887	4,471	46.65	53.66
Average			5,353		50.44

Table 4-6. Comparison of Unit Costs of Components from Selected Projects

Community (Cost Index)	Main (\$/ft)					Manholes (\$ each)	Cleanouts (\$ each)	Mainline Lift Stations (\$ each)	Force Main (\$ each)	Residential Lift Stations (\$/ft)	Septic Tanks (Installed)		Connections (\$/ft)
	2-in	3-in	4-in	6-in	8-in						(750-gal) (\$ each)	(1,000-gal) (\$ each)	
	(Avg. Depth, ft)												
Westboro, WI (2494)	-	-	5.33 (7.6)	-	7.50 (9)	420	-	10,366	0.55	1,097	-	327 ^a	-
Badger, SD (3260)	-	-	4.15 (7.9)	6.46 (10.8)	-	672	-	21,400	0.39	250	-	450	4.28
Avery, ID (3304)	-	-	8.75	-	-	2,000	100	8,554	1.64	-	-	1,500	4.61
Maplewood, WI (3376)	-	-	-	8.90 (5.7)	-	633	69	20,721	2.92	-	-	650	8.10
S. Corning, NY #1 (3452)	-	-	5.70 (7.5)	8.00 (8.0)	-	1,350	150	-	-	6,000	-	800	5.36
S. Corning, NY #2- (3452)	-	-	11.84 (7.6)	11.95 (6.9)	15.20 (7.8)	2,168	110	-	-	6,000	-	1,250	9.70
New Castle, VA (3452)	-	-	7.00 (5.5)	-	15.00 (9.1)	1,110	79	20,000	2.60	-	-	750	7.00
Miranda, CA (3575)	-	19.59 (9.2)	20.15 (16.7)	-	-	2,217	261	-	0.17	4,749	1,477	1,990	10.00
Gardiner, NY (3575)	-	-	8.90 (6.9)	16.29 (8.6)	17.79 (9.9)	1,056	300	15,000	0.32	2,000	600	650	4.51
Lafayette, TN (3792)	-	-	6.45 (3)	7.30 (3)	-	1,076	107	6,322	0.37	2,600	-	500	3.45
West Point, CA (4151)	7.26 (3.5)	-	-	-	-	-	300	40,000	5.60	-	-	1,600	9.73
Zanesville, OH (4153)	7.87 (3.5)	8.09	10.48	-	-	477 ^b	771	-	-	1,543	-	1,335	8.71
Adjusted Average (4777 - Jan. 1991)	8.70 (3.5)	17.74 (6.3)	12.19 (7.4)	13.44 (7.2)	19.98 (9.0)	1,660	290	24,325	2.33	4,143	1,388	1,315	9.08

^a Includes service connection.

^b Includes ball valves and release valves.

Table 4-7. Summary of Component Costs from Selected Projects

Community (Cost Index)	In-Place Pipe	Manholes	Cleanouts	Lift Stations	Force Main	Bldg. Sewer	Septic Tanks	Service Conn.	Street Repair	Crossings	Site Restoration	Misc.	Total
(\$/ft pipe installed)													
Westboro, WI (2494)	5.27	0.60	-	1.65	0.55	0.76	1.68	- ^a	1.47	0.22	0.75	0.06	13.03
Badger, SD (3260)	2.67	1.93	-	3.23	0.39	0.03	1.36	2.59	- ^b	0.23	- ^b	-	15.61
Avery, ID (3304)	8.57	0.60	0.25	5.11	1.64	-	12.71	0.69	- ^b	12.49	- ^b	1.33	43.39
Maplewood, WI (3376)	17.30	0.44	0.62	10.72	2.92	-	8.02	2.79	1.72	- ^b	1.29	0.03	45.85
S. Corning, NY #1 (3452)	13.36	0.44	0.48	-	-	1.62	11.59	7.72	3.57	1.12	3.08	0.65	43.63
S. Corning, NY #2 (3452)	15.11	0.72	0.32	-	-	2.51	13.80	11.87	2.37	1.64	2.11	0.42	50.87
New Castle, VA (3452)	9.89	2.40	0.78	2.88	2.60	-	9.76	- ^b	- ^b	- ^b	- ^b	2.27	30.58
Miranda, CA (3575)	24.36	1.61	1.60	-	0.17	4.94	18.24	7.44	9.48	- ^b	0.53	0.96	69.33
Gardiner, NY (3575)	15.07	1.47	0.37	0.78	0.50	0.72	3.62	2.50	2.97	2.07	0.77	-	30.84
Lafayette, TN (3792)	6.90	0.64	0.14	1.26	0.37	0.11	1.78	4.19	0.56	0.34	- ^b	-	16.29
West Point, CA (4151)	7.26	-	0.35	2.22	1.56	-	16.13	6.00	1.47	0.36	-	3.29	38.64
Zanesville, OH (4153)	8.09	0.18	1.05	-	-	9.46	6.86	8.71	5.72	-	1.12	5.45	46.65
Adjusted Average (4777 - Jan. 1991)	15.10	1.42	0.79	4.95	1.66	3.22	11.70	7.13	4.34	3.45	2.12	2.01	57.89

^a Included in septic tank costs.

^b Included in pipe costs.

Table 4-8. Summary of Component Costs from Selected Projects

Community (Cost Index)	In-Place Pipe	Manholes	Cleanouts	Lift Stations	Force Main	Bldg. Sewer	Septic Tanks	Service Conn.	Street Repair	Crossings	Site Restoration	Misc.
(percent of total construction cost)												
Westboro, WI	40	5	-	13	4	6	13	-	11	2	6	1
Badger, SD	30	12	-	21	2	0	9	23	-	1	-	-
Avery, ID	20	1	1	12	4	-	29	2	-	29	-	3
Maplewood, WI	38	1	1	23	6	-	17	6	4	-	3	0
S. Corning, NY #1	31	1	1	-	-	4	27	18	8	3	7	1
S. Corning, NY #2	30	1	1	-	-	5	27	23	5	3	4	1
New Castle, VA	32	8	3	9	9	-	32	-	-	-	-	7
Miranda, CA	35	2	2	-	0	7	26	11	14	-	1	1
Gardiner, NY	49	5	1	3	2	2	12	8	10	7	2	-
Lafayette, TN	42	4	1	8	2	1	11	26	3	2	-	-
West Point, CA	19	-	1	6	4	-	42	15	4	1	-	8
Zanesville, OH	17	1	2	-	-	20	15	19	12	-	2	12
Average	26	2	1	9	3	6	20	15	12	7	4	3

cleanouts might be higher, crossings lower, etc. However, the top two categories will almost always dominate. 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, except in a few instances where tanks are placed on the right-of-way, farther from the served dwellings. Many contractors are reluctant to work on private property because of the insistence of the property owner about 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.

4.7.2 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 5-10 hr/wk is sufficient for service calls or emergency maintenance.

Interceptor tank pumping is usually performed by outside contractors. Most projects are pumping each tank every 2-3 years which has been found to be more frequent than necessary. Pumping of residential tanks every 7-10 years appears to be sufficient in most instances.

Commercial establishments, particularly those with food service may require pumping every 6-12 months.

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

4.7.3 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. In the projects reviewed, user charges ranged were \$10-20/month per connection.

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.

4.8 System Management Considerations

4.8.1 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 unimpaired.

4.8.2 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.

4.9 References

When an NTIS number is cited in a reference, that reference is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

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CHAPTER 5

Design Examples

5.1 Pressure Sewers

In this example the rational method of design is used. Variations of this method exist, but most variations differ little in conclusion. The example is shown graphically but may be accomplished mathematically or by computer.

No portions of the example collection system are shown to be higher than the point of discharge, so two-phase flow does not exist. If two-phase flow were present calculations should be made for the additional headlosses not accounted for in standard hydraulic equations. Thus, the design example is simplified, explaining basically the pipe size selection and pump selection processes.

For this example, flows are based on Equation 5-1, which assumes that infiltration and inflow are well controlled;

$$Q = 0.5N + 20 \quad \text{Equation 5-1}$$

Where,

Q = Design flow (gpm)
N = Number of homes served

Pipeline sizes are taken as nominal, even though most commonly used sizes and types of PVC have inside diameters slightly larger than nominal.

The Hazen-Williams equation is used for calculating headloss:

$$V = 1.318 C R^{0.63} S^{0.54} \quad \text{Equation 5-2}$$

Where,

V = Velocity of flow (fps)
C = Flow coefficient (140 in this example)
R = Hydraulic radius
S = Slope of hydraulic grade line

This example simplifies the procedure some, but intends to convey the basic ideas without being unnecessarily complicating. The procedure is as follows:

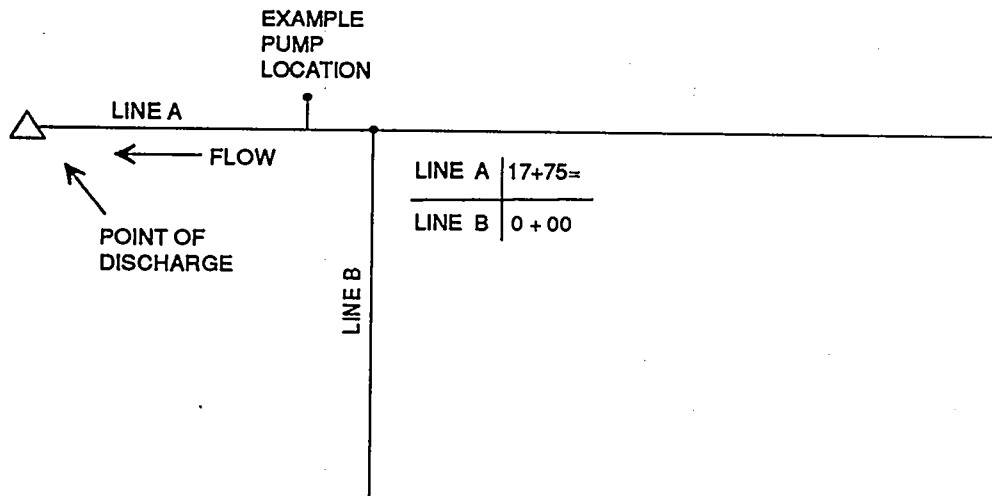
1. On a plan of the area to be served, group the homes or dwelling units (DU) and total them into accumulated nodes. On Figure 5-1 they are shown as 270 DU, 80 DU, and 45 DU.
2. Determine design flows for each node using Equation 5-1. On Figure 5-1 they are 155, 60, and 43 gpm, corresponding to the DUs noted in Step 1.
3. For each separate reach between nodes, select a trial pipe diameter and determine the slope of the hydraulic grade line (S) and velocity of flow (V). Velocity is determined by the equation $V = Q/A$. Slope is determined by the Hazen Williams equation. Write the trial pipe diameter (D) and corresponding S and V by the node.

The minimum scouring velocity required if using grinder pumps is 60 cm/s (2 fps) or preferably 90 cm/s (3 fps). Using STEP systems, minimum self-cleaning velocity is not usually considered.

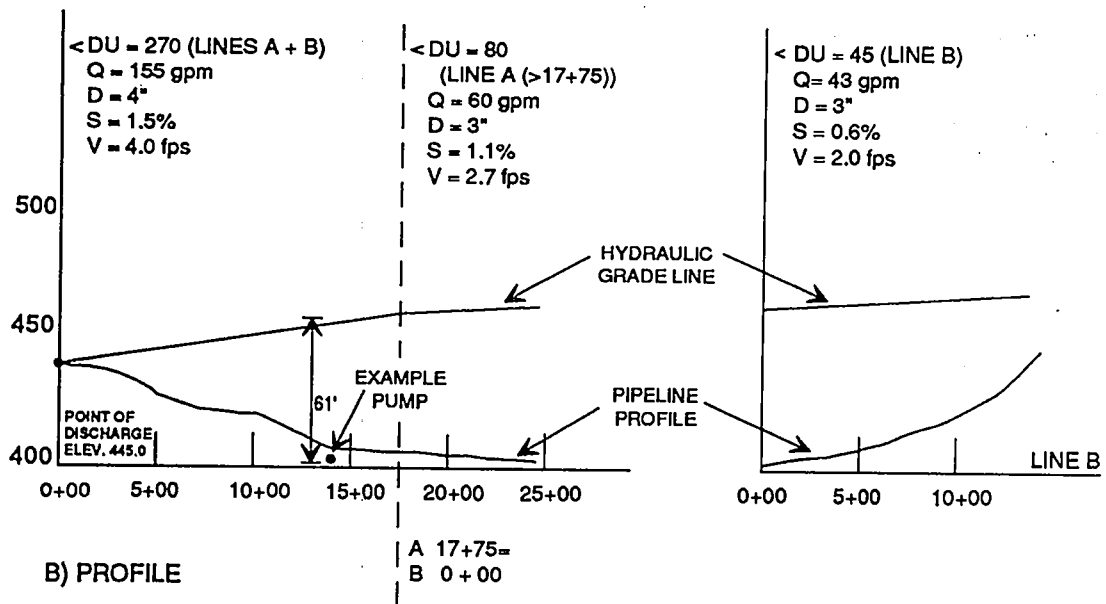
In the example three-inch mains are used as the smallest size for reasons mentioned elsewhere in this manual, but 5-cm (2-in) mains could be used to serve small numbers of DUs.

4. Beginning at the most downstream point (point of discharge elevation 445.0 at station 0+00 in the example), draw the hydraulic grade line.
5. On the profile, plot the low liquid level elevations of each tank at the stations where the tank and pump assemblies will be installed.
6. Scale the elevation difference between the liquid level elevation in the tank and the hydraulic grade line

Figure 5-1. Example pressure sewer design.



A) PLAN VIEW



B) PROFILE

at that station - 20 m (61 ft) in the example. This gives the head that the pump must discharge against.

7. Given the design pumping head (Step 6), select a pump having an effective pump curve that can discharge a sufficient flow rate through its service line without being so near to shutoff head that long term performance would be questionable.

If required pumping heads exceed the capabilities of available pumps, return to Step 3 and try using larger diameter piping. This will result in flatter slopes of the energy grade line, and lower the required pumping head.

5.2 Vacuum Sewer System

[This design example is a variation of one from the AIRVAC design manual, which is protected under U.S. Patent Number 4179371. Changes to the text were made to allow for terminology consistency with the rest of this document and for the sake of simplicity. These changes do not alter in any way the context of the example.]

Consider the vacuum sewer layout in Figure 5-2. The location of the vacuum station, sewers, and valves have been selected in accordance with the requirements of Section 3.4, which are restated below:

- Minimize lift
- Minimize length
- Where possible, equalize flows on each sewer

Each valve is assumed to serve two homes and peak flow per home is 0.64 gpm, or 1.28 gpm/valve installation.

Three main sewers will be required to effectively serve the area depicted in Figure 5-2. Each of these main sewers is connected directly to the vacuum tank at the vacuum station. Sewers are not joined together into a manifold outside the station.

Division valves must be located to isolate areas of the sewer network for troubleshooting purposes.

Profiles (Figures 5-3 through 5-5) have been prepared for a portion of main #2. The profiles for mains #1 and #3 would be similar.

Profiles for main #2 follow principles stated in Chapter 3:

- Maximum length of 10-cm (4-in) sewer - 2,000 ft
- 80-percent pipe diameter drop, or 0.2-percent fall between lifts - whichever is greater on 4-in and smaller mains
- 40-percent pipe diameter drop, or 0.2-percent fall between lifts - whichever is greater on 15-cm (6-in) and larger mains

- Where the ground profile falls greater than 0.2 percent in the flow direction, the sewer profile follows the ground

The location of vacuum valves, division valves, and branch sewer connection points follows the principles stated of Section 3.4.

The buffer tank valve installation shown between Points C and D is representative of a high-flow user, such as a laundromat or school; 10 gpm is used as the rate for this location.

Main 3 is representative of a sewer main laid down an alley way, which allows up to 4 homes to be connected to each vacuum installation.

5.2.1 Procedure

Commence at Point F. Calculate losses to Point D. Calculate losses and flows from Point E to Point D. Determine the line with the greatest loss and carry forward. In this example, the total line loss from Point F to Point D is greater than the total line loss from Point E to Point D. Therefore, only the total line loss from Point F to Point D is carried forward, and line F-D-C becomes the main sewer for total line loss calculation purposes. The total line losses for all upstream flow from Point D to Point C are calculated in Table 5-1 and continue towards the vacuum station. Note that line losses were not calculated for the branch entering Point B; this is because it is clearly evident that there are negligible losses present. This piping and additional flows have been entered at Point B for the remaining mainline calculations.

See Table 5-2 for calculation of line losses in main #2, from Point D through Point A. The friction losses for slopes greater than 2.0 percent have been ignored, and calculated static losses due to a profile change equal the lift height minus the pipe inside diameter.

Using the same method, total line loss, flows and pipe sizes can be calculated for main #1 and #3. Flows, pipe sizes, and lengths for these mains have also been estimated to allow piping and vacuum station calculations to be completed.

The last step involves the preparation of piping and vacuum station calculation sheets from the sewer profiles (see Tables 5-3 and 5-4).

The engineer must then select suitable standard size pumps and tanks, usually in concert with the manufacturer, and recalculate the vacuum station requirements using the selected equipment sizes. Vacuum and wastewater pump sizes should be selected to allow for additional

Figure 5-2. Design example layout.

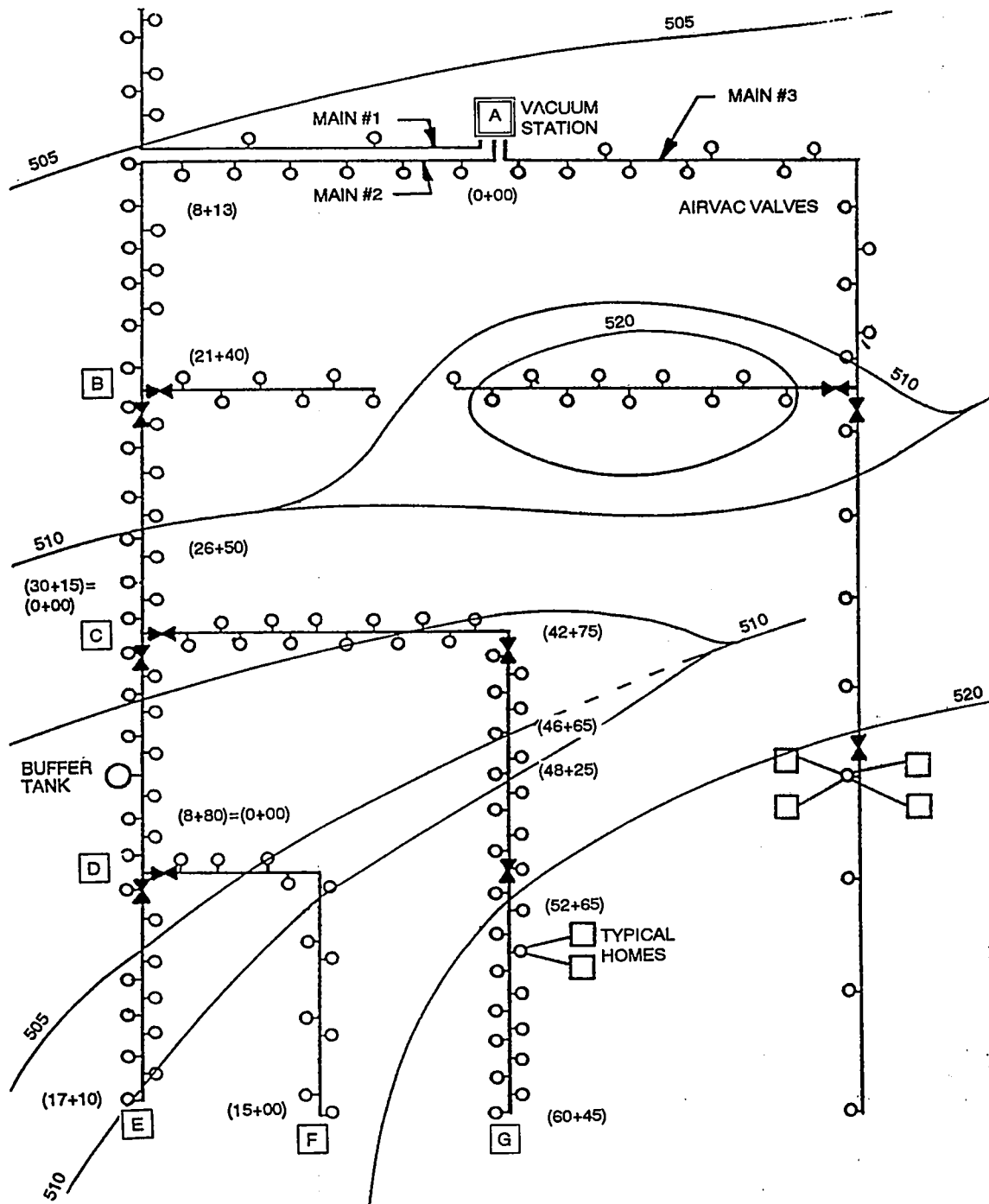
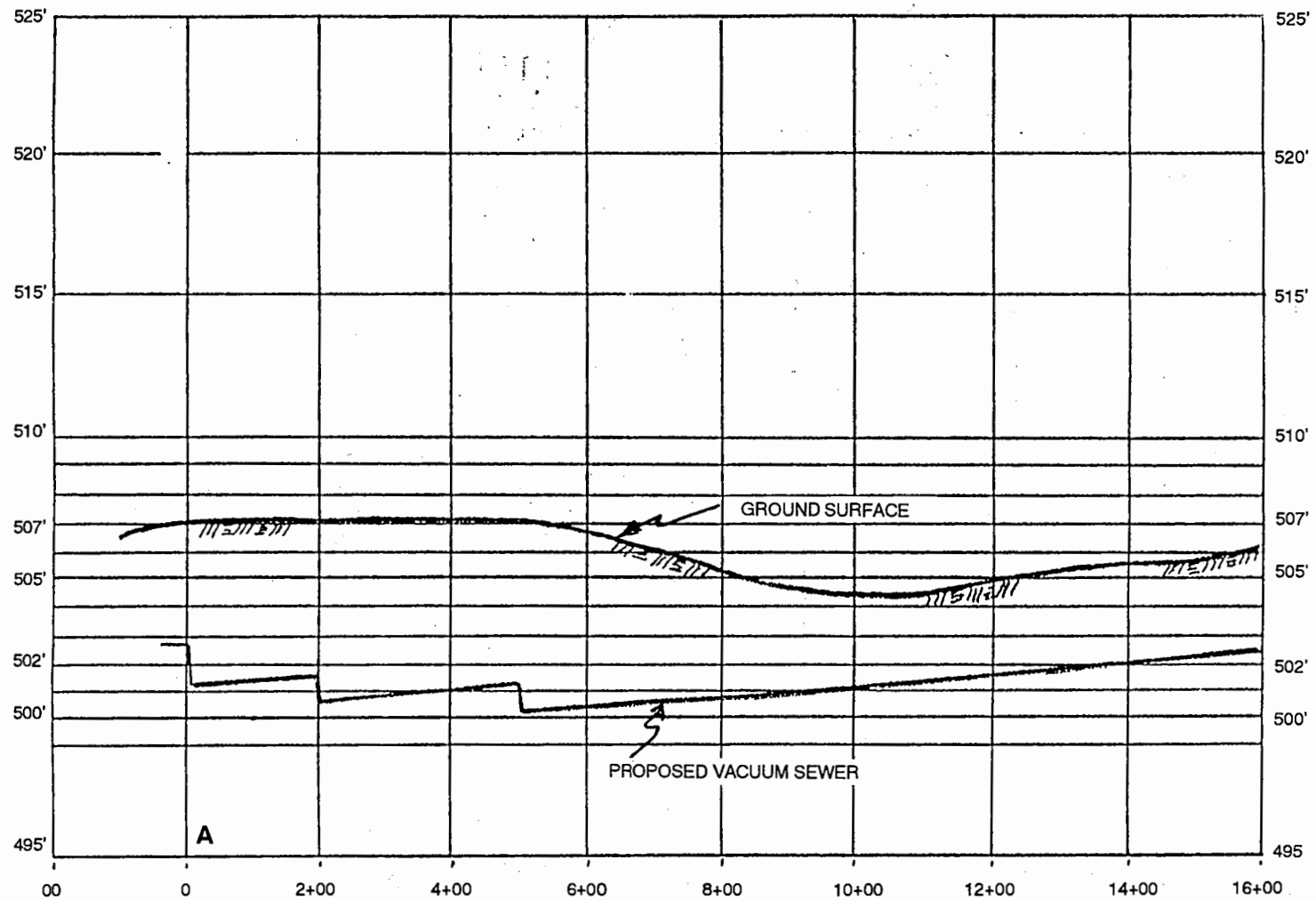




Figure 5-3. Design example profiles.

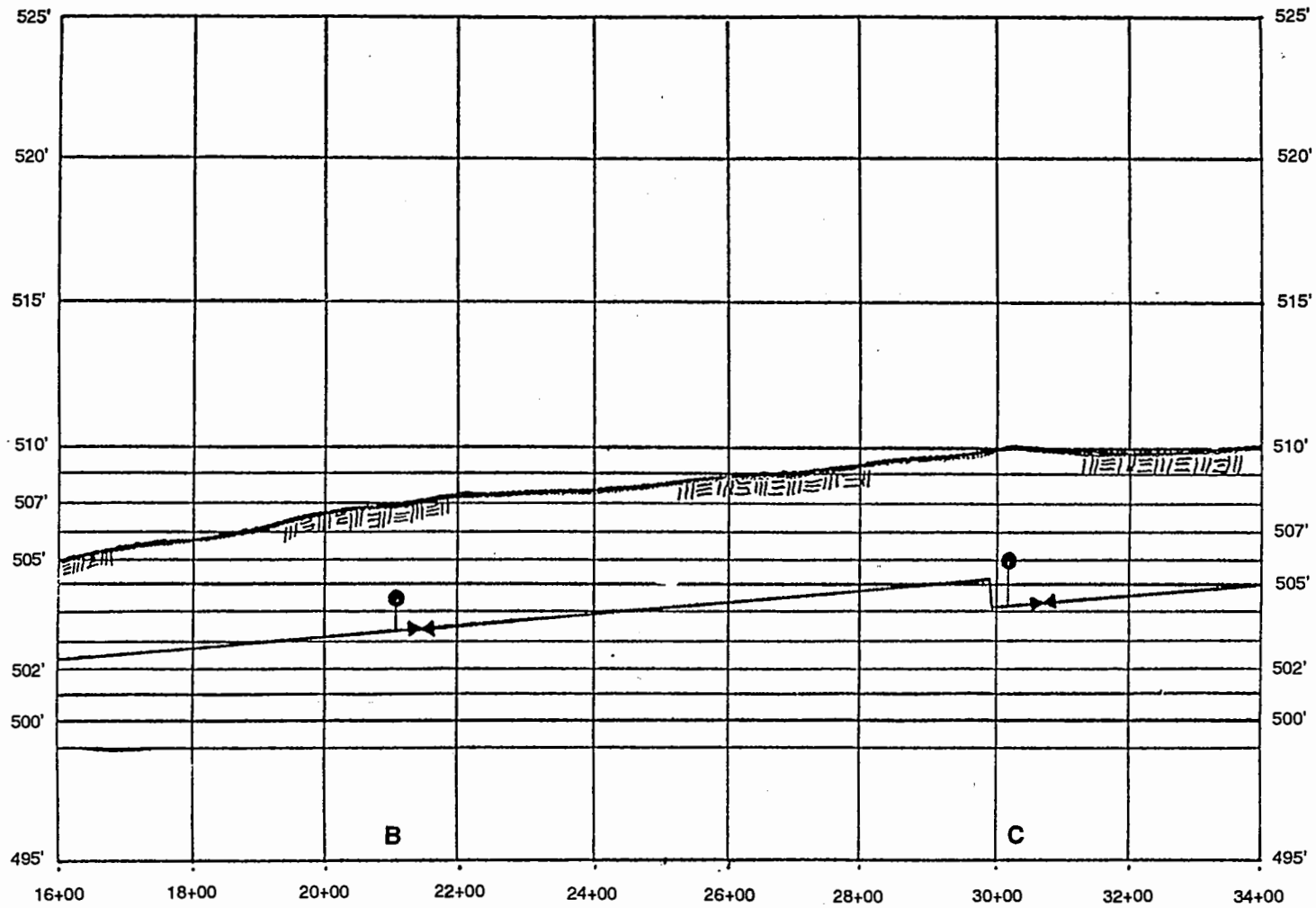




LEGEND:  DIVISION VALVE
 CONNECTION FROM A BRANCH SEWER

SCALE: HORIZONTAL 1"=200'
 VERTICAL 1"=5'

SEWERS LAID TO 0.2% FALL IN FLOW DIRECTION

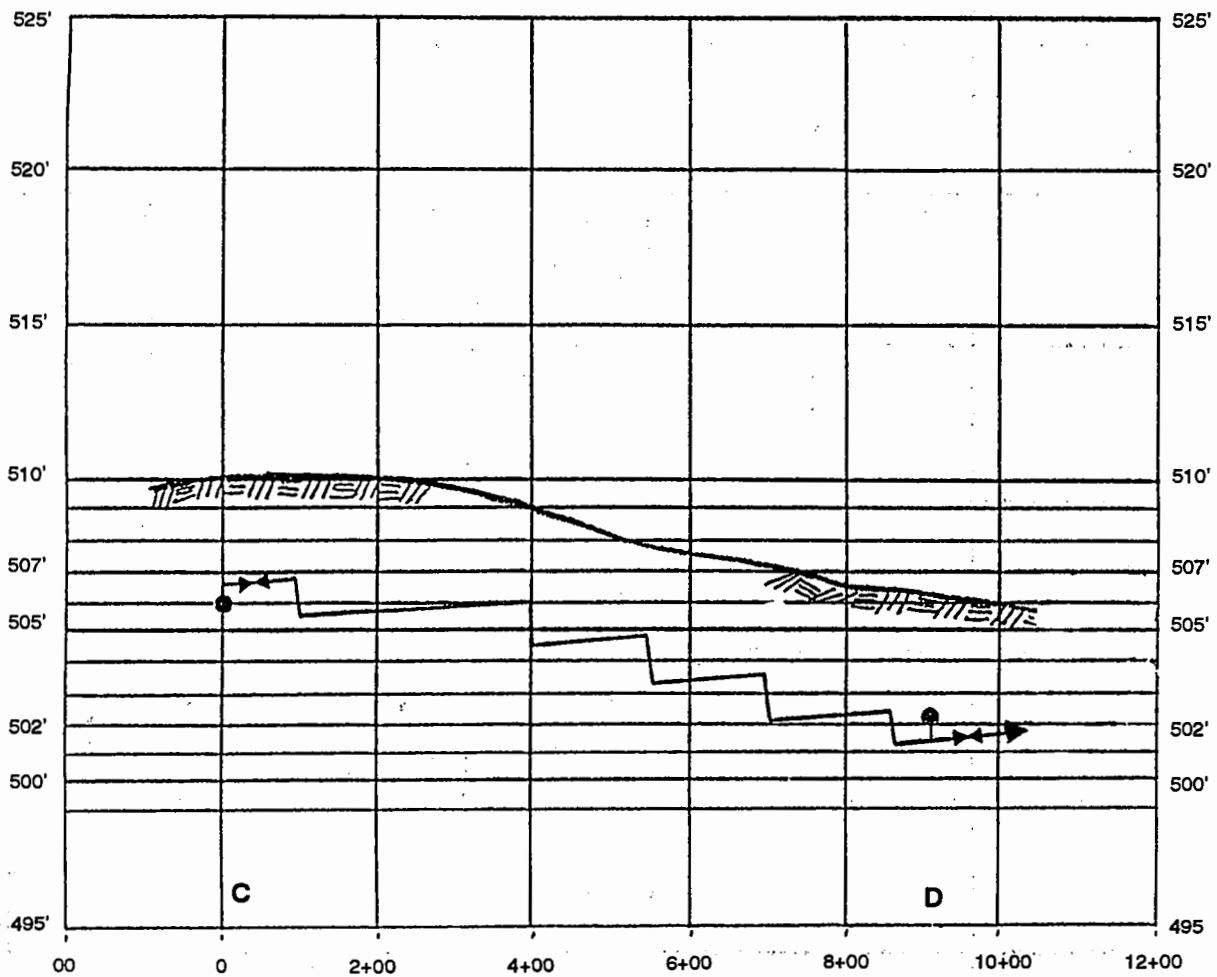
Figure 5-4. Design example profiles.



LEGEND:  DIVISION VALVE
 CONNECTION FROM A BRANCH SEWER



SCALE: HORIZONTAL 1"=200'
 VERTICAL 1"=5'
 SEWERS LAID TO 0.2% FALL IN FLOW DIRECTION

Figure 5-5. Design example profiles.



MAIN #2

SCALE: HORIZONTAL 1"=200'
VERTICAL 1"=5'

LEGEND:  DIVISION VALVE
 CONNECTION FROM A BRANCH SEWER

SEWERS LAID TO 0.2% FALL IN FLOW DIRECTION

Table 5-1. Design Example Line Loss Calculations (all calculations in ft)

Station to Station	Line Length	Q		H _f /100	Head Loss Line	Static Loss	Total Loss Line	Accum. Head Loss	Pipe Length				No. Valves
		Mean	Accum.						3-in	4-in	6-in	8-in	
Start with Losses carried forward from F-D:								1.5535					
(D) 8+80 - 8+60	20	25.6	25.6	0.0184	0.0037		0.0037	1.5572			20		
8+60 - 7+00	160	26.9	28.2	0.0198	0.0317	0.5	0.5317	2.0889			160		2
7+00 - 5+50	150	29.4	30.7	0.0225	0.0338	1	1.0338	3.1227			150		2
5+50 - 4+00	150	37.0	43.3	0.0352	0.0528	1	1.0538	4.1755			150		3
4+00 - 1+00	300	45.9	48.4	0.0528	0.1584	1	1.1584	5.3339			300		4
1+00 - 0 (C)	100	49.0	49.7	0.0594	0.0594	1	1.0594	6.3933			100		1

Branch sewer G-C joins at this point; calculate G-C before continuing with main.

Calculation for G-C yields an accumulated head loss of 5.0243, which is less than 6.3933. Therefore, F-D-C head losses (6.3933) are carried over for the remaining mainline calculation, shown in Table 5-2.

Table 5-2. Design Example Line Loss Calculations (all calculations in ft)

Station to Station	Line Length	Q		H _f /100	Head Loss Line	Static Loss	Total Loss Line	Accum. Head Loss	Pipe Length				No. Valves
		Mean	Accum.						3-in	4-in	6-in	8-in	
Start with Losses carried forward from F-D-C:									6.3933				
(C) 30+15 - 29+95	20	97.1	97.1	0.2097	0.0419	0.5	0.5419	6.9352			20		
29+95 - 26+50	345	100.3	103.5	0.2219	0.7656		0.7656	7.7008			345		5
26+50 - 21+40	510	104.1	111.2	0.0718	0.3662		8.0670	8.0670				510	6
(B) 21+40 - 8+13	1,327	124.6	130.4	0.1009	1.3389		1.3389	9.4059		750 (branch)		1,327	9
8+13 - 5+00	313	131.0	131.7	0.1101	0.3446	0.38	0.7246	10.1305				313	1
5+00 - 2+00	300	133.0	134.2	0.1132	0.3396	0.38	0.7196	10.8501				300	2
2+00 - 0 (A)	200	136.1	138.0	0.1180	0.2360	0.58	1.1160	11.9661				200	3
Total			138.0					11.9661		4,815	2,540	2,650	101

Accumulated head losses are under 13 ft, so design is acceptable.

Table 5-3. Design Example Piping Calculations (all calculations in ft, except as noted)

Line	Pipe Length			Peak Flow (gpm)	No. Crossovers	No. Valves	No. Homes
	4-in	6-in	8-in				
1	2,400	1,400		78.1	31	62	124
2	4,815	2,715	2,650	138.0	42	102	200
3	3,700	2,200		49.9	10	31	78
Total	10,915	6,315	2,650	266.0	83	195	402
Avg. Crossover Length					40		
Total 3-in Pipe					3,320		
Volume of Pipework (based on SDR 21 PVC pipe):							
V_p	=	$(0.0547 \times \text{Length 3-in} + 0.0904 \times \text{Length 4-in} + 0.1959 \times \text{Length 6-in} + 0.3321 \times \text{Length 8-in}) \text{ cu ft}$					
V_p	=	$(182 + 987 + 1,237 + 880) = 3,286 \text{ cu ft}$					
V_p	=	$7.5 \times 3,286 \text{ cu ft} = 24,645 \text{ gal}$					
$2/3 V_p$	=	16,430 gal					

Table 5-4. Design Example Vacuum Station Calculations (all calculations in ft)

Peak Flow	=	Q_{max}	=	266 gpm	
Average Flow	=	Q_a	=	$Q_{max}/\text{Peak factor} = Q_{max}/3.5$	= 76 gpm
Minimum Flow	=	Q_{min}	=	$Q_a/2$	= 38 gpm
Vacuum Pump Capacity Required	=	Q_{vp}	=	$(A \times Q_{max})/7.5 \text{ gal/cu ft}$	

Determine A from:

<u>Longest Line Length</u> (ft)	<u>A</u>
0 - 5,000	6
5,001 - 7,000	7
7,001 - 10,000	8
10,001 - 12,000	9
12,001 - 15,000	11

Vacuum Pump Capacity Required	=	$(7 \times 266)/7.5 \text{ gal/cu ft}$ NOTE: Min. $Q_{vp} = 150 \text{ acfm}$	=	248 acfm	Select next standard pump size = 300 cfm
Discharge Pump Capacity	=	Q_{dp}	=	Q_{max}	= 266 gpm

Collection Tank Operating Volume:
(for 15-min cycle at Q_{min})

V_o	=	$15 Q_{min} (Q_{dp} - Q_{min})/Q_{dp}$	=	$15 (38) (266 - 38)/266$	= 489 gal
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Total Volume of Collection Tank	=	V_{α}	=	$3 V_o$ NOTE: Min $V_{\alpha} = 400 \text{ gal}$	= 1,468 gal	Round up to 100-gal interval
Vacuum Reservoir/Moisture Removal Tank	=	V_{rt}	=		= 400 gal	

System Pump Down Time for Operating Range of 16-20 in Hg Vacuum:

$t = (0.045) [(2/3)(V_p) + (V_{\alpha} - V_o) + V_{rt}/Q_{vp}]$	=	$(0.045) [(16,430) + (1,500 - 500) + (400)]/300$ NOTE: Use actual tank and pump values	=	2.67 minutes
---	---	---	---	--------------

t should be less than 3 minutes.

If over, increase Q_{vp} to give t under 3 minutes.

If t under 1 minute, increase V_{rt} .

house connections to be made without overloading. For very large vacuum stations, 3 vacuum pumps may be used to prevent use of extremely large pumps. Typically, 25-hp vacuum pumps are the largest used.

5.3 SDGS

An SDGS is to be constructed to serve a small unsewered development. The development is subdivided into lots with 30 m (100 ft) frontage. Sixteen lots are currently occupied with single family homes. The proposed sewer will serve a total of 25 lots, but an additional 10 upstream from the proposed terminus of the sewer may be subdivided later. Therefore, the SDGS is designed for 35 residential connections.

The first step in design is to draw a system profile, beginning with the ground surface profile. The location and elevation of all interceptor tank outlet inverts should be added. The profile of the sewer is drawn such that it is below all the tank outlet invert elevations and limits depths of excavation (See Figure 5-6). Subsequent hydraulic analysis will show whether the proposed profile is satisfactory.

To perform the hydraulic analysis, the sewer is divided into convenient sections. Each section should have a relatively uniform gradient or flow condition (open channel or surcharged) to simplify the computations.

The computations for this example are presented in Table 5-5:

Column 1:

The selected sections are numbered beginning from the sewer outlet (Station 0+00).

Column 2:

Downstream station of the individual section is recorded.

Column 3:

Upstream station of the individual section is recorded.

Column 4:

The design flow is based on the total number of connections contributing flow to the section. The estimated flow per connection used in this example is 0.04 L/s (0.6 gpm).

Column 5:

The length of the sewer section is determined by the distance between the downstream and upstream stations (Columns 2 and 3)

Column 6:

The proposed elevation of the sewer invert at the upstream station of the section is recorded.

Column 7:

The proposed elevation of the sewer invert at the downstream station of the section is recorded.

Column 8:

The difference in the upstream and downstream section stations is determined by subtracting Column 6 from Column 7.

Column 9:

The average slope of the section is calculated by dividing Column 8 by Column 5. If Column 8 is zero, then surcharged conditions must be assumed.

Column 10:

The proposed pipe diameter is recorded.

Column 11:

The capacity of the sewer section is calculated. In this example, the Manning equation was used with a "n" of 0.013.

Column 12:

The ratio of the design flow to the calculated pipe capacity (full pipe flow) is determined by dividing Column 4 by Column 11. If less than 1, the pipe flows partially full. If greater than 1, the pipe is surcharged.

Column 13:

The velocity at full pipe flow is determined by dividing the Column 11 by the cross sectional area of the pipe. This computation is necessary for the following calculations.

Column 14:

The depth of flow at design flows is determined by using a hydraulic elements chart from any sewer design or hydraulic handbook.

Column 15:

The velocity at design flow is determined from the hydraulic elements chart. It is not necessary for design, but is often of interest to the designer.

Those sections that are continuously surcharged (Column 14) and long sections laid level are critical sections in SDGS design. If wastewater backups into individual connections is to be prevented, the slope of the hydraulic grade line during peak flow conditions should not be allowed to rise above any service connection inverts. If this occurs, the pipe must be increased in diameter, the

Figure 5-6. SDGS design example system profile.

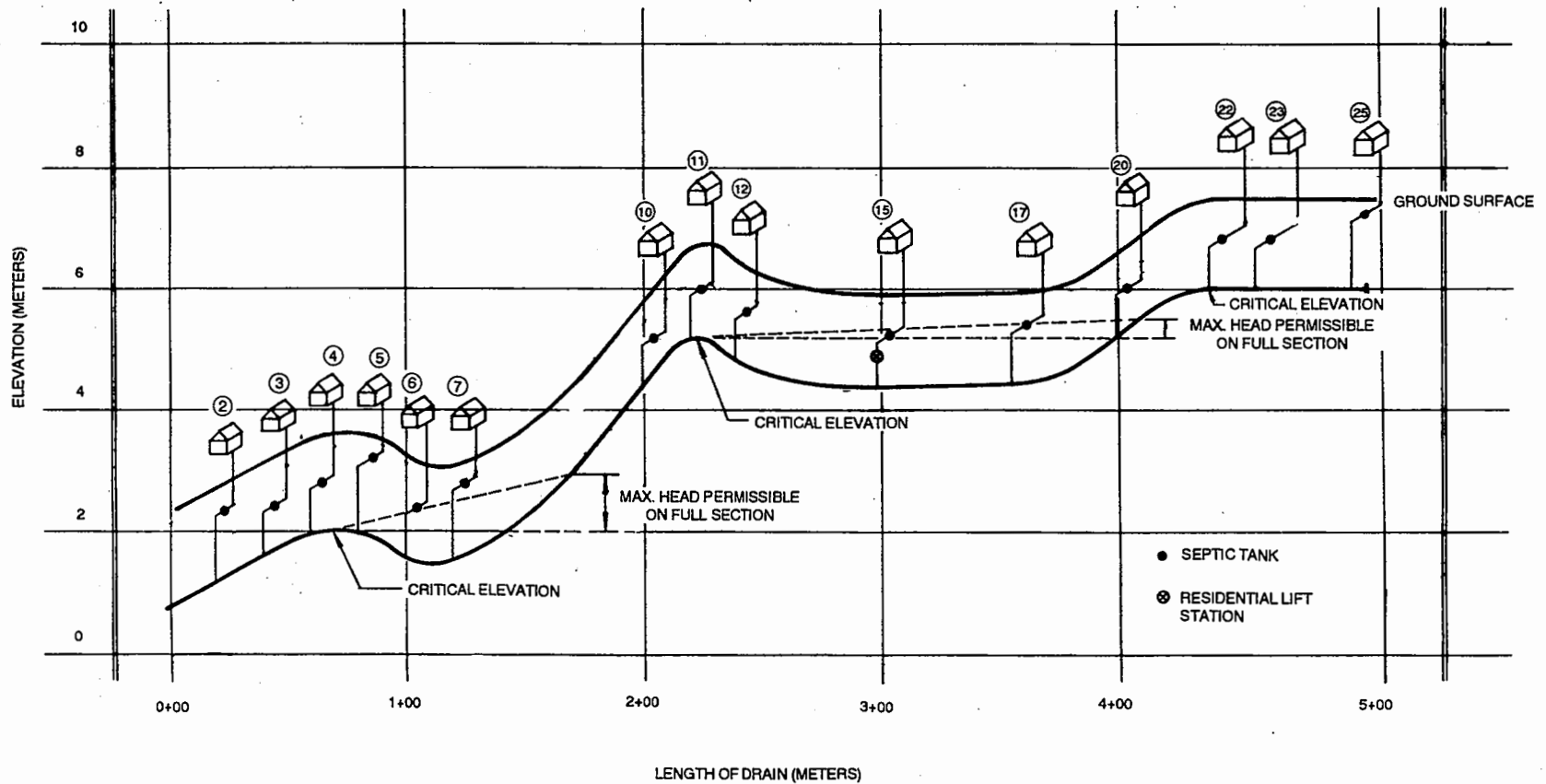


Table 5-5. Computations for SDGS Design Example

Section No.	Station (from)	Station (to)	Design Flow (L/s)	Length (m)	Elev. Upstream Station (m)	Elev. Downstream Station (m)	Elev. Difference (m)	Slope	Pipe Diameter (mm)	Flow at Full Pipe (L/s)	Ratio of Design to Full Pipe Flow	Velocity at Full Pipe Flow (m/s)	Ratio of Depth of Flow to Pipe Dia.	Velocity at Design Flow (m/s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
1	0+00	0+60	1.40	60	2.4	0.8	1.6	0.027	50 100	1.32 0.46	1.06 0.17	1.10	0.32	0.66
2	0+60	1+43	1.32	83	2.4	2.4	0	0						
	0+60	1+70	1.32	110	2.9 ^a	2.4	0.5	0.005 ^a 0.026 ^b 0.001 ^b	50 100	1.32 1.32	1.00	0.17	Surcharge	0.17
3	1+43	2+20	1.16	77	5.2	2.4	2.8	0.036	50	1.55	0.75	0.78	0.73	0.76
4	2+20	4+00	1.00	180	5.2	5.2	0	0						
	2+20	4+07	1.00	187	5.5	5.2	0.3	0.002 ^a 0.015 ^b 0.0004 ^b	50 100	1.00 1.00	1.00	0.13	Surcharge	0.13
4 ^c	2+20	4+00	1.00	180	5.2	2.5 ^d	2.7 ^d	0.015	50	1.00	0.50	1.00	1.00	0.50
1 ^c	1+43	2+20	1.16	77	2.5	2.4	0.1	0.001	50 100	0.29 1.85	3.90 0.63	0.23	0.38	0.16
5	4+00	4+33	0.64	33	6.0	5.2	0.8	0.024	50	1.27	0.51	0.63	0.57	0.54
6	4+33	4+73	0.56	40	6.0	6.0	0	0 0.005 ^b	50	0.56	1.00	0.28	Surcharge	0.28

a Maximum rise or slope at the HGL, based on upstream condition.

b Slope of HGL necessary to carry the design flow.

c Recomputation of pipe hydraulics due to change in sewer profile.

d Necessary elevation and elevation difference to carry the design flow.

downstream invert elevation lowered, or STEP units installed at the affected connections.

In this example, Sections 2 and 4 are continuously surcharged. To determine if the pipes in these sections are adequately designed, the maximum slopes of the hydraulic grade lines through the sections are sketched on the profile beginning from the outlet from the surcharged sections. The grade lines must remain below all connection inverts if gravity connections are to be used. Using the maximum slopes, the hydraulic capacities of the sections are calculated. These capacities must be greater than the design flows through the sections. Section 2 is surcharged from Station 0+60, the outlet where free discharge occurs, to a point where the hydraulic grade line intersects the pipe upstream.

Because all service connections must remain above the hydraulic grade line to allow gravity drainage, the maximum slope of the grade line is established by connection 6 (Figure 5-6). The maximum slope is determined to be 0.005 m/m. A 5-cm (2-in) diameter pipe

would require a slope of 0.026 m/m to carry the design flow. This slope would cause the hydraulic grade line to be above connection 6, so a 10-cm (4-in) diameter pipe was selected.

In Section 4, connections 15 and 17 establish the maximum slope of the hydraulic grade line. The sewer profile originally proposed sets the static water level of this surcharged section at the same elevation as connection 15. Either a STEP unit must be used at this connection or the sewer invert elevation lowered at Station 2+20. If a STEP unit is used at connection 15, connection 17 will establish the maximum slope of the grade line at approximately 0.002 m/m. A 5-cm (2-in) diameter pipe is not large enough to carry the design flow. Therefore, a 10-cm (4-in) diameter pipe is selected.

Other options would have been to provide STEP units at both connections or lower the sewer invert at Station 0+10. An economic analysis would be necessary to determine the most cost effective solution.