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Pressure and Vacuum Sewer Demonstration Project - Bend, Oregon

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PRESSURE AND VACUUM SEWER DEMONSTRATION PROJECT BEND, OREGON

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FOREWORD

The U. S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

ABSTRACT

A pressure sewer system collecting domestic septic tank effluent and a vacuum system collecting raw domestic sewage were constructed in the City of Bend, Oregon. Each of the systems collected sewage from eleven houses and discharged into existing gravity sewer mains. Groups of one, two and three houses were served by single collection sump/vacuum valve or collection sump/pump combinations. The systems were operated and monitored for a period of approximately one year. The systems were evaluated for construction costs, operation and maintenance costs, reliability, operating characteristics, and chemical characteristics of collected sewage and septic effluent.

This report was submitted in fulfillment of Grant No. S803295 by the City of Bend, Oregon under the sponsorship of the U. S. Environmental Protection Agency. This report covers the period from July, 1974 to July, 1977.

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LIST OF ABBREVIATIONS

^{o}C	-- degrees Celcius
^{o}F	-- degrees Farenheit
R & D	-- research and development
DEQ	-- Oregon Department of Environmental Quality
No.	-- number
SDR	-- standard pipe dimension ratio
PVC	-- polyvinyl chloride
m	-- meter
cm	-- centimeter
gpm	-- gallons per minute
TDH	-- total dynamic head
hp	-- horsepower
kw	-- kilowatt
kwh	-- kilowatts per hour
Hg	-- mercury
STEP	-- septic tank effluent pumping
DWV	-- drain-waste-vent
MTBSC	-- mean time between service calls

ACKNOWLEDGMENTS

The cooperation and assistance of the numerous people who contributed to this project is gratefully acknowledged. The field survey for design of the project facilities was done by members of the Bend Engineering Department under the direction of Mr. Jack Donahue, Bend City Engineer. Operation and maintenance of the system, collection of data and laboratory analysis were done by members of the wastewater treatment plant staff under the direction of Mr. Mike Elmore, Superintendent.

The cooperation of the homeowners who volunteered their homes for this project and endured the disturbances of the construction with good cheer is gratefully acknowledged.

Finally, the preliminary work done by Mr. Lloyd Clark and Mr. Wayne Taylor is acknowledged. Their interest in finding better methods for construction of sewers in the rocky terrain of the Central Oregon plateau provided the initial impetus for obtaining the funding which made this demonstration project possible.

SECTION 1

INTRODUCTION

BACKGROUND

Bend, Oregon, is a city of approximately 17,000 population (1975 census) located in Central Oregon, east of the Cascade Mountains. The city sits at an elevation of approximately 1,096 meters (3,600 feet) on a plateau formed by volcanic eruptions and lava flows. Projecting basalt rock formations and cinder cones are prominent features of the landscape. Soils are generally shallow, over underlying basalt formations.

The Bend climate is arid-temperate. Precipitation averages 0.3 meters (12 inches) annually, occurring mostly during winter months. Summers are dry and moderately hot. Winters are moderately cold. Mean temperature in January, the coldest month, is -1.1^{o} C (30^{o} F); the temperature does not rise above 0^{o} C (32^{o} F) an average of 12 days each winter.

The central business area of Bend has been sewered since 1915, but the system has not been extended into most of the residential area. Wastewater is carried to a treatment plant at the edge of town by a gravity interceptor. Several small housing areas adjacent to the interceptor discharge into the interceptor. A motel complex on the north edge of the city pumps sewage to the interceptor. Effluent from the treatment plant is discharged into a lava sink hole near the treatment plant.

Wastewater from approximately 90 percent of Bend's population is treated by septic tanks and subsurface disposal systems. A common practice for septic tank effluent disposal is to drill a disposal well 0.15 or 0.20 meters (6 or 8 inches) in diameter and up to 18 meters (60 feet) deep. The vesicular basalt and volcanic ash geological structures are generally capable of absorbing a great amount of water, although some older residences have found it necessary to drill more than one disposal well after the absorption capacity of the earlier wells deteriorated. Conventional septic tank-soil absorption systems are also used in areas where this approach is feasible.

During the mid-1960's regulatory agencies became concerned about the probability of contaminating groundwater by subsurface discharge of inadequately treated wastewater. In 1969 regulations were adopted by the Oregon Department of Environmental Quality (DEQ) which prohibit discharge of untreated wastewater into waste disposal wells. The prohibition is to become effective in 1980. The City of Bend has been directed by DEQ to construct a sewage collection system before 1980.

Construction of a conventional gravity sewer system in Bend presents a formidable task of rock excavation. Normal trench excavation practice in Bend has been to remove soil overburden, then drill, return the overburden, blast, and re-excavate.

In addition to high costs for rock excavation, considerable liability for damage is incurred when using explosive for excavation in developed areas of Bend. The random nature of the conglomerate of volcanic lava, ash and boulders makes it difficult to prejudge the effect of an explosive charge. The probability of damage to buildings or other structures is correspondingly high.

Faced with the high cost for installing conventional gravity sewers, it was decided that funds should be sought for a research program to investigate innovative methods of sewage collection and rock excavation.

A preliminary survey indicated that the problem of installing sewer in rock terrain is widespread. In response to the survey, 150 cities in 16 states stated that they faced similar problems.

In the late 1960's, the pressure and vacuum sewer technology was being developed. Several systems had been installed and had been described in technical journals. Both pressure and vacuum systems were known to have the advantage of not requiring deep excavation to maintain line and grade as do conventional gravity sewers.

Outcome of the search for funding was a research and development (R & D) program to construct, operate, monitor, and evaluate small pressure and vacuum sewage collection systems in the City of Bend. The program was funded 75 percent by the U. S. Environmental Protection Agency (EPA) Municipal Environmental Research Laboratory, 17-1/2 percent by the Oregon Department of Environmental Quality, and 7-1/2 percent by the City of Bend. The City of Bend supplied its portion of the cost by providing in-kind service for operating and monitoring the system.

Funding was not found for conducting research in rock excavation.

GOALS AND GUIDELINES

Goals and guidelines for the experimental pressure and vacuum sewer systems project are summarized as follows:

1. The pressure and vacuum sewer systems were to be of comparable size and configuration, for comparison to each other.

2. Funding limited the project's size to approximately 12 houses in each system.

3. Only single family residential dwellings were to be included in the system.

4. Homeowners were to be asked to volunteer to participate in the project. As an incentive to volunteer, the participants were not to be charged sewer installation costs if the experimental systems were permanently incorporated into the city sewer system.

5. Groups of one, two and three houses in each system were to be served by a single effluent pump station or by a single-vacuum valve.

6. The pressure system was to be of the septic tank effluent pumping (STEP) type.

7. The vacuum system was to be a one-pipe design, collecting raw domestic sewage generated by normal household fixtures.

8. Cost of equipment, construction, operation, and maintenance would be recorded and compared to each other and to conventional gravity sewers.

9. The system would include monitoring instrumentation to record operating characteristics of the system.

10. Samples of a sewage and septic effluent would be collected and chemically analyzed, the principal intent being to project the effect of mixing septic effluent with normal raw sewage.

SECTION 2

SUMMARY AND CONCLUSIONS

SUMMARY

The purpose of this project was to construct, operate, and evaluate pressure and vacuum sewers as alternative methods of sewage collection which would not require deep trench cuts to maintain line and grade as do conventional gravity sewers. Small pressure and vacuum collection systems were constructed, operated and monitored in Bend, Oregon.

Project Description

Separate sites were selected to construct the pressure and vacuum collection systems. The pressure system consisted of six pump stations which collected septic tank effluent from 11 homes and pumped it into a gravity interceptor. The pressure system main line consisted of 305 meters (1,000 feet) of 5.1-cm (2-inch) diameter, class 160, PVC pipe with a maximum increase in elevation of 7.6 meters (25 feet).

The vacuum system collected raw sewage to a central vacuum station from 11 homes utilizing 8 collection sump-vacuum valve installations. The vacuum system collection line consisted of 563 meters (1,847 feet) of 7.2-cm (3-inch) diameter, schedule 40, PVC pipe with a maximum lift of 4 meters (13 feet) and net elevation change of 2.4 meters (8 feet).

Instrumentation was included in the project design to collect data to indicate a) frequency of operation of pressure-system pumps, vacuum valves, vacuum pumps and vacuum-system discharge pumps; b) energy used by the two systems; and c) water used by residents of the two systems. Wastewater volumes could be calculated from pump and valve operating frequencies and sump configuration data. Equipment for collecting composite samples of effluent from the two systems for chemical analysis was included in the project design.

Construction Costs--

Equipment and construction cost data were collected during the project bidding and construction phases. Total equipment and construction costs reported by the general contractor (but not including profit and overhead for the general contractor) totaled $138,084.00.

A Ditch Witch[tm] R-100 rock trenching machine was used to cut pipeline trenches when rock was encountered and when the site allowed access by the machine. The trenching machine cut 20-cm (8-inch) wide trenches up to 1.2 m (4 feet) deep. Trenches averaged approximately 1.0 m (3.2 feet) deep, with approximately 50 percent rock, and cost an average of $16.84 per meter ($5.13 per foot) to excavate. This cost can be compared to the reported range of excavation costs in Bend for similar trenches of $6.50 to $65.00 per meter ($2.00 to $20.00 per foot).

Operation and Maintenance

The pressure and vacuum systems were operated and monitored from the spring of 1976 to midsummer of 1977. A daily log of operation and maintenance tasks was maintained during this period.

Pressure System--

The only failures in the pressure system reported during this period resulted from a defective check valve. After being repaired the same check valve became clogged with debris which appeared to have fallen into the sump during repair of the initial failure.

One complaint of malodor from a pump sump was received. After repairing the sump-cover gasket and tightening the cover bolts, no further complaints were received.

Corrosion in the septic atmosphere of the pump sump was subjectively judged to be severe, although no failure from corrosion has yet occurred.

Grease buildup was not severe enough to be objectionable at the end of one year of operation.

Vacuum System--

Problems with operation of the sliding-vane vacuum pumps used on the Bend project occurred repeatedly. An excessive amount of water condensed in the lubrication system of the pumps, possibly because of the small size of the Bend vacuum system. Manometer-type condensate drains installed on the vacuum pumps to reduce maintenance required to manually drain the condensate each day allowed the pumps to lose their oil. Bearing surfaces on one pump have been rebuilt.

Failures of vacuum valves have resulted from malfunctions in the valve controller, but not from malfunction of the valve itself. One valve failed in an open position due to a small particle of debris in the pneumatic circuits of the valve controller. Another valve failed because of freezing of moisture in a check valve in the control circuit.

Neither corrosion nor grease buildup appeared to be excessive during the first year of operation.

Wastewater Volumes--

The volumes of wastewater collected from both the pressure and vacuum systems were surprisingly low, generally being in the ranges of 151 to 227 liters (40 to 60 gallons) per capita day in the pressure system and 30 to 50 gallons per capita day in the vacuum system. No significantly different patterns of wastewater generation were observed to occur at different seasons of the year.

Water Use--

Bend has an abundant supply of high quality surface water. Water bills are a flat monthly rate. Water was therefore used generously for lawn watering during the summer; up to many thousands of liters per day for some residences. During the winter, water use generally dropped off to less than 1,000 liters (260 gallons) per day per residence.

Energy Consumption--

Average energy consumption by the pressure system was approximately 0.74 kwh per day per residence. However, approximately 0.48 kwh per day was used by a strip heater in each of the control boxes, which would not be needed if the control box were located inside the house. The 0.26 kwh per day per residence used to operate the sump pumps represents less than $.01 per day at current electrical prices in Bend. The vacuum system used an average of approximately 1.36 kwh per day per residence, representing cost of approximately $.04 per day per residence at current electrical prices in Bend. Electrical energy was a relatively small cost item for both the pressure and vacuum systems.

No significant change in the energy consumption of the pressure system was observed over the course of the monitoring period. Energy consumption by the vacuum pumps increased by a factor of approximately 1.4 during the year of monitoring. There also appeared to be a small increase in energy consumption by the vacuum pumps during warmer weather.

Chemical Characteristics--

The averages of measured chemical characteristics of the septic tank effluent and raw sewage sampled from the Bend pressure and vacuum collection systems during the year of monitoring were as follows:

		Pressure System Septic Tank Effluent	Vacuum System Raw Sewage
Temperature	OC	13.2	14.0
	OF	54.4	57.0
pH		6.7	8.0
Dissolved Oxygen mg/l		0.5	0.7
Alkalinity mg/l as $CaCO_3$		204.0	127.7
Grease mg/l		65.0	110.7
Total Ortho Phosphate mg/l P		10.4	3.2
Total Kjeldahl Nitrogen mg/l N		40.9	28.4
Total Sulfide mg/l S		1.8	not measured
Suspended Solids mg/l		36.4	164.1
BOD mg/l		157.0	187.7
COD mg/l		276.0	363.3

Cost Comparison--

A comparison of the costs of hypothetical pressure and vacuum systems was made, using the cost data from the Bend project. Adjustments were made for the project monitoring equipment, for the differences in the two sites, and for the potential number of residences the systems could serve. Total annual capital recovery, operation, and maintenance costs per residence estimated for the two hypothetical systems were close, $399.00 per year per residence for the pressure system and $421.00 per year per residence for the vacuum system.

CONCLUSIONS

Both the pressure and vacuum system constructed and operated in Bend collected and transported sewage successfully.

The STEP pressure system performed satisfactorily during the first year of operation. The septic environment in the STEP pressure sump was severely corrosive to ferrous metals. Care should be taken to design and construct STEP stations' components of corrosion-resistant materials.

The vacuum system experienced failures from malfunction of the vacuum valve controllers. However, it was felt that the first year of operation did not give sufficient operating data to judge long term reliability. The sliding vane vacuum pumps did not give satisfactory service as used on the Bend project.

The multiple home connections to single pump stations or vacuum valves operated without any problems and appear to be technically feasible. However, a separate electrical distribution system to serve only the pressure system pumps as installed in the Bend project is considered impractical for a non-research project. The sump pump would be connected to the electrical circuits of one of the homes and a formula would need to be agreed upon by the homeowners connected to the sump as to how to share payment for electrical energy to operate the pump.

The comparison of costs for the pressure and vacuum systems installed at Bend indicated that pressure and vacuum systems may have comparable total system costs. However, pressure and vacuum sewer systems do not lend themselves to generalized statements of comparison. Each system uses different components than the others. Application to any specific site will require a different design approach and a different mix of components for each system.

Pressure and vacuum systems have unique capabilities and limitations. Neither pressure nor vacuum sewers should be either totally rejected as not workable nor accepted as the total answer to all sewage collection problems. Rather, pressure and vacuum sewers should be considered as alternative sewage collection methods to be evaluated for each specific application.

The design engineer considering pressure or vacuum sewers for the first time should be aware that they require a greater, or at least newer and less well known, level of design sophistication than design of conventional gravity sewers and should proceed with appropriate caution.

SECTION 3

PROJECT DESCRIPTION

GENERAL

Equipment configurations used in the pressure and vacuum sewage collection systems installed in Bend, Oregon are described in this section. Discussion of considerations used in designing the Bend systems are deferred to Section 5, where a discussion of general pressure and vacuum technology is presented, along with some of knowledge and experience gained from designing, constructing and operating the Bend system.

SITE SELECTION

Sites for the pressure and vacuum sewer systems were selected to meet the following criteria:

1. The sites not serviceable by conventional gravity sewers.

2. Availability of an existing sewer to receive collected sewage.

3. Suitability of the sites to meet and test operating parameters of pressure and vacuum system technology.

4. Willingness of area residents to participate in the program.

5. Suitability of the sites to meet goals and guidelines listed in Section 1.

6. Suitability of sites to minimize cost of construction.

7. Suitability of sites to minimize traffic disruption during construction. The location of sites selected for construction of the pressure and vacuum systems are shown in Figure 1.

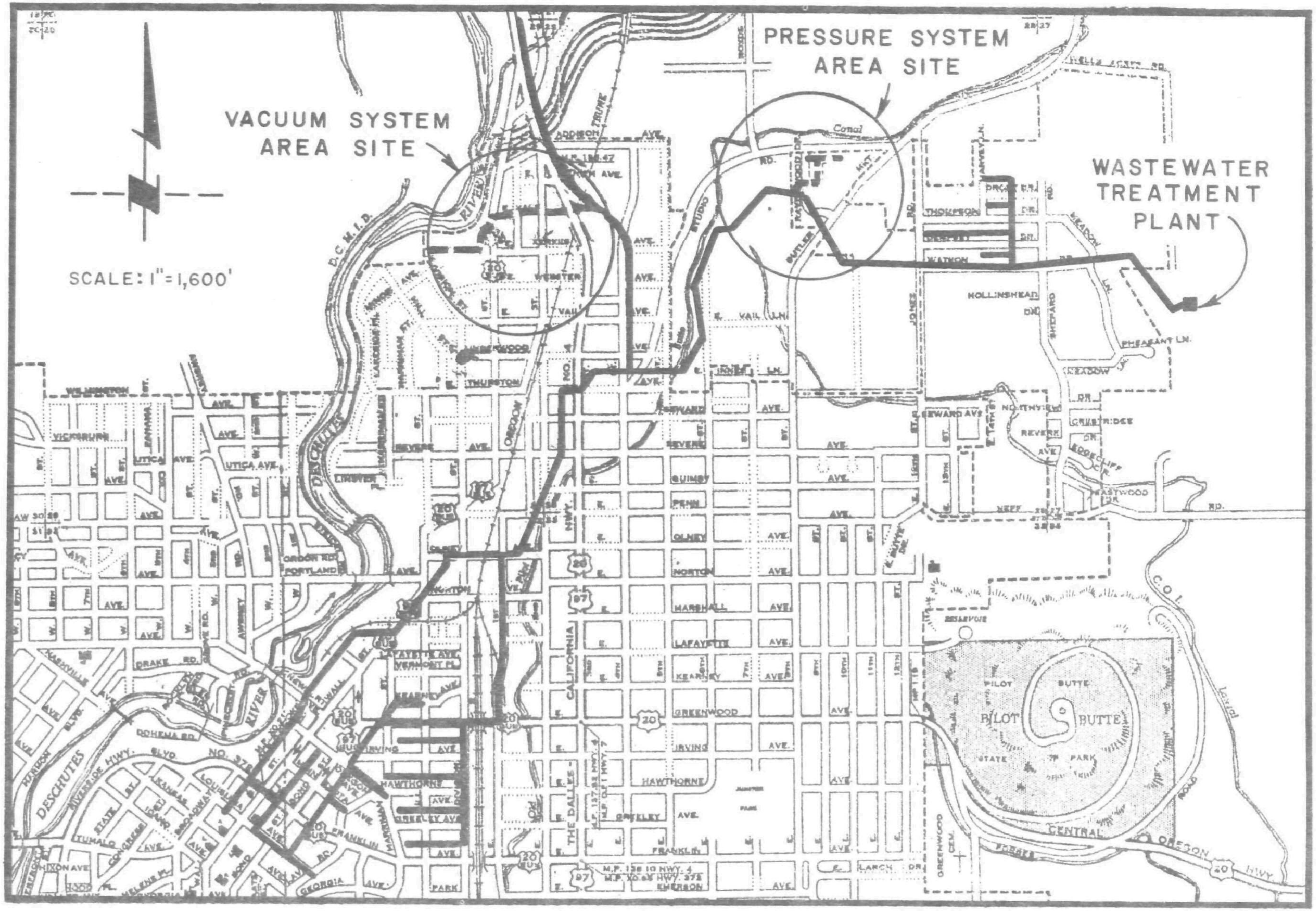

Figure 1. Project vicinity map, Bend, Oregon.

Existing sewer

Project sewer

PRESSURE SYSTEM

Site and Layout

The site selected for the pressure system (See Figure 2) was a relatively new housing development. Houses were generally less than five years old. The neighborhood could be characterized as typical upper middle class. The pressure system site was located on the toe of an old lava flow which sloped downward to the northeast. A gravity interceptor passed the area on the southwest corner. Sewer service was therefore available to the area if means were provided to lift sewage into the interceptor.

Eleven homeowners volunteered to participate in the program. The houses were divided into groups of two singles, three doubles, and one triple. Each group is served by a single pump station, making a total of six pump stations. The number of people usually resident in each house is indicated on Figure 2. The total pressure system population was approximately 34 people during the study period.

Pipe length from the farthest sump (No. 6) to point to discharge into a manhole on the interceptor was approximately 305 meters (1, 000 feet), and incorporated a lift of 7. 6 meters (25 feet).

House Sewer Interceptor Fitting

A "Y" fitting was installed in each house sewer between the septic tank and subsurface disposal field. Septic tank effluent flow was thereby diverted through one leg of the "Y" into the pump sump. The system was designed to be failsafe, i.e., in the event of pump failure, effluent would back up and overflow into the original subsurface disposal field, instead of backing up into the homeowner's plumbing (See Figure 3).

Septic tank effluent was carried to pump sumps through four-inch diameter Class 125, SDR 32.5, PVC pipe with elastomeric ring joints.

Septic Tanks

The existing septic tanks were cleaned and inspected for cracks, evidence of leaks or other conditions which might affect test results before start-up of the pressure system.

Pump Sumps

Pump sumps (See Figure 3) were of fiberglass construction, 0. 48 cm (3/16 inch) nominal thickness, nominally 0. 76 meter (30 inches) in

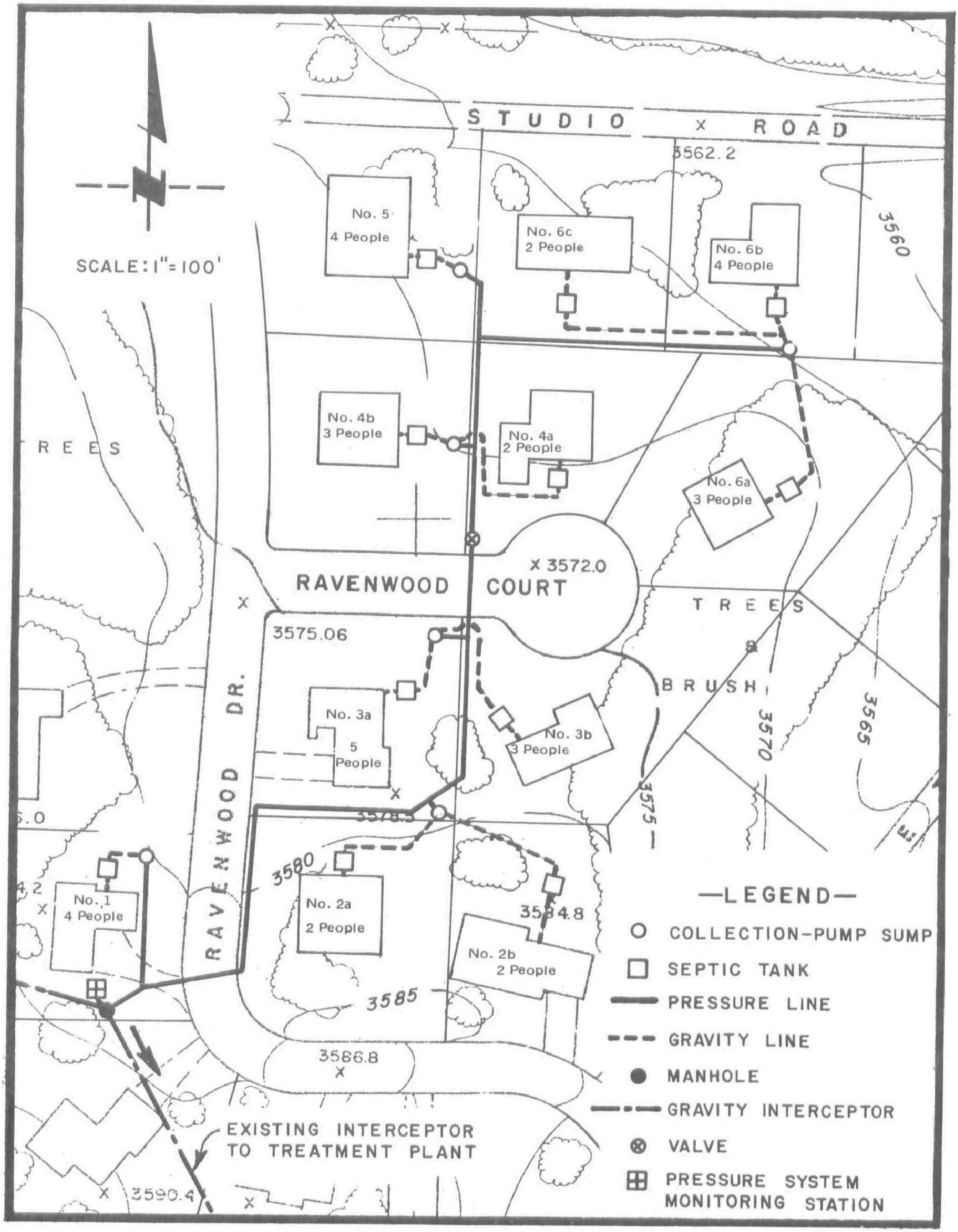

Figure 2. Pressure collection system site map.

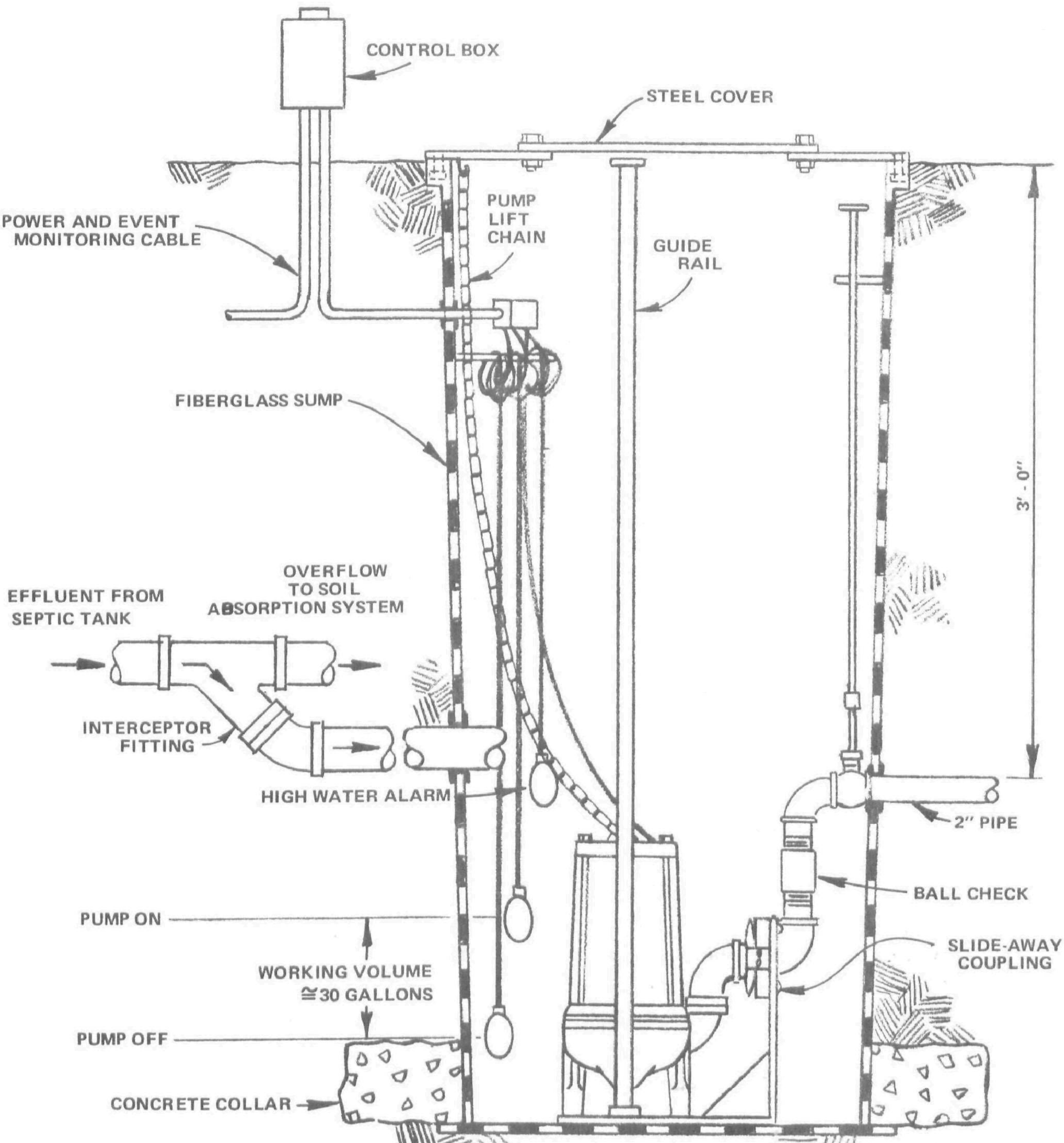

Figure 3. Low pressure pump installation.

diameter with a slight mold taper, and 1.4 meter (5 feet) deep. Upper rims of the sumps were reinforced by fiberglass flanges approximately 6.3 cm (2-1/2 inches) wide by 1.9 cm (3/4 inch) thick. Nuts for cover screws were imbedded in the flange.

Sump covers were 0.63-cm (1/4-inch) thick steel plate, painted and coated with bituminous epoxy paint on the inside. Covers are bolted to the sump flange. A smaller diameter steel plate bolted over a hole in each sump cover gave access to the pump.

Inlet pipes intersected the sumps at a minimum of 0.61 meter (2 feet) above the bottom. Pump discharge lines intersected the sump 0.91 meter (3 feet) below the surface. These intersecting pipes were sealed to the sump by flexible rubber grommets.

Effluent lines had a mating flange for a pump slide-away coupling, a PVC ball check valve on the vertical pipe run and a gate valve on the horizontal pipe run. Sumps contained guide rails and lift chains for convenient pump removal and replacement.

A sealed electrical junction box in each sump contained terminals for the pump power, pump control, and alarm wiring.

Pumps

Each pump station for the pressure system contained a single submersible sump pump. Spare pumps were available for installation in the event of pump failure.

Pumps were sized to deliver a minimum velocity of 0.61 meter (2 feet) per second through the 5.08-cm (2-inch) diameter pressure main. Two pump sizes were specified to meet this requirement, i.e., 1.57 liters per second (25 gpm) at 6.7 meters (22 feet) TDH and 1.57 liters per second (25 gpm) at 11.34 meters (37 feet) TDH.

Pumps supplied which meet this specification were:

Peabody Barnes Model E52 (Sumps Nos. 1, 2, 3, and 4).

Peabody Barnes Model SE52 (Sumps Nos. 5 and 6).

Pump motors were 0.373 kw (1/2 hp), single phase, 230 volt, oil filled, hermetically sealed, and submersible. The lower head pumps operated at 1750 rpm and had 3.175-cm (1-1/4-inch) diameter discharge pipe. The higher head pumps operated at 3450 rpm and had 5.08-cm

(2-inch) diameter discharge pipe. The pumps were fitted with guides and a slide-away discharge coupling to mate with the discharge pipe for convenient pump removal and replacement.

Each pump assembly weighed approximately 80 pounds and could be manually lifted from the sump by an attached chain. To remove the pump from the site would have required opening the sealed electrical terminal box to disconnect the pump power cables.

Pump Controls and High Water Alarms

Pump operation was controlled by two mercury float switches suspended in the sump at selected "pump-on" and "pump-off" levels. A third mercury float switch signaled high water condition by actuating an alarm, in the event of pump failure. A high water alarm signal was transmitted to the pressure system monitoring station, where it would actuate a light, indicating the sump with high water condition. The high water alarm signal was also transmitted to the treatment plant and/or police station where it would actuate a light, indicating a failure in the pressure system.

Pump starter switches and other electrical gear were housed in weatherproof control boxes mounted on posts near the pump stations (See Figure 3).

Pipe

Pressure system pipe was 5.08-cm (2-inch) diameter, 110-n/cm^2 (160-psi), SDR26, ring-joint, PVC pipe. PVC "T" fittings are used for intersections of pump lines to the pressure main (See Figure 4). The pressure pipe was buried at 0.91 meter (3 feet) minimum depth, bedded and covered by a minimum of 10.2 cm (4 inches) of sand. Segregated native backfill was used for backfill above the pipe zone.

A valve was installed in the main line between pump stations Nos. 3 and 4, as shown in Figure 2, the site map. The pressure pipe profile maintained a continuous upward slope from the pump stations to the point of discharge. Air release valves were therefore not needed.

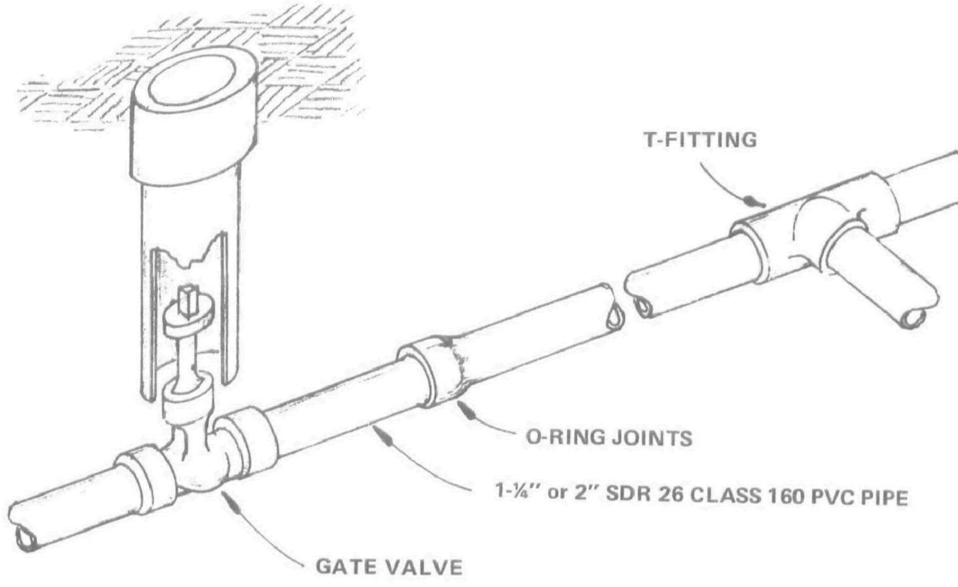

FIGURE 4 TYPICAL PRESSURE SYSTEM PIPE AND FITTINGS

Effluent Discharge Manhole

The pressure system discharged into a manhole on the existing gravity interceptor line. The system discharge pipe was installed above the high water level in the manhole and was angled so as to discharge in the same direction as the gravity sewer flow to minimize gas release from the septic effluent (See Figure 5).

A "T" fitting for an effluent sampling tube was incorporated into the discharge pipe in the manhole.

Pressure System Monitoring and Sampling Equipment

Monitoring Station--

A metal enclosure was installed near the discharge manhole to house system monitoring and sampling equipment as shown in Figure 5.

Event monitoring equipment--Signal wires from each pump control to the pressure monitoring station, appropriate circuitry and a strip chart recorder installed in the monitoring station permitted recording the time each pump operated.

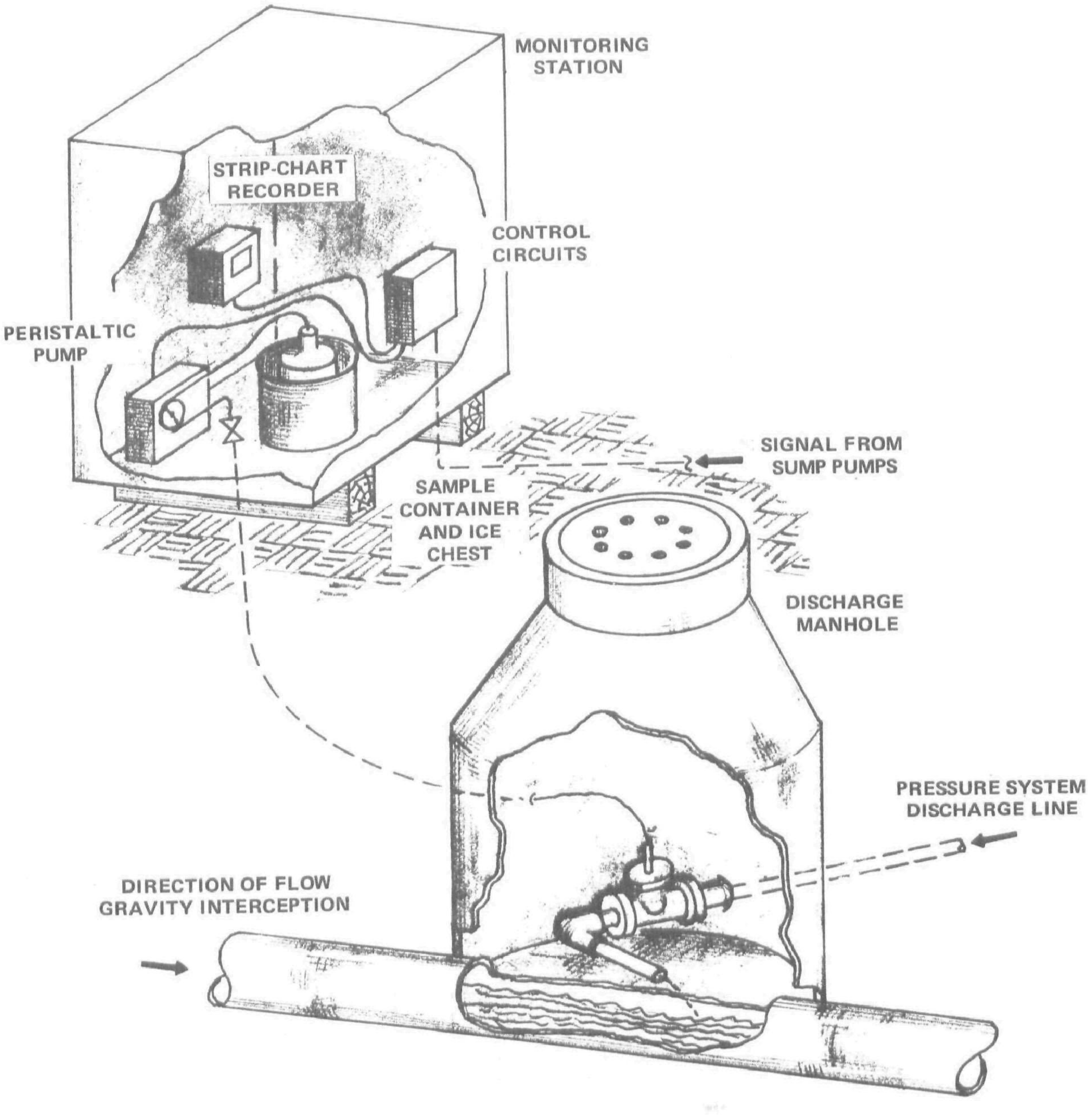

FIGURE 5 LOW PRESSURE SYSTEM DISCHARGE MANHOLE AND MONITORING STATION

Effluent sampling equipment--An effluent sampling system was installed in the discharge manhole and in the pressure system monitoring station as shown in Figure 5.

A sampling well consisting of a 7.62-cm (3-inch) diameter "T" fitting was installed in the discharge line in the discharge manhole. A 0.95-cm (3/8-inch) diameter tube ran from the sampling well to a peristaltic sampling pump in the monitoring station. The peristaltic pump, coupled with an electrically actuated valve to prevent loss of sampling pump prime drew effluent samples from the sampling well. Composited effluent samples were collected in a plastic carboy sitting in an ice chest.

In order to collect a representative composited effluent sample, the sampling pump was interconnected so that it operated during the operation of any of the system pumps. Pumping rate of the sampling pump was adjustable so that any appropriately sized sample could be collected.

Energy Consumption--

Two standard kilowatt-hour meters obtained from the electric company were installed to totalize electrical energy consumption by the pressure system. The kilowatt hour meters were installed in the project area so as to minimize electrical distribution wiring. Meter No. 1 totalized energy consumed by pump stations Nos. 1, 2, 3, and the pressure system monitoring station. Meter No. 2 totalized energy consumed by pump stations Nos. 4, 5, and 6.

Water Use--

Neptune^{tm} water meters were installed to totalize water use by each participating residence. The water meters were installed in the house service lines so that they measured both consumptive water use and water which was discharged into the sewage system.

VACUUM SYSTEM

Site and Layout

The site selected for the vacuum system (Figure 6) lay adjacent to the Deschutes River. The project site was intersected by First Street, a major city thoroughfare. The area was an older neighborhood. The houses and their residents had a somewhat varied character. Lots abutting on the Deschutes River had a high market value due to the aesthetically attractive environment. Sizes of houses in the neighborhood varied; some were rented units. Several of the houses were occupied by elderly retired people.

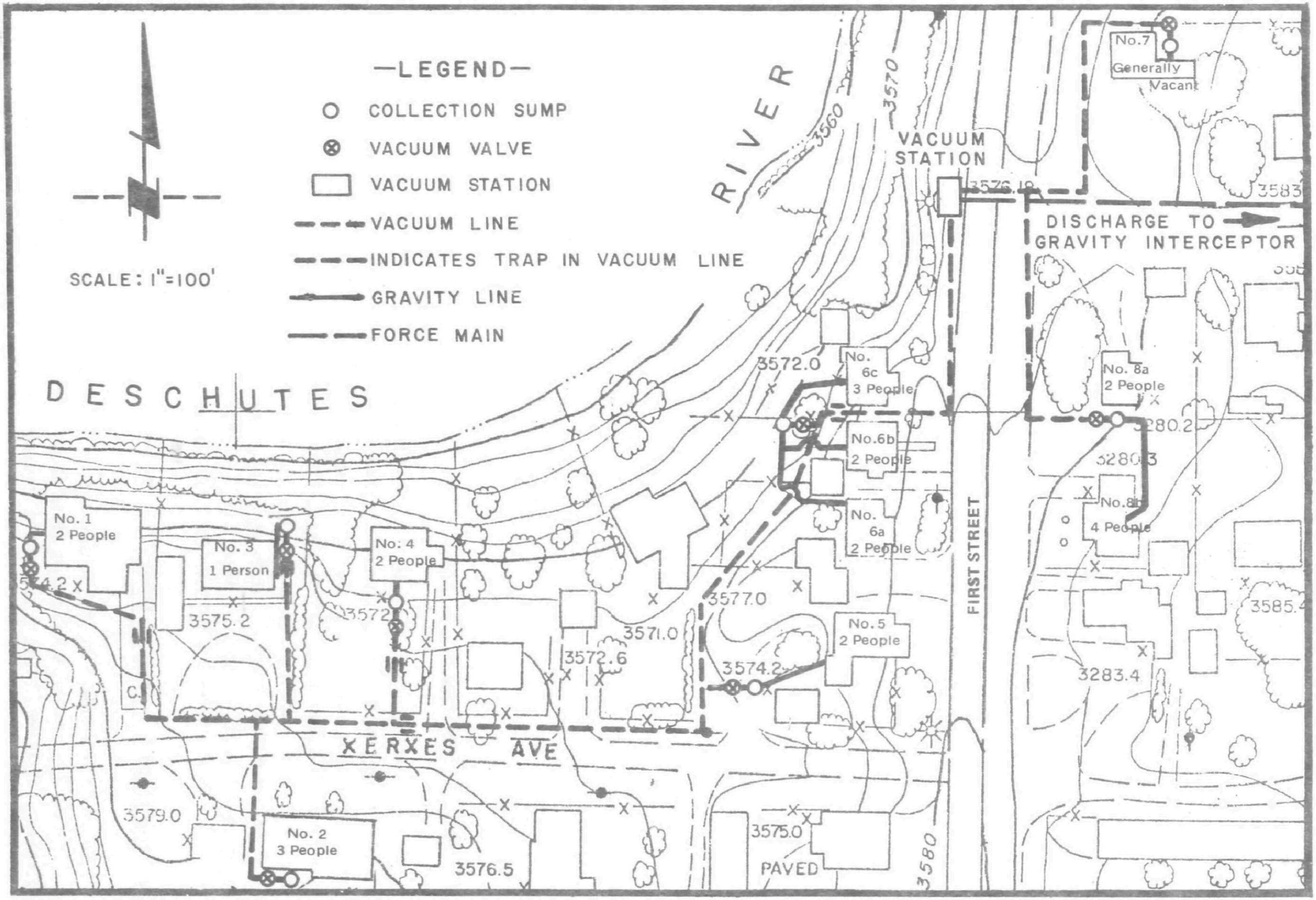

Figure 6. Vacuum collection system site map.

The area also had a semi-commercial character. The residence served by No. 5 valve included a family-operated grocery store and gas station. During the course of the project, one house (No. 7) was converted from a single family dwelling to rented office space and was unoccupied during most of the project. The number of people usually resident in each house during the project monitoring period is shown on Figure 6. Approximately 23 people were generally resident in the vacuum system area during the study period.

The immediate area did not have a sewer. Sewage collected by the vacuum system was pumped to an existing force main, approximately 305 meters (1,000 feet) east of the vacuum collection area, which in turn discharged into a gravity interceptor.

Homes abutting on the Deschutes River could not be served by a conventional gravity system, but lifts were within the operating parameters of a vacuum collection system.

Eleven homeowners volunteered to participate in the project. They were divided into groups of six singles, one double, and one triple. Each group was served by one collection sump and vacuum valve, for a total of eight valve installations.

The vacuum system incorporated a maximum pipe run of approximately 305 meters (1,000 feet) from the vacuum station to the most distant vacuum valve (No. 1). The most critical lift (No. 3) was a total of approximately 4 meters (13 feet), with 2.4 meters (8 feet) net elevation change.

House Sewer Interceptor Fittings

A "Y" fitting was installed in each house sewer line between the house plumbing and the septic tank (See Figure 7). Sewage was thereby diverted through one leg of the "Y" into a sewage collector sump. The system was designed to be failsafe, that is, in the event of failure of the vacuum system, sewage would back up and overflow into the existing septic tank, instead of backing up into the homeowner's plumbing. Sewage was carried to collection sumps through four-inch diameter Class 125, SDR 32.5, PVC pipe with elastomeric ring joints.

Collection Sumps - Valve Pits

Sewage diverted from house sewer lines was collected in a sump (See Figure 7). Sumps were of fiberglass construction, 0.48 cm (3/16 inch) thick, 0.6 m (2 feet) nominal diameter with a slight mold taper, and

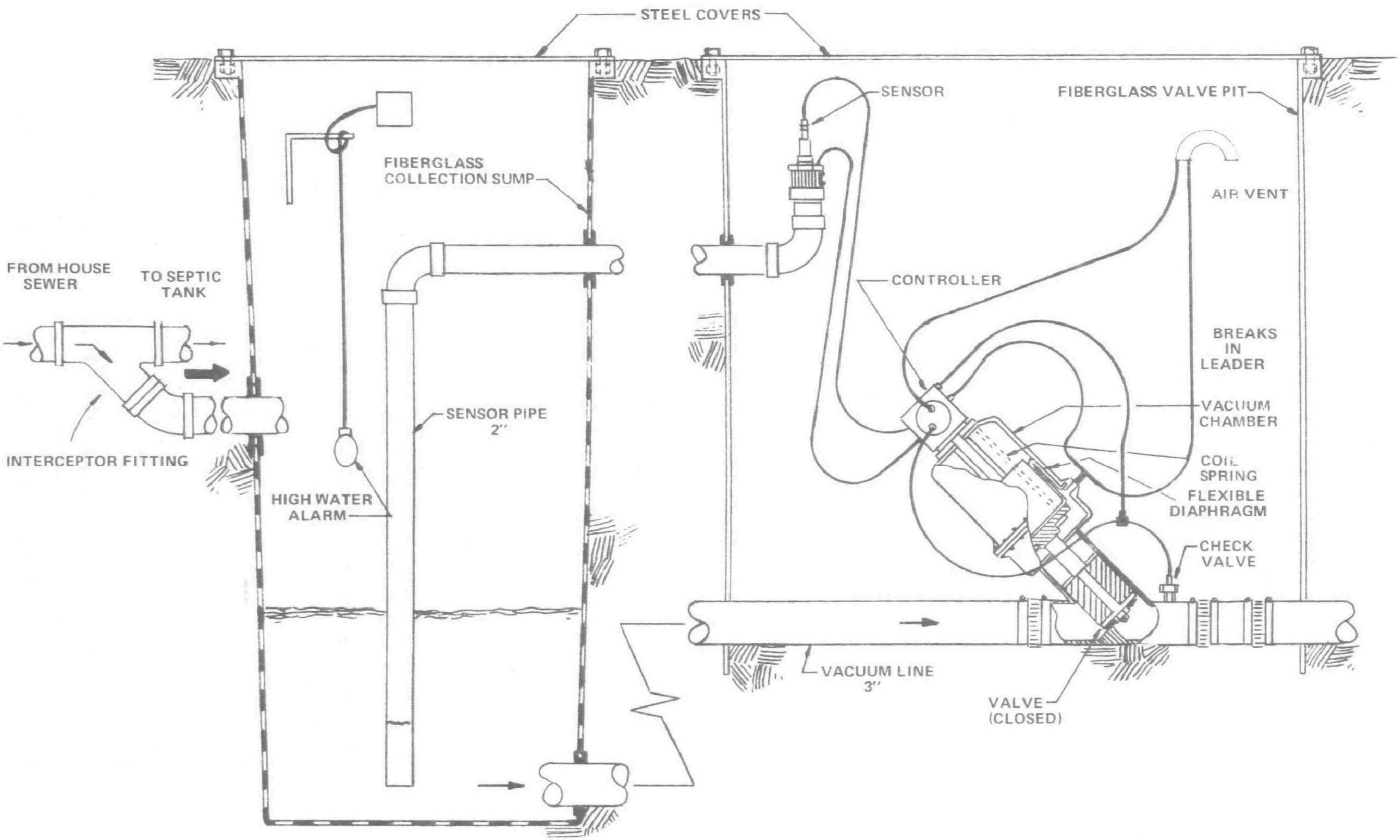

Figure 7. Vacuum, collection sump, valve pit, and valve installation.

0.9 m (3 feet) deep. The upper rim of the sumps were reinforced by fiberglass flanges approximately 6.35 cm (2-1/2 inches) wide by 1.9 cm (3/4 inch) thick. Nuts for cover screws were imbedded in the flange.

Sump covers were 0.64 cm (1/4 inch) thick steel plate, bolted to the sump flanges.

Vacuum valves were housed in pits of similar construction to the collection sumps, except 0.9 m (3 feet) in diameter, 0.9 m (3 feet) deep, and without a sealed bottom. This was possible because high water tables do not occur in the vacuum system area at Bend. However, in areas where high water tables occur, a sealed bottom is normally part of the valve pit construction.

Sewage and sensor pipes intersected the sumps and valve pits as shown in Figure 7. Pipe intersections with the sumps and valve pits were sealed by flexible rubber grommets.

<u>Vacuum Valves</u>

Vacuum valves used on the Bend project were 7.6-cm (3-inch) diameter valves manufactured by Airvac, as shown in Figure 7. Operation of the valve was powered by the pneumatic pressure differential between atmospheric pressure and vacuum in the collection lines. The valve vacuum chamber was sealed from the collection line by a flexible diaphragm which allowed the valve to open and close. Operation of the valve was initiated by the head of sewage collected on the upstream side of the valve. Pneumatic valves in the controller operated to switch the vacuum chamber from atmospheric pressure to system vacuum, and vice versa, at appropriate times.

The valve had two adjustments:

1. To operate when a preselected head of sewage, from 7.6 to 76 cm (3 to 30 inches) H_2O, had accumulated behind the valve.

2. To remain open for a preselected period of time, from 3 to 30 seconds.

The following sequence of events constituted a valve cycle: The valve was held in a normally closed position by a coil spring in the valve vacuum chamber and by the pressure differential between system vacuum and atmospheric pressure in the valve vacuum chamber. The pressure head of the sewage accumulated behind the valve was transmitted to the sensor by air compressed in the sensor pipe. When the preselected head was reached, a diaphragm valve in the sensor was closed. Closing of the diaphragm valve caused switching of pneumatic valves in the controller which introduced system vacuum into the valve vacuum chamber. The valve was then pulled open by line vacuum. After a time interval determined by an adjustable air leak timer in the controller, pneumatic valves in the controller switched the valve vacuum chamber back to atmospheric pressure. The valve was again closed by force of the coil spring and the pull of the vacuum.

The vacuum valve was fitted into the vacuum line by clamp couplings. A short section of pipe below the valve could be removed for insertion of a cleaning rod, if necessary.

Vacuum Pipe

Pipe used in the vacuum collection system was 7.6-cm (3-inch) diameter Schedule 40 PVC pipe with solvent weld joints, and was assembled with PVC drain-waste-vent (DWV) type fittings. The pipe and its configuration were designed in accordance with recommendations by Airvac, with the exception of sump No. 3 where the lift exceed Airvac's recommendation.

Briefly, the vacuum pipe configuration consisted of abrupt rises followed by gradually downward sloping runs as shown in Figure 8. "Pockets" (See Figure 9) were installed before lifts. "Rolled Y" (See Figure 10) were used to prevent drainage of liquid into tributary lines during transport through the main line.

The vacuum pipe was buried at 0.76 m (2.5 feet) minimum depth. Low points where standing water could be expected were buried a minimum depth of 0.91 m (3 feet).

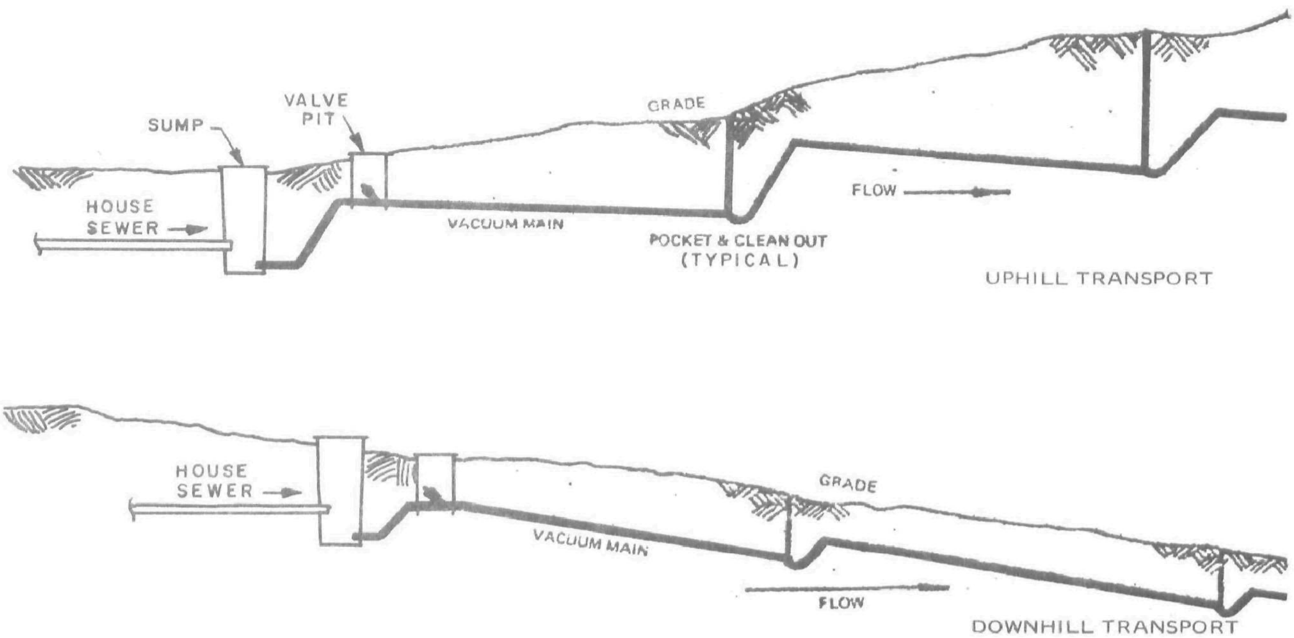

Figure 8. Typical vacuum pipe configuration details for uphill and downhill wastewater transport.

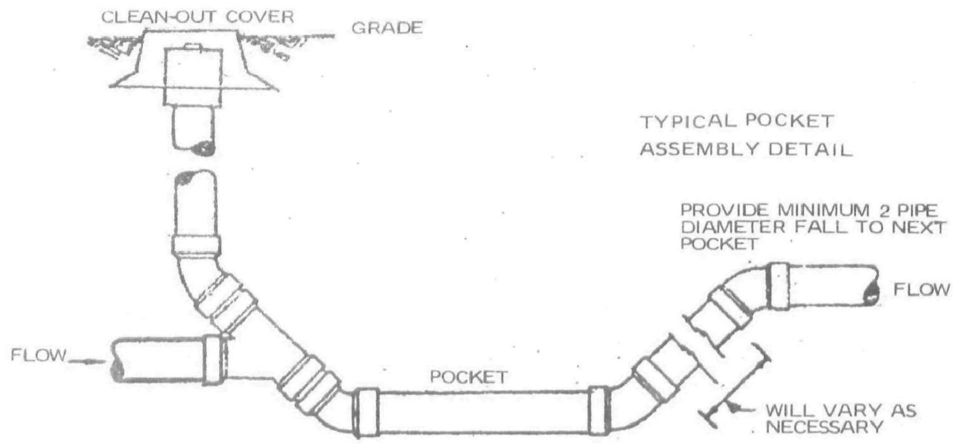

Figure 9. Typical vacuum collection line pocket assembly detail

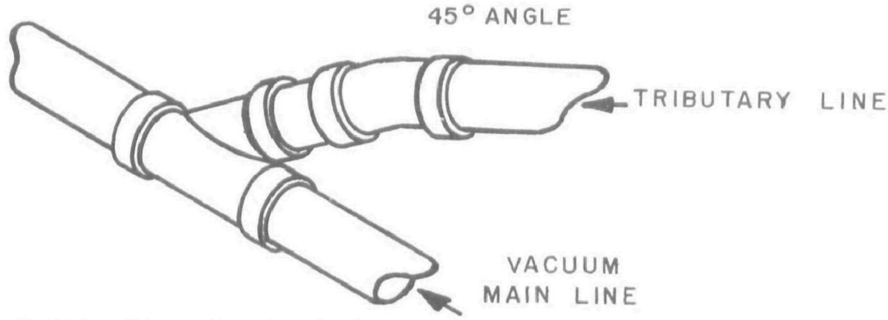

Figure 10. Rolled Y Fitting for tributary vacuum line.

Vacuum Collection Station

Vacuum station equipment was housed in a 5.48-m long by 2.44-m wide by 2.44-m high (18-ft. x 8-ft. x 8-ft.) precast concrete vault. The vault was installed partially below grade on a sloping bank as shown in Figure 6. Access was through a roof hatch and stairway. A diagram of the vacuum station equipment is shown in Figure 11.

Vacuum Pumps--

Vacuum pumps, shown in Figure 12, were sliding vane pumps: 3.73 kw (5 hp), three-phase, 460 volt, rated at 0.0354 m^3/second (75 cfm) manufactured by Lammert Division of Gould, Inc.

Sliding vane pumps operate on the principle of an eccentrically placed rotor with sliding vanes, rotating in a pump cavity. Pumping action is obtained by the changing volumes formed by the vanes and cavity as the rotor turns.

The vanes and pump shaft bearings required oil lubrication. An oil reservoir and coalescing unit were integral with the pump discharge. Oil dripped onto the shaft bearing and then drained into the pump cavity and onto the vanes. Vane lubricating oil was vaporized and carried into the coalescing unit along with air and vapor discharged by the pump. Oil and water vapor coalesced and condensed onto plates in the coalescing unit and drained into the pump oil reservoir.

Condensed water drained into an oil reclaimer unit near the bottom of the pump, and then was discharged through a manometer type drain into the station sump. The station sump could be evacuated into the vacuum collection tank.

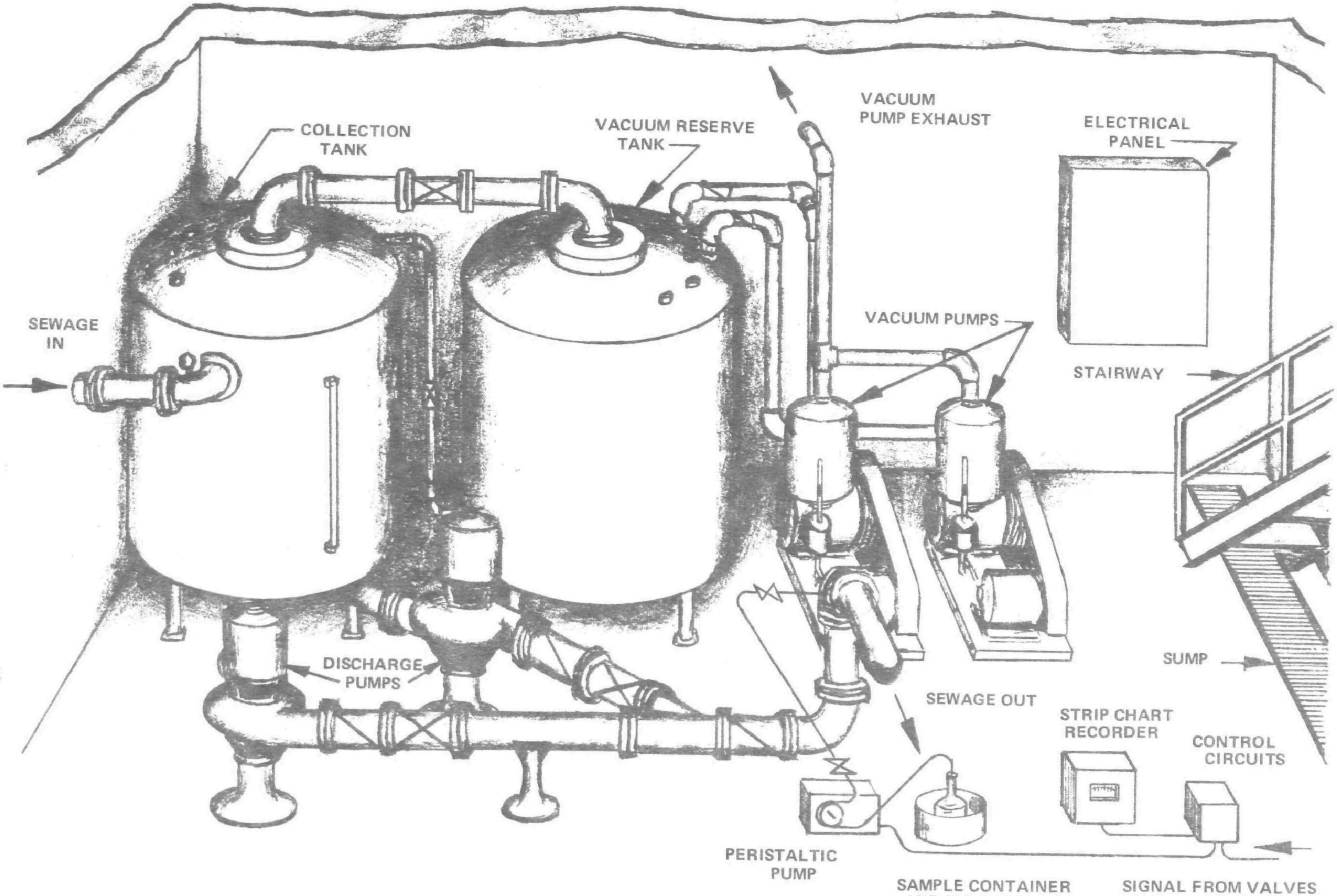

Figure 11. Vacuum station.

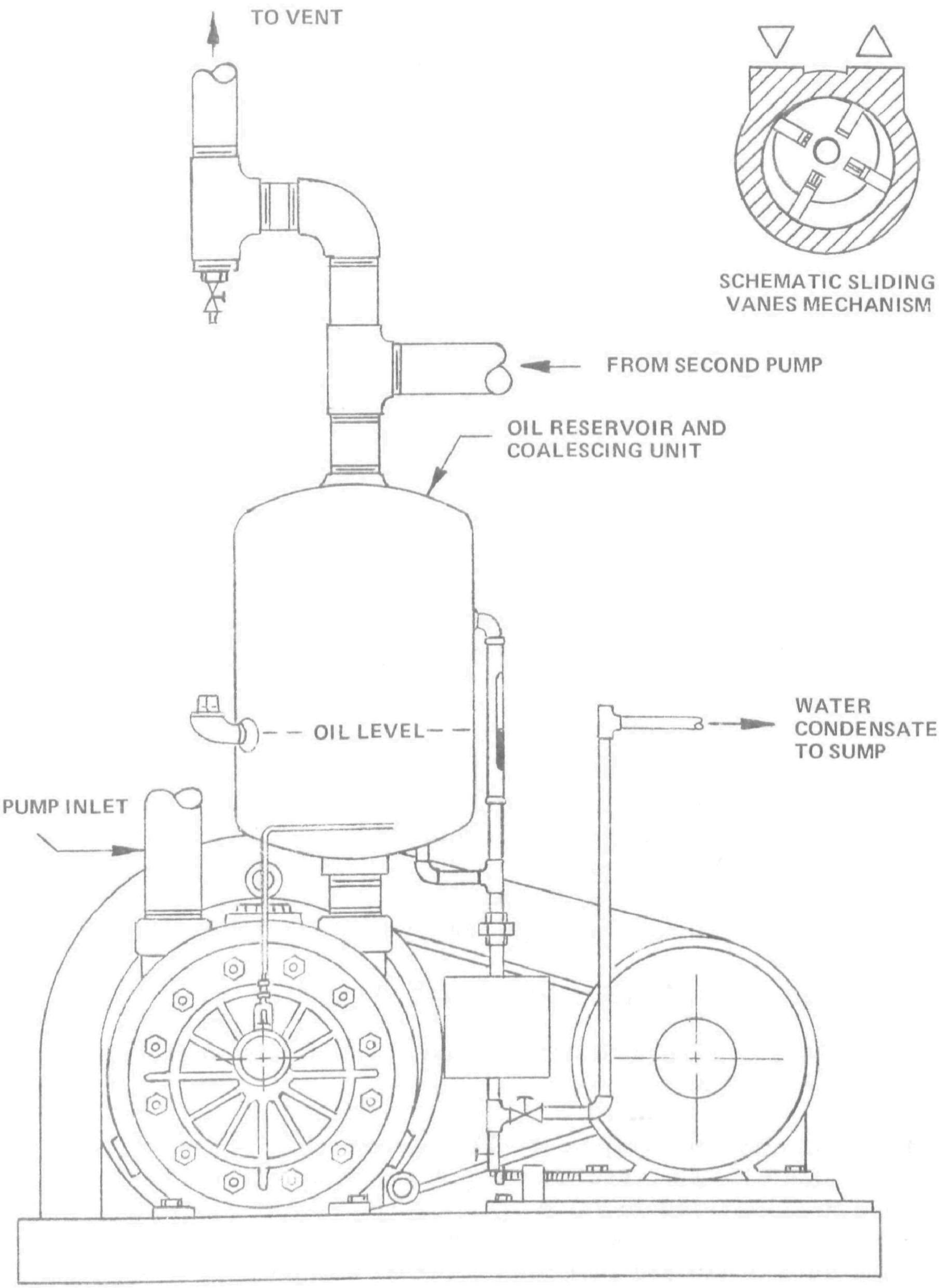

Figure 12. Sliding vane pump.

The vacuum pumps were controlled by adjustable vacuum sensor switches on the vacuum reserve tank. By Airvac recommendation, the lead pump was set to start at 41 cm (16 inches) of Hg absolute pressure and to shut off at 50 cm (20 inches) of Hg (absolute). The pumps alternated in lead starting roles.

The low vacuum alarm was transmitted to the treatment plant and police station if vacuum fell below 25 cm (10 inches) of Hg absolute pressure.

Collection and Vacuum Reserve Tanks--

The collection and vacuum reserve tanks were two similar 1.5-m^3 (400-gallon) steel tanks as shown in Figure 11. The collection tank received sewage, while vacuum reserve tank provided larger evacuated volume to reduce vacuum pump running frequency. The vacuum reserve tank also provided a buffer zone to protect vacuum pumps from contamination by sewage.

Discharge Pumps--

Sewage was pumped from the vacuum collection tank to discharge into the gravity interceptor by two centrifugal sewage pumps. The pumps were PACO^{tm} Model 495, vertical shaft, dry pit, nonclog sewage pumps, 5.6 kw (7-1/2 hp), three-phase, 460 volts.

The pumps were controlled by mercury float switches in the sewage collection tank. Working volumes (volume between "pump-on and "pump-off") was set at approximately 0.38 m^3 (100 gallons). The pumps were controlled to alternate lead operation roles. Both pumps would operate if sewage level continued to rise above the lead pump start switch. An alarm would be transmitted to the treatment plant and police station if sewage level continued to rise above lag pump starting level.

Vacuum System Monitoring and Sampling Equipment

Monitoring equipment for the vacuum system was located in the vacuum collection station.

Event monitoring equipment--The vacuum chamber of each vacuum valve was fitted with a pressure actuated switch which would momentarily close each time the vacuum valve cycled. The switch was actuated by the change in pressure when the valve vacuum chamber cycled from atmospheric pressure to system vacuum. A signal was thereby transmitted to a strip chart recorder via a wire each time a vacuum valve cycled.

A strip chart recorder and appropriate circuitry in the vacuum collection station permitted recording of the time of operation of each vacuum valve. Operation of each vacuum pump and each discharge pump could also be recorded with the strip chart recorder.

Sewage sampling equipment--A sewage sampling system consisting of the following components was installed in the vacuum collection station. A 0.95-cm (3/8-inch) diameter sampling cock and sampling line was installed on the discharge line of the sewage discharge pumps as shown in Figure 11. A peristaltic pump, coupled with an electrically actuated valve to prevent static pressure in the discharge line from causing leakage through the sampling pump whenever it was not operating, was used to draw sewage samples from the discharge line. Composited sewage samples were collected in a plastic carboy sitting in an ice chest.

In order to collect a representative composited sewage sample, the sampling pump was interconnected to operate during operation of either of the discharge pumps. Pumping rate of the sampling pump was adjustable, so that any appropriate sample volume could be collected.

Energy consumption--Three standard kilowatt-hour meters, obtained from the electric company, were installed in the vacuum station to totalize energy consumed by the vacuum system. Meter No. 1 totalized energy consumed by the vacuum pumps; meter No. 2 totalized energy consumed by the discharge pumps and, meter No. 3 totalized energy consumed by station lighting, heating, and ventilating circuits.

Water Use--

Neptune^{tm} water meters were installed to totalize water used by each participating residence. The water meters were installed in the house service lines so that they measured both consumptive water use and water which was discharged into the sewer.

SECTION 4

DATA AND ANALYSIS

GENERAL

This section presents and analyses data obtained from the Bend R & D project. Data accumulated from the project consists of two categories. The first is equipment and construction cost data accumulated from the project bidding and construction phases. The contractor was required to report actual construction costs incurred during construction. The second category is data collected from operating and monitoring the two systems. A log of daily operation and maintenance tasks was kept to accumulate maintenance and reliability data for the two systems. The two systems were instrumented, as described in Section 3, to permit collection of the following specific operating data:

1. Point of time of operation of pressure system pumps, vacuum valves, vacuum pumps and vacuum system discharge pumps.

2. Water use by the participating residents.

3. Energy consumption by the two systems.

4. Collection of composited sewage and septic tank effluent samples for chemical analysis.

The period during which the systems were monitored extended from July 12, 1976 to July 24, 1977. The dates at which monitoring and sampling tasks were performed are indicated in Table 1. The intent of the monitoring program was to collect operating data over approximately a 1-year period, with intervals of intensive monitoring during representative periods of cold winter weather, moderate spring or fall weather, and warm summer weather. Daily temperature extremes recorded for the Bend area on the project monitoring and sampling days are indicated in Table 1.

TABLE 1

SCHEDULE OF MONITORING AND SAMPLING

Date	Operation Events		Energy Consumption		Water Use		Wastewater Sampling		Temperature Degrees C	
	Pressure	Vacuum	Pressure	Vacuum	Pressure	Vacuum	Pressure	Vacuum	Max.	Min.
July 12, 1976		X							20.0	3.9
July 13, 1976		X							22.8	2.2
August 9, 1976	X		X	X	X	X			21.7	7.2
August 10, 1976	X								23.9	5.6
August 16, 1976								X	14.4	3.9
August 17, 1976							X	X	16.1	4.4
August 18, 1976							X		19.4	5.6
August 25, 1976							X		27.2	10.0
August 26, 1976							X		17.2	- 1.1
September 9, 1976			X	X	X	X			21.1	- 2.8
September 27, 1976								X	26.7	2.8
September 28, 1976								X	27.8	5.6
October 11, 1976			X	X		X			20.6	- 1.1
October 12, 1976				X		X			20.0	- 0.6
October 13, 1976				X		X			26.1	1.7
October 14, 1976				X		X		X	28.3	2.8
October 15, 1976				X		X		X	22.8	- 3.3
October 18, 1976			X						13.9	- 7.2
October 19, 1976			X						13.9	- 9.4
October 20, 1976			X						15.6	- 9.4
October 21, 1976			X				X		18.9	- 5.6
October 22, 1976			X				X		21.7	- 3.3
October 23, 1976			X						18.3	- 8.3
October 24, 1976			X						14.4	- 7.8
October 25, 1976			X						12.2	2.2
October 26, 1976			X						9.4	- 3.3
October 30, 1976							X		12.8	0.0
November 1, 1976								X	13.9	5.6

TABLE 1 (Cont.)

Date	Operation Events		Energy Consumption		Water Use		Wastewater Sampling		Temperature Degrees C	
	Pressure	Vacuum	Pressure	Vacuum	Pressure	Vacuum	Pressure	Vacuum	Max.	Min.
November 22, 1976								X	17.2	- 6.1
November 23, 1976							X	X	10.0	- 5.6
November 24, 1976							X		16.1	- 1.1
December 13, 1976			X	X	X	X			12.8	- 2.2
December 28, 1976							X		10.0	-11.1
December 29, 1976							X		7.2	-11.1
January 4, 1977								X	2.8	-14.4
January 5, 1977								X	3.3	-15.0
January 12, 1977			X	X	X	X			3.3	- 1.1
January 25, 1977							X		7.2	- 7.8
January 26, 1977							X		0.0	-10.6
February 7, 1977									4.4	- 5.0
February 8, 1977									0.0	- 4.4
February 9, 1977	X						X		10.6	- 4.4
February 10, 1977	X						X		12.8	- 0.6
February 11, 1977	X								16.7	1.7
February 12, 1977	X								16.7	1.7
February 13, 1977	X								18.3	- 2.2
February 14, 1977	X	X							16.1	- 8.3
February 15, 1977		X		X		X			18.3	- 8.3
February 16, 1977		X		X		X		X	21.1	- 1.7
February 17, 1977		X		X		X		X	18.3	- 2.2
February 18, 1977		X				X			18.3	- 5.0
February 19, 1977		X		X		X			18.9	- 7.8
February 20, 1977		X		X		X			21.1	- 5.0
February 21, 1977		X							6.7	- 7.8
February 22, 1977		X							7.8	- 1.1
February 23, 1977		X							6.7	- 7.8
March 8, 1977		X						X	10.6	1.1
March 9, 1977		X						X	11.1	- 2.8
March 10, 1977		X	X	X	X	X			6.7	- 6.1

TABLE 1 (Cont.)

Date	Operation Events		Energy Consumption		Water Use		Wastewater Sampling		Temperature Degrees C	
	Pressure	Vacuum	Pressure	Vacuum	Pressure	Vacuum	Pressure	Vacuum	Max.	Min.
March 15, 1977	X								6.1	-6.7
March 16, 1977	X								10.6	-8.9
April 12, 1977			X	X	X	X			20.0	-3.9
April 20, 1977	X						X		15.6	-5.6
April 21, 1977	X								17.2	1.7
April 22, 1977							X		19.4	1.7
April 26, 1977		X							21.1	0.0
April 27, 1977		X						X	16.7	-3.3
April 28, 1977		X						X	21.7	-0.6
May 16, 1977			X	X	X	X			9.4	-5.0
May 17, 1977		X						X	11.7	0.0
May 18, 1977		X						X	12.8	-0.6
June 1, 1977	X						X		27.2	6.7
June 2, 1977							X		15.6	-2.8
June 16, 1977			X	X	X	X			26.7	1.7
June 22, 1977	X								27.2	6.7
June 28, 1977	X								27.2	5.0
June 29, 1977	X						X		30.0	6.7
June 30, 1977	X						X		26.7	3.9
July 7, 1977								X	22.2	1.7
July 8, 1977								X	28.3	6.7
July 11, 1977				X		X			26.1	6.7
July 12, 1977				X		X			29.4	7.8
July 13, 1977		X		X		X		X	23.9	0.0
July 14, 1977		X		X		X		X	25.6	5.0
July 15, 1977				X		X			27.8	5.6
July 16, 1977				X		X			31.1	7.2
July 17, 1977				X		X			31.1	12.2
July 18, 1977			X		X				26.7	12.2
July 19, 1977			X		X				23.9	1.7

TABLE 1 (Cont.)

Date	Operation Events		Energy Consumption		Water Use		Wastewater Sampling		Temperature Degrees C	
	Pressure	Vacuum	Pressure	Vacuum	Pressure	Vacuum	Pressure	Vacuum	Max.	Min.
July 20, 1977			X		X		X		25.6	6.1
July 21, 1977			X		X		X		31.7	8.9
July 22, 1977			X		X				30.6	7.2
July 23, 1977			X		X				31.1	9.4
July 24, 1977			X		X				29.4	10.0

The winter of 1976-1977 was relatively mild for the Bend area and did not provide a severe cold weather test for the systems. Average and minimum temperatures recorded and departure from normal were:

Temperature °F

	Average	Minimum	Departure from Normal
December 1976	35.4	24	+2.7
January 1977	30.7	-6	+0.5
February 1977	38.0	2	+3.2

EQUIPMENT AND CONSTRUCTION COSTS

Vacuum Equipment Costs

Vacuum system equipment was purchased separately from general construction contract bidding. Two companies responded to the invitation for bids for vacuum system equipment: Colt-Envirovac and Airvac.

Items included in bids and bid prices are summarized in Table 2. Deduct items bid for optional items are noted. Estimated or quoted equipment price, f.o.b. from the manufacturer, are also noted.

Pressure and Vacuum Systems Construction Costs

Costs for materials, equipment, and labor for construction of the pressure and vacuum system are summarized in Tables 2, 3, and 4. Materials, labor, and equipment costs are as reported by the general contractor to have been incurred during construction, i.e., actual costs, not contract price. Indirect overhead and profit to the general contractor are not included in the reported costs. Material costs are the vendor price paid by the general contractor. Costs reported for subcontracted work is the subcontract price paid by the general contractor and include profit and overhead to the subcontractor.

Breakdown into components of some lump costs reported by the general contractor have been estimated. These estimated cost breakdowns are so indicated on Tables 3 and 4. Vacuum equipment costs listed in Table 2 are not included in Table 4.

TABLE 2

VACUUM EQUIPMENT BID SUMMARY

Item	Colt-Envirovac	Airvac
Sewage collection and vacuum reserve tanke	Single 600-gallon steel tank	Two similar 400-gallon steel tanks ($2,150 deduct price for vacuum reserve tank)
Vacuum pumps	Two Nash Model AHF 19 vacuum pumps, horizontal base mounted liquid ring type, with 50-gallon sealed water tank, 1.5 hp, 20 cfm at 15" hg ($7,376 deduct price for one pump) ($2,600 FOB Portland)	Two Lammert vacuum pumps, sliding vane type, 5 hp, 75 cfm ($2,225 deduct price for one pump) ($1,500 FOB Portland)
Discharge pumps	Two Fairbanks Morse, Model 5432BK, nonclog, vertical, centrifugal sewage pump, 5 hp, 1750 rpm, discharge, suction, and check valves ($2,240 deduct price for one pump) (Estimated price one pump $2,200 FOB Portland)	Two PACA Model 495 vertical, centrifugal sewage pump, 7.5 hp, 1750 rpm ($2,500 deduct price for one pump) (Estimated price one pump $1,300 FOB Portland)
Control package	Automatic control of vacuum and discharge pump. Pumps alternate service on each start. High water and low vacuum alarms.	
Vacuum valves	Seven each (Proposal to use Airvac valve)	Seven each $500 each for additional valves
Miscellaneous station piping and vacuum gauges	Not included	Estimated value of $2,500
Total Bid Price	$41,388	$25,300

TABLE 3
PRESSURE SYSTEM CONSTRUCTION COST SUMMARY

Scope of Work and Material	Number of Units	Average Unit Cost	Total Cost: Materials and Subcontracts	Total Cost: Labor and Equipment	Total Cost: Total
1. Excavation a. Gravity lines from house sewer to sump. Average 0.76 m (2.5 ft.) deep, 10% rock b. Pressure lines. Average 1.1 m (3.5 ft.) deep, 35% rock c. Excavation for sump	247 m (812 ft.) 305 m (1,000 ft.) 6 ea.	$3.75/ft. (average unit cost includes Items a, b and c)	$ 328	$ 6,480	$ 6,808
2. Pump Stations (include:) 4 low head pumps 1.57 l/sec @ 6.7 m (25 gpm @ 22 ft) TDH 2 high head pumps 1.57 l/sec @ 11.4 m (25 gpm @ 37 ft) TDH	6 ea.	$1,336 ea.	$ 7,941	$ 74	$ 8,015
3. Spare Pumps low head high head	1 ea. 1 ea.	$166 $229	$166 $229		$166 $229
4. Pipe and Pump Sump Installation and Backfill a. Gravity line, 10.2 cm (4 in.) diameter, ring joint PVC b. Pressure line 5.1 cm (2 in.) diameter, ring joint PVC c. Sumps (installation only)	247 m (812 ft.) 305 m (1,000 ft.) 6 ea.	$10.66/m ($3.25/ft.)* $11.25/m ($3.43/ft.)* $100 ea.* *estimates	$ 2,117	$ 4,549	$ 6,666
5. Electrical (subcontracted) (includes monitoring equipment of $6,000 estimated cost)			$11,869		$11,869
6. Site Clearing and Restoration			$ 1,328	$ 2,994	$ 4,322

TABLE 4
VACUUM SYSTEM CONSTRUCTION COST SUMMARY

Scope of Work and Materials	Number of Units	Average Unit Cost	Total Cost		
			Materials and Subcontracts	Labor and Equipment	Total
1. Excavation a. Gravity lines from house sewer to sump. Average 0.76 m (2.5 ft.) deep, 25% rock b. Collection sumps and valve pits c. Receiving station (subcontracted) d. Vacuum lines. Average 1.1 m (3.5 ft.) deep, 50% rock e. Discharge line. Average 1.1 m (3.5 ft.) deep, 80% rock	 117 m (385 ft.) 8 ea. 1 ea. 563 m (1,847 ft.) 317 m (1,040 ft.)	$19.36/m ($5.90/ft.) (average unit cost includes Subitems a, b, d, and e)	$ 767 (Receiving station excavation, Item c)	$19,328	$20,095
2. Receiving Station a. Structure (subcontract) b. Station piping (installation only)	1 ea.		 $ 8,653 $ 71	 $ 1,819	$10,543
3. Electrical (subcontracted) (includes monitoring system, $4,500 estimated cost)			$14,324		$14,324
4. Site Clearing and Restoration			$ 598	$ 4,920	$ 5,518
5. Pipe, Sumps and Valve Pits (material installation and backfill) a. Gravity line 10.2 cm (4 in.) diameter, ring joint PVC b. Vacuum line 7.6 cm (3 in.) diameter, solvent weld PVC c. Discharge line 10.2 cm (4 in.) diameter a/c d. Pressure relief valves e. Sumps and valve pits (installation only)	 117 m (385 ft.) 563 m (1,847 ft.) 317 m (1,040 ft.) 2 ea. 8 ea.	 $10.66/m ($3.25 ft.)* $19.36/m ($5.90 ft.) * $17.22 /m ($5.25/ft) * $150/ea. * $580 * *estimates	$ 9,034	$10,947	$19,981
6. Sumps and valve pits (material only)	8 ea.	$531	$ 4,248		$ 4,248

Excavation

As noted before, the primary motivation for the Bend R & D Project was to investigate sewer technology which would avoid the high costs of deep excavation required to maintain line and grade for conventional gravity sewers. Research of less costly methods of rock excavation was also an accessory interest of the project.

Excavation methods utilizing conventional excavation equipment have been used in Bend whenever soil depths permitted. Whenever rock has been encountered, the usual excavation method has been to drill and blast. Depending on the possibility of damage to surrounding buildings and utilities, excavation by blasting has entailed the following procedures. The soil, if present, has been excavated to rock before drilling and placement of the charge. The trench has been refilled and/or covered with mats and weighted cables before blasting. Deep trenches may require more than one blasting operation.

Blasting operations may require extensive care to prevent damage to adjacent structures. The effect of a given charge on the conglomerate of soil, cinders, boulders, and lava flows typical of Bend terrain is difficult to predict. Cases have occurred in which force from a blast has found a pathway to structures several hundred feet distant. Liability for damages has been correspondingly high.

Excavation of 1.0 to 1.2-m (3 to 4-feet) deep trenches, such as used on the Bend R & D Project, have cost in the range of \$6.50 to \$65.00 per meter (\$2 to \$20 per foot) (1975 price), depending on percentage of rock and care required to protect adjacent structures.

On the Bend R & D Project, excavation was done with a backhoe whenever soil was encountered. When rock was encountered, a Ditch Witch™ Model R-100 trenching machine was used for excavating whenever possible (See Figure 13). However, access by the trenching machine was not possible in several areas. In these areas, rock was broken by jackhammer and hand excavated.

The Model R-100 trencher is a tractor-mounted, chain-type excavator. The chain has conical, carbide, drag-type, rock-cutting teeth. Cutter bars and chains are reported by Ditch Witch sales representatives to be available with capability to cut trenches up to 2.4 meters (8 feet) deep and up to 0.6 meters (2 feet) wide. The chain used on the Bend project cut a trench approximately 0.2 meters (8 inches) wide, maximum depths of cut were approximately 1.2 meters (4 feet).

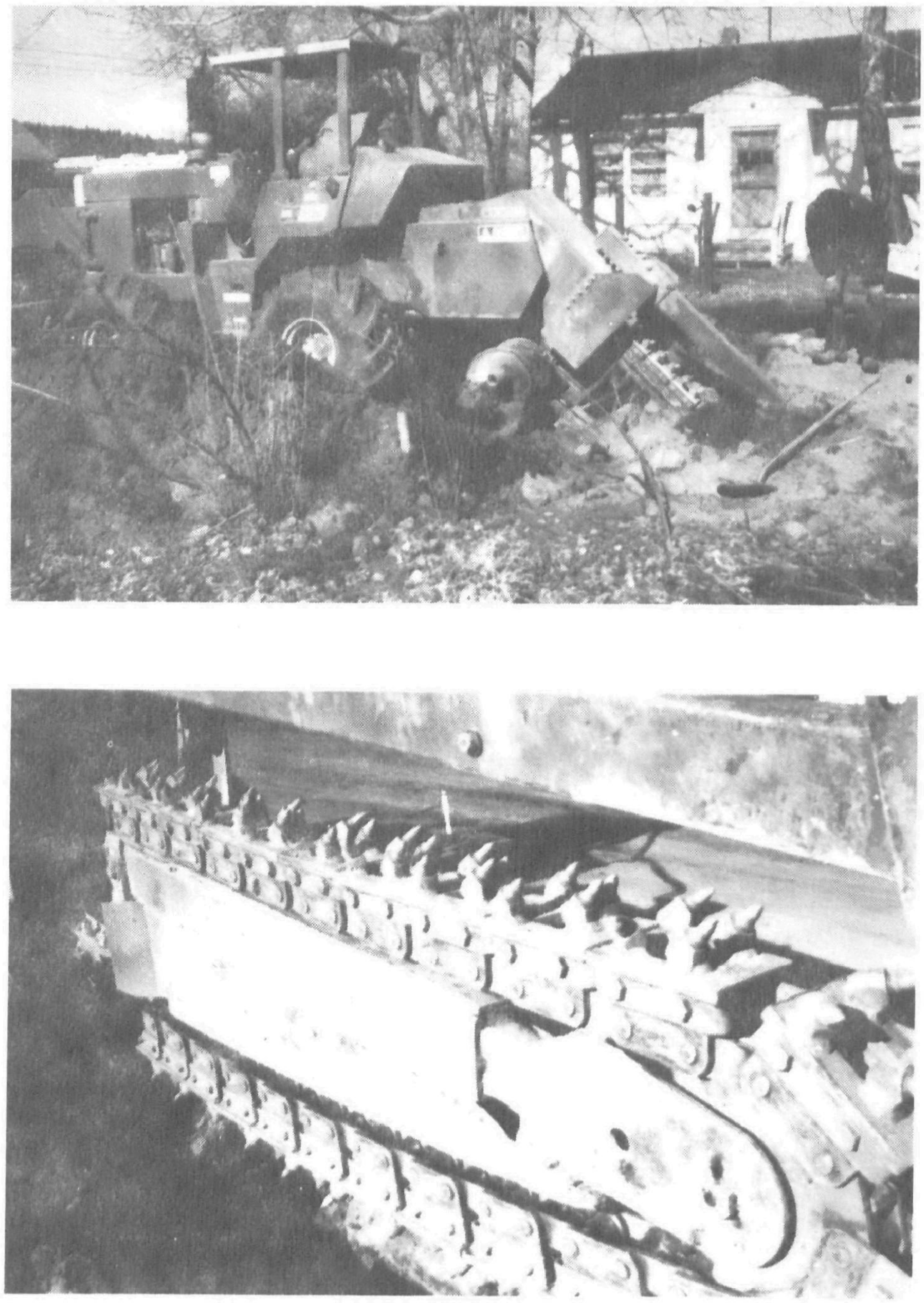

Figure 13 Ditch Witch (TM) R-100 used on Bend R & D Project

The Ditch Witch Model R-100 was reported to cost approximately $50,000.

Generally, the Ditch Witch required two operators. One operator guided and controlled the machine. The second operator was needed in the ditch to remove loose rubble and debris which tended to foul and bind the cutter chain.

Trenching speeds up to 3 meters (10 feet) per hour were achieved. Best results were obtained when cutting solid, unfractured rock with no rubble to foul the chain.

Spoil from cutting lava rock consisted of chips and flakes up to 2.5 cm (1 inch) in diameter. Generally, the rock-cutting spoil was of suitable quality for use as backfill. However, considerable care was needed to keep suitable rock-cutting spoil segregated from unsuitable rubble. Screening could have been effectively utilized for this purpose.

Average excavation costs of $12.50 per meter ($3.75 per foot) for pressure system trenches, which contained approximately 25 percent rock, $19.36 per meter ($5.90 per foot) for vacuum system trenches, which contained approximately 50 percent rock, are listed in Tables 2 and 3. These excavation costs compare very favorably with the $6.50 to $65.00 per meter ($2 to $20 per foot) cost range estimated for conventional excavation methods in the Bend area.

Subsequent to construction of the Bend R & D project a rock excavating machine of similar principle to the Ditch Witch[tm] R-100, but much larger, has been used for excavating gravity sewer trenches in Redmond, Oregon. Excavation costs are not available.

OPERATION AND MAINTENANCE

Operating Period

The pressure system started operating in March, 1976. The vacuum system started operating in May, 1976. The monitoring period extended through July of 1977. The following discussion is therefore limited to recounting events encountered during approximately the first year of operation. One year of operation experience does not provide adequate background for assessment of long-term reliability. The account of operating problems therefore probably includes some incidents that, in the long run, would be classified as start-up problems rather than operating problems.

A daily log was kept of time spent operating, maintaining, and monitoring the systems. System monitoring time and effort is not included in the following account since it would not be done on a normal operating system.

Maintenance and Reliability

Pressure System--

Check Valves-- After start-up, Pump No. 2 was observed to be operating repeatedly on about a three minute on-six minute off cycle. The cause was diagnosed as a sticking check valve. The valve was replaced by the contractor on August 4, 1976. The valve was found to be defective; an improperly seated 0-ring had caused the ball to stick.

Several months later, in October, Sump No. 2 received a high-water alarm. The cause of the high water was investigated and the check valve was found to be partially plugged with bark chips. The top of Pump Station No. 2 had been installed slightly below ground level and covered with bark chips. It is speculated that bark chips fell into the sump during replacement of the check valve and had taken several months to be sucked into the pump inlet to clog the valve.

The operator noted that check valves installed in the vertical pipe run were difficult to service. A discussion of design considerations for convenient maintenance of the sump is included in Section 5.

Odors-- One complaint was received that a pump station produced objectionable odors. The gasket on the sump cover was repaired and the cover securely tightened. No further complaints were received.

Corrosion-- Immediately after start-up of the pressure system, the corrosion problem associated with septic effluent became apparent. Any metal surfaces in the sumps which were subject to corrosion began to corrode.

Brass, stainless steel, or cadmium-plated screws and bolts had been used; threads cut on the galvanized iron pump discharge pipe and the steel plate cover were coated with bituminous epoxy paint. However, it was apparent that corrosion was occurring under any break in these protective coatings.

Points noted as being particularly affected by corrosion were:

1. Welds on pump guide rails and pump guide flanges--The guide rails were fabricated from galvanized iron pipe with welded

steel attachment tabs. The pump guide flanges were fabricated from torch-cut steel plate.

2. Pump access cover nuts and bolts--The pump access covers were attached to the sump covers by cadmium-plated bolts and nuts welded to the underside of the sump covers (see Figure 3). The nuts and bolts were subjected to the corrosive atmosphere from inside the sump and physical abuse and fouling with debris whenever the cover was removed.

3. Sump cover plates--The steel cover plates were corroding under pinholes or scratches in the protective coating.

It should be noted that when the pressure system sumps were reinspected after approximately a year of service, the rate of corrosion appeared to have abated and stabilized considerably, i.e., initial corrosion was more apparent by contrast, but stabilized after formation of surface coats of corrosion materials.

The evaluation of corrosion in the sumps presented above is admittedly subjective. System compents were not disassembled and rigorously inspected for corrosion effects. No failures of sump components occurred because of corrosion.

Grease Build-Up--After approximately one year of service, pressure system sumps were inspected for grease buildup on sump walls. The pressure system sumps, which received septic tank effluent, typically had a ring of grease near high-water level of less than .32-cm (1/8-inch) thickness. No grease buildup was observed which would interfere with operation of pump control or alarm float switches.

Vacuum System--

Vacuum pumps--Vacuum pumps installed in the Bend system were sliding vane pumps as described in Section 3. The sliding vane vacuum pumps proved to be a high-maintenance, low-reliability item for this application.

Initially the vacuum pumps were installed without water condensate drain lines, i.e., manual draining of water condensate from the oil sump was required. However, water condensate accumulated in the oil recovery units at a rate that required daily draining. Consequently, manometer type drain lines which permit condensate to overflow were installed to reduce maintenance requirements.

The high rate at which water condensate accumulated was probably due to the small size of the system load relative to vacuum pump capacity. Each vacuum pump may have operated as little as 2 or 3 minutes per hour. Vacuum systems in which the vacuum pumps operate frequently enough to keep the oil coalescing unit and discharge header pipe warm are reported by Airvac personnel to have less condensate accumulation.

On November 15, 1976, at approximately 2:00 p.m., a vacuum valve stuck in the open position, as described in the following subsection. The vacuum pumps were unable to re-establish vacuum, and a low vacuum alarm was transmitted to the treatment plant. Both vacuum pumps ran at a no-vacuum load for approximately 30 minutes until maintenance personnel reached the vacuum station. The vacuum pumps were found to have lost their oil, i.e., there was oil on the vacuum station floor, oil was not visible in the oil level sight glasses, and the air was filled with a blue haze of vaporized oil.

The failed valve controller was replaced. The pumps were refilled with oil and restarted. The pumps performed satisfactorily. At the time no damage appeared to have been done to the pumps' bearing surfaces.

On February 9, 1977, and on March 7, 1977, the vacuum pumps again lost their oil to a level below the sight-glass indicators. Causes of these two oil-loss occurrences were not determined.

On April 4, 1977, a low-vacuum alarm was received. The vacuum pumps were found to be running and unable to restore vacuum. Some oil had been lost from the vacuum pumps. The vacuum station was filled with a haze of vaporized oil. The cause of the vacuum failure was found to be a leak in the vacuum-tank cover gasket. The leak was closed by tightening the vacuum-tank cover bolts. The vacuum pumps were refilled with oil and service was restored.

On May 13, 1977, Vacuum Pump No. 1 had difficulty starting. Pump No. 1 was pulled from service and Pump No. 2 was left to handle the system. Vacuum Pump No. 1 was rebuilt with new vanes, springs, and rod and shaft bearings and placed back in service on June 6, 1977. Vacuum Pump No. 1 appeared to be overheating and was again pulled from service on July 6, 1977 and the shaft bearings were honed.

The vacuum pumps were considered to have low reliability as installed in the Bend vacuum station because of the incidents described above. Oil loss, if not promptly detected and corrected, could result in damage to the pumps. The suspected reliability of the vacuum pumps therefore necessitated frequent checking of their condition.

It should be noted that the incidents cited did not give adequate experience to judge long-term reliability or maintenance requirements. Better understanding of the cause of the oil-loss incidents might have changed the estimate of the vacuum pumps' reliability. Installation of an oil-level measuring device and a telemetry system to transmit a low-oil alarm signal to the treatment plant would have permitted less frequent checking of the vacuum pumps, or a different type of vacuum pump might have been more reliable.

A fuse for the vacuum pump No. 1 motor blew on May 4, 1977. Later in 1978 the motor burned out the windings in two phases. The cause of the motor failures were not identified, but it is speculated that the cause may have been an intermittent short in the electrical system.

Vacuum valves-- No failures were diagnosed which involved the valve mechanism itself. Valve failures which occurred resulted from malfunctions in the pneumatic valve control circuits.

On November 15, 1976, a low-vacuum alarm was received. Number 5 valve was found to be stuck in the open position. The controller was replaced, and the system was restored to operation. The effect of the open valve on the vacuum pumps was described in the preceding subsection.

The failed controller was shipped to Airvac for repair. Pneumatic valves in the controller were reported by Airvac to have been jammed by a small particle of debris which prevented switching the vacuum valve vacuum chamber back to atmospheric pressure.

On December 30, 1976, a high-water alarm was received from Sump No. 7. Investigation indicated the failure was caused by the check valve (See Figure 7). Temperature lows of -11° C (12° F) had been recorded in the Bend area during the preceding two days; it appeared that the check valve was frozen. The check valve was thawed and operation of the vacuum valve resumed. The weather subsequently warmed and no further problems with the valve occurred due to cold weather.

Corrosion-- The vacuum system sumps did not contain either the corrosive atmosphere or the metal components subject to corrosion that were in the pressure system sumps. Sump covers did not appear to be corroding at an objectionable rate. As with the pressure system sumps, the cover bolts and nuts imbedded in the sump flanges were corroding and receiving physical damage from removal and replacement of the sump covers.

Grease Buildup--The walls of the vacuum system sumps, which received raw domestic sewage, were observed to have rings of grease buildup near high-water level up to 2 cm (3/4 inch) thick.

OPERATING FREQUENCIES AND WASTEWATER VOLUMES

This subsection presents data indicating the frequency of operation of the pumps in the pressure system and the vacuum valves, vacuum pumps and discharge pumps in the vacuum system. Each of the systems was subjected to periods of intensive monitoring to investigate operating characteristics during cold, moderate and hot climatic conditions. The volumes of wastewater generated in each system area is estimated. Records of water used at each residence is presented for comparison.

Pressure System

Pressure system operating parameters--Operating parameters for the pressure system are presented in Table 5. The volumes evacuated were calculated from sump configurations and the observed wastewater levels at which pump-operating cycles were initiated. The wastewater levels at which the pumps' operating cycles were initiated were determined by float switches in the sumps as described in Section 3. The time duration of pump-operating cycles were determined by measuring several operations and averaging the results. These time measurements were taken with a stopwatch. The strip-chart recorder could have been used for the time measurements but a faster chart speed than was used for recording the time the event occurred would have been needed; the stopwatch method was deemed more convenient. The volumes evacuated per pump operating cycle were used to estimate volumes of wastewater generated within the pressure system area.

Flow velocities in the pressure system main when each pump was operating are noted in Table 5. The velocity achieved by Pump No. 4 did not meet the design criteria of 0.61m /sec (2.0ft/sec). However, no problem was anticipated because the velocity to scour solids from the line would be achieved by other pumps in the system.

TABLE 5

PRESSURE SYSTEM OPERATING PARAMETERS

(Measured October 25, 1976)

Sump Pump Number	Volume Evacuated Per Pump Cycle (liter)	(gal)	Pumping Time (sec)	Pumping Rate (liter/sec)	(gpm)	Velocity in 2" Pipe (in/sec)	(ft/sec)
1	151.4	40.0	61.0	2.48	39.3	1.22	4.0
2	112.0	29.6	41.9	2.67	42.4	1.32	4.3
3	124.9	33.0	93.3	1.34	21.2	0.66	2.2
4	94.6	25.0	89.3	1.06	16.8	0.52	1.7
5	81.5	21.5	43.6	1.87	29.6	0.92	3.0
6	105.0	28.0	76.7	1.38	21.9	0.68	2.2

Sump Pump Operating Frequencies

The recorded frequencies of pump operations in the pressure system are presented in Table 6. It should be kept in mind that the operating frequencies must be multiplied by the evacuated volume of each sump, which are not the same for all sumps, to obtain volumes of wastewater generated.

Table 6 illustrates the wastewater generation habits that could be expected from a domestic source. Wastewater flow began in the morning, peaked during the midmorning and afternoon, and declined to near nothing during the late evening and very early-morning hours. Intermittent peaks of wastewater generation were probably caused by weekly-wash days. There does not appear to be a great amount of water wastage from open taps, as indicated by extended periods without pump operation during early-morning hours and days when it appears that the resident is absent. This may be somewhat surprising considering the profligate use of water for irrigation, which will be discussed later.

TABLE 6

PRESSURE SYSTEM PUMP OPERATION FREQUENCY

Hour	Date	Operations per hour — Sump No. / No. of residences					
		1/1	2/2	3/2	4/2	5/1	6/3
12 - 1	Monday August 9, 1976, PM			1	1	1	1
1 - 2							2
2 - 3		1			1	1	
3 - 4		1		1		1	1
4 - 5		1		1			
5 - 6		1					
6 - 7			1	1	1	1	1
7 - 8				1		1	1
8 - 9				1	1	1	
9 - 10			1	3		1	1
10 - 11					1		
11 - 12			1	1	2		4
12 - 1	Tuesday August 10, 1976, AM		1	1		1	1
1 - 2				1			
2 - 3							
3 - 4							
4 - 5							
5 - 6							
6 - 7							
7 - 8			1	1	1		2
8 - 9				1		3	1
9 - 10		1		1	1		2

TABLE 6. (Continued)

Hour	Date	Operations per hour — Sump No. / No. of residences: 1/1	2/1	3/2	4/2	5/1	6/3
6 - 7	Wed. Feb. 9, '77 — PM	1	1	1	1	1	1
7 - 8		1		1	1	1	
8 - 9							1
9 - 10							1
10 - 11			1	1	1		1
11 - 12		1		1	1	1	1
12 - 1	Thursday February 10, 1977 — AM						
1 - 2				1			
2 - 3			1				
3 - 4							
4 - 5							
5 - 6				1			
6 - 7							
7 - 8					1	1	
8 - 9			1	1	1	2	1
9 - 10					2	2	1
10 - 11					2		1
11 - 12						1	1
12 - 1	PM			1		1	
1 - 2			1		2		1
2 - 3				1			
3 - 4						1	
4 - 5		1			1	1	1
5 - 6		1		1			
6 - 7					1		
7 - 8			2				2
8 - 9					1	1	
9 - 10			1		1		1
10 - 11						1	1
11 - 12				1	2		2

TABLE 6. (Continued)

Hour	Date	Operations per hour — Sump No. / No. of residences: 1/1	2/2	3/2	4/2	5/1	6/3
12 - 1	Friday February 11, 1977 — AM			1			
1 - 2			1				
2 - 3					1		
3 - 4							
4 - 5							
5 - 6							
6 - 7							1
7 - 8			1	1	1	1	
8 - 9		1		1		2	1
9 - 10							3
10 - 11			1		1		3
11 - 12				1			2
12 - 1	PM				1	2	1
1 - 2		1	1			1	
2 - 3				1			1
3 - 4		1		1		1	
4 - 5							1
5 - 6		1		1	1	1	
6 - 7				1	1		
7 - 8					2		1
8 - 9			1				2
9 - 10				1			1
10 - 11		1			1		1
11 - 12				1			1
12 - 1	Saturday February 12, 1977 — AM		1				
1 - 2					1		
2 - 3							
3 - 4							
4 - 5							
5 - 6							
6 - 7				1		1	
7 - 8			1		1		
8 - 9						2	1
9 - 10		1	1		1	1	2
10 - 11			1	1			2
11 - 12				1		2	1

TABLE 6. (Continued)

Hour	Date	Operations per hour — Sump No. / No. of residences: 1/1	2/2	3/2	4/2	5/1	6/3
12 - 1	Saturday February 12, 1977 — PM				1		1
1 - 2				1		2	
2 - 3		1		1	1		3
3 - 4		1		1			1
4 - 5							
5 - 6				1	1		1
6 - 7				1		1	1
7 - 8			1		2		
8 - 9		1	1	1	1		1
9 - 10			1	1			
10 - 11					1		2
11 - 12						1	
12 - 1	Sunday February 13, 1977 — AM						1
1 - 2			1		1		
2 - 3				1			
3 - 4							
4 - 5							
5 - 6							
6 - 7							
7 - 8							
8 - 9					1	1	1
9 - 10			1	1		3	3
10 - 11			1	1		1	2
11 - 12			1	1	1	1	2
12 - 1	PM			1			2
1 - 2			1		1	2	1
2 - 3						2	
3 - 4				1	1		1
4 - 5						1	
5 - 6		1		1			1
6 - 7					1		1
7 - 8			1	1	1	1	1
8 - 9		1			1		1
9 - 10			1	1			1
10 - 11			2		2		1
11 - 12				1		1	1

TABLE 6. (Continued)

Hour	Date	Operations per hour — Sump No. / No. of residences: 1/1	2/2	3/2	4/2	5/1	6/3
12 - 1	Monday February 14, 1977 — AM						
1 - 2							
2 - 3			1				
3 - 4							
4 - 5							
5 - 6							
6 - 7							
7 - 8		1	1	1	1		1
8 - 9		1		1	1	4	3
9 - 10				1		1	2
10 - 11							
8 - 9	Tuesday March 15, 1977 — PM				1		
9 - 10					2		
10 - 11							1
11 - 12		2			1		
12 - 1					1		
1 - 2			1				1
2 - 3				1		2	
3 - 4		1				2	
4 - 5		1			1	2	
5 - 6					1		1
6 - 7			1	2	3		
7 - 8					1	2	1
8 - 9				1	2	2	
9 - 10				1	1		1
10 - 11				1	1	2	1
11 - 12		1	1		1	1	1
12 - 1	Wednesday March 16, 1977 — AM			1			
1 - 2							
2 - 3							
3 - 4							
4 - 5							
5 - 6							
6 - 7							
7 - 8							

TABLE 6. (Continued)

Hour	Date	Operations per hour: Sump No. / No. of residences 1/1	2/2	3/2	4/2	5/1	6/3
8 - 9	Wednesday April 20, 1977 AM		1		1		3
9 - 10		1				2	1
10 - 11						1	1
11 - 12					1	1	1
12 - 1	Wednesday April 20, 1977 PM			1			
1 - 2						2	1
2 - 3							
3 - 4				1			
4 - 5					1		2
5 - 6							
6 - 7				1	2		1
7 - 8						1	
8 - 9		1	1	1		1	1
9 - 10		1		2	1		1
10 - 11			1	1			
11 - 12			1	1	1	1	1
12 - 1	Thursday April 21, 1977 AM						
1 - 2							
2 - 3			1				
3 - 4							
4 - 5							1
5 - 6							
6 - 7							
7 - 8				1		1	
8 - 9							
9 - 10		1		1			
10 - 11							
11 - 12							

TABLE 6. (Continued)

Hour	Date	Operations per hour — Sump No. / No. of residences: 1/1	2/2	3/2	4/2	5/1	6/3
8 - 9	Wednesday June 1, 1977 — AM	1	1		1	1	2
9 - 10			2	1	1		1
10 - 11					1		1
11 - 12					1		1
12 - 1	Wednesday June 1, 1977 — PM				1	1	
1 - 2							2
2 - 3		1			1		1
3 - 4		1		1			
4 - 5		1	1				
5 - 6						1	1
6 - 7		1		1	1		1
7 - 8							
8 - 9		1		1		2	1
9 - 10			1				
10 - 11				1	1	1	1
11 - 12				2			1
12 - 1	Thursday June 2, 1977 — AM						1
1 - 2					1		
2 - 3			1				
3 - 4							
4 - 5							
5 - 6							
6 - 7							
7 - 8							
8 - 9			1			3	

TABLE 6. (Continued)

Hour	Date	Operations per hour: Sump No. / No. of residences 1/1	2/2	3/2	4/2	5/1	6/3
9 - 10	Wednesday June 22, 1977 AM	1					1
10 - 11		1					
11 - 12			1	1		1	1
12 - 1	PM						
1 - 2		1			1	2	1
2 - 3		1			1		
3 - 4							3
4 - 5		2	1				
5 - 6				2			1
6 - 7						1	1
7 - 8		1		1			
8 - 9					1	1	1
9 - 10			1	1			3
10 - 11						1	2
11 - 12							1
12 - 1	Thursday June 23, 1977 AM						
1 - 2							
2 - 3							
3 - 4							
4 - 5							
5 - 6			1				
6 - 7				1			
9 - 10	Tuesday June 28, 1977 AM	1		2			2
10 - 11			1	1		1	2
11 - 12							2
12 - 1	PM			1	1		
1 - 2						1	
2 - 3		1		1	1	1	
3 - 4							1
4 - 5				2		1	1
5 - 6			1	1	1		
6 - 7		1		1		1	
7 - 8				1		1	2
8 - 9			1				2
9 - 10		1		1	2		1
10 - 11				2		1	1
11 - 12			1				1

TABLE 6. (Continued)

Hour	Date	Operations per hour: Sump No. / No. of residences — 1/1	2/2	3/2	4/2	5/1	6/3
12 - 1	Wednesday June 29, 1977 AM						
1 - 2						1	
2 - 3							
3 - 4							
4 - 5				2			
5 - 6							
6 - 7							
7 - 8							
8 - 9		1		1		1	
9 - 10			1			1	
10 - 11							
11 - 12							
12 - 1	Wednesday June 29, 1977 PM	1			1	3	1
1 - 2			1				
2 - 3					1	2	1
3 - 4				1			
4 - 5						2	
5 - 6			1	1			1
6 - 7				1	1	1	1
7 - 8		1					1
8 - 9				1		1	1
9 - 10			1	1			2
10 - 11							1
11 - 12				1		1	1
12 - 1	Thursday June 30, 1977 AM						
1 - 2					1		
2 - 3			1				
3 - 4							
4 - 5							
5 - 6							
6 - 7				1		2	1

Pressure System Wastewater Volume

Volumes of wastewater collected by the pressure system are summarized in Table 7. The data presented in Table 7 were derived by multiplying volumes evacuated per pump cycle, recorded in Table 5 times pump operating frequencies recorded in Table 6. The data indicates surprisingly low wastewater flows, generally in the range of 151 to 227 liters (40 to 60 gallons) per capita day. There does not appear to be any significant difference in wastewater volumes generated at different seasons of the year.

Pressure System Water Use

Water recorded to have been used by homeowners connected to the Bend pressure system during the project monitoring period is presented in Table 8. As noted in Section 3, the water meters were installed in the house service lines so that they recorded consumptive water use as well as water which was returned to the sewer system.

Bend has an abundant supply of high-quality water from surface sources. Water use has not normally been metered; water customers have been charged a flat monthly rate. There has therefore been little economic incentive for water conservation either by the City or by individual water users. Unlimited use of city water for lawn irrigation has been a common practice. In almost all cases the water usage indicated in Table 8 is substantially greater than wastewater flows indicated in Table 7. In some cases the water consumption indicated are many thousands of liters per day per residence during summer periods when lawns were being watered and dropping off to generally less than 1,000 liters (260 gallons) per day per residence during winter periods.

Vacuum System

Vacuum system operating parameters--Operating parameters for the vacuum system are presented in Table 9. As with the pressure system, the volumes evacuated were calculated from the sump and holding tank configurations and the observed wastewater level at which vacuum valve or discharge pump operating cycles were initiated. The wastewater levels at which vacuum valve or discharge pump cycles were initiated were determined by level sensors as described in Section 3. The time duration of vacuum valve and discharge pump operations were determined by measuring several cycles and averaging the results. The time measurements were taken with a stopwatch, because the valve operating sensor gave only a momentary signal and, as with the pressure system, use of a stopwatch was considered more convenient than attempting to use the strip-chart recorder to measure vacuum or discharge pump-operating durations.

TABLE 7

PRESSURE SYSTEM WASTEWATER VOLUMES

Date/Time	Units	Sump No./No. Residences						Waste-Water Volume	Waste-Water Per Capita
		1/1	2/2	3/2	4/2	5/1	6/3		
Mon., Aug. 9, 1976 Noon to Tue., Aug. 10, 1976 10:00 AM (22 hrs.)	No. Pump Operations	5	5	15	9	11	17		
	Volume/Residence liter	757	560	1,874	851	895	1,802	6,738	198.1
	Volume/Residence gal	200	148	495	225	236	476	1,780	52.4
Wed., Feb. 9, 1977 6:00 PM to Midnight (6 hrs.)	No. Pump Operations	3	2	4	4	3	5		
	Volume/Residence liter	454	224	500	378	244	530	2,332	68.6
	Volume/Residence gal	120	59	132	100	65	140	616	18.1
Thurs., Feb. 10, 1977	No. Pump Operations	2	6	7	14	11	12		
	Volume/Residence liter	303	672	874	1,324	895	1,272	5,345	157.2
	Volume/Residence gal	80	178	231	350	237	336	1,412	41.5
Fri., Feb. 11, 1977	No. Pump Operations	5	5	10	9	8	19		
	Volume/Residence liter	757	560	1,249	852	651	2,014	6,083	178.9
	Volume/Residence gal	200	148	330	225	172	532	1,607	47.2
Sat., Feb. 12, 1977	No. Pump Operations	4	7	10	10	10	16		
	Volume/Residence liter	605	784	1,249	946	814	1,696	6,094	179.2
	Volume/Residence gal	160	207	330	250	215	448	1,610	47.4
Sun., Feb. 13, 1977	No. Pump Operations	2	2	10	10	13	20		
	Volume/Residence liter	303	1,008	1,249	946	1,060	2,120	6,685	196.6
	Volume/Residence gal	80	266	330	250	280	560	1,766	51.9
Mon., Feb. 14, 1977 Midnight to 10:00 AM (10 hrs.)	No. Pump Operations	2	2	3	2	5	6		
	Volume/Residence liter	303	224	375	189	405	636	2,131	62.7
	Volume/Residence gal	80	59	99	50	107	168	563	16.6

TABLE 7 (Continued)

Date/Time	Units		Sump No./No. Residences						Waste-Water Volume	Waste-Water Per Capita
			1/1	2/2	3/2	4/2	5/1	6/3		
Tue., Mar. 15, 1977 8:00 AM to Midnight (20 hrs.)	No. Pump Operations		5	3	6	16	13	7		
	Volume/Residence	liter	757	337	750	1,514	1,056	742	5,156	151.6
	Volume/Residence	gal	200	89	198	400	279	196	1,362	40.1
Wed., Mar. 16, 1977	No. Pump Operations		1	2	3	3	6	9		
	Volume/Residence	liter	151	224	375	284	488	954	2,476	72.8
	Volume/Residence	gal	40	59	99	75	129	252	654	19.2
Wed., April 20, 1977 5:00 PM to Thurs. April 21, 1977 Noon (17 hrs.)	No. Pump Operations		3	4	8	4	4	5		
	Volume/Residence	liter	454	446	999	379	326	530	3,134	92,2
	Volume/Residence	gal	120	118	264	100	86	140	828	24.4
Wed., June 1, 1977 8:00 AM to Midnight (16 hrs.)	No. Pump Operations		6	7	7	8	6	13		
	Volume/Residence	liter	908	784	874	757	489	1,379	5,190	152.6
	Volume/Residence	gal	240	207	231	200	129	364	1,371	40.3
Wed., June 22, 1977 9:00 AM to Thurs. June 23, 1977 7:00 AM (22 hrs.)	No. Pump Operations		7	4	6	3	6	15		
	Volume/Residence	liter	1,060	447	749	284	488	1,590	4,618	135.8
	Volume/Residence	gal	280	118	198	75	129	420	1,220	35.9
Tue., June 28, 1977 9:00 AM to Midnight Midnight (15 hrs.)	No. Pump Operations		4	4	13	5	7	15		
	Volume/Residence	liter	606	446	1,624	473	568	1,590	5,307	156.1
	Volume/Residence	gal	160	118	429	125	150	420	1,402	41.2
Wed., June 29, 1977	No. Pump Operations		3	4	9	3	13	10		
	Volume/Residence	liter	454	447	1,124	284	1,056	1,060	4,425	130.1
	Volume/Residence	gal	120	118	297	75	279	280	1,169	34.4
Thurs. June 30, 1977 Midnight to 7:00 AM (7 hrs.)	No. Pump Operations		0	1	1	1	2	1		
	Volume/Residence	liter	0	113	125	95	163	106	602	17.7
	Volume/Residence	gal	0	30	33	25	43	28	159	4.7

TABLE 8

PRESSURE SYSTEM PARTICIPATING RESIDENT WATER USE

Date	No. of Days	Pump Sta. No. 1	Pump Sta. No. 2 a	Pump Sta. No. 2 b	Pump Sta. No. 3 a	Pump Sta. No. 3 b	Pump Sta. No. 4 a	Pump Sta. No. 4 b	Pump Sta. No. 5	Pump Sta. No. 6 a	Pump Sta. No. 6 b	Pump Sta. No. 6 c
	Water use - liters per day (Volume in liters times 0.264 equals volume in gallons)											
8/ 9/76	31	5,150	5,100	6,850	11,330	7,590	5,520	7,250	8,640	5,300	8,720	4,190
9/ 9/76	31	820	2,320	3,620	9,290	5,610	3,480	6,170	4,020	3,570	9,120	3,880
10/11/76	32	740	1,730	5,720	7,480	5,410	2,580	3,540	2,070	4,560	5,690	3,170
10/18/76	7	710	590	3,990	5,970	6,960	2,920	850	4,420	2,630	5,550	1,270
10/19/76	1	1,190	990	400	880	2,100	710	960	1,160	450	760	0
10/20/76	1	400	930	650	910	2,320	1,730	760	850	680	400	540
10/21/76	1	620	400	400	1,440	1,870	1,300	570	960	370	620	400
10/22/76	1	1,160	570	570	740	2,940	1,080	570	1,470	540	650	450
10/23/76	1	1,730	1,330	60	2,630	6,060	2,070	1,870	3,710	1,560	2,770	930
10/24/76	1	450	400	5,490	2,920	2,520	230	250	880	650	960	310
10/25/76	1	680	930	310	1,730	2,580	1,080	790	710	620	590	310
10/26/76	1	990	680		790		1,670	340	740	370	880	570
12/13/76	48	820	620		1,420		590	710	930	570	820	400
1/12/77	30	540	590	2,100	1,930	1,700	710	480	740	620	790	400
2/ 8/77	26	680	540	650	1,610	2,210	650	680	880	540	850	370
2/ 9/77	1	570	510	570	1,190	2,120	510	820	850	370	910	310
2/10/77	1	590	480		1,220	1,250	1,080	650	850	370	540	280
2/11/77	1	370	400		1,470	1,440	570	790	760	930	820	250
2/12/77	1	790	480	450	2,270	12,430	620	820	790	450	1,440	310
2/13/77	1	510	2,010	620	13,250		790	820	910	510	5,780	250

TABLE 8 (Cont.)

Date	No. of Days	Water use - liters per day (Volume in liters times 0.264 equals volume in gallons)										
		Pump Sta. No. 1	Pump Sta. No. 2		Pump Sta. No. 3		Pump Sta. No. 4		Pump Sta. No. 5	Pump Sta. No. 6		
			a	b	a	b	a	b		a	b	c
3/10/77	25	588	466	—	1,706	2,097	596	553	809	471	937	335
4/12/77	33	695	2,445	—	2,371	3,607	1,640	1,200	1,712	1,210	3,585	1,194
5/16/77	34	684	4,799	4,050	7,756	4,096	1,611	5,181	3,143	1,956	5,606	1,590
6/16/77	31	571	3,141	6,338	6,624	5,248	3,095	5,530	3,914	1,359	6,798	2,735
7/18/77	32	821	8,240	11,336	2,877	8,900	5,685	10,409	7,678	6,111	11,316	6,888
7/19/77	1	1,148	2,503	16,120	3,255	1,624	8,719	7,476	6,548	3,950	4,524	2,673
7/20/77	1	453	6,457	7,888	22,222	1,597	11,875	15,610	9,583	7,797	8,953	2,549
7/21/77	1	914	9,014	16,037	16,343	12,725	2,462	10,629	7,858	15,255	17,743	7,816
7/22/77	1	1,223	9,727	25,095	18,008	6,604	8,436	26,640	10,320	3,353	7,658	8,152
7/23/77	1	19	5,740	1,216	10,176	4,184	9,364	9,716	3,274	9,802	12,246	6,940
7/24/77	1	0	540	974	16,339	11,328	219	8,451	963	53	9,988	1,624

TABLE 9
VACUUM SYSTEM OPERATING PARAMETERS

(Measured October 25, 1976)

Vacuum Pump Operating State	Hg(cm)	Hg(inch)
Vacuum Pump Off	50.5	19.9
Lead Vacuum Pump On	40.6	16.0
Lag Vacuum Pump On	35.6	14.0
Low Vacuum Alarm	25.4	10.0

Time for one pump to restore vacuum	51 seconds

Vacuum Valve Number	Volume Evacuated Per Valve Cycle (liter)	(gal)	Valve Open Time (seconds)	Liquid Evacuation Time (seconds)	Liquid Velocity in 3" Pipe (meter/sec)	(ft/sec)
1	51.1	13.5	11.7	0.8	14.0	45.8
2	62.1	16.4	7.2	0.7	19.4	63.7
3	44.3	11.7	8.5	0.9	10.7	35.3
4	41.6	11.0	7.8	0.7	13.0	42.7
5	64.3	17.0	6.0	1.3	10.8	35.5
6	117.3	31.0	5.9	3.7	6.9	22.8
7	65.1	17.2	5.0	1.6	8.9	29.2
8	51.5	13.6	5.6	0.8	14.0	46.2

Volume evacuated by discharge pump cycle	1.5 cubic meters 100 gallons
Discharge pump operating time	55 seconds

The vacuum valve sump level sensors and operating timers were adjusted by Airvac personnel at the beginning of the project monitoring period. It can be noted that the valves most distant from the collection station were set with considerably longer "open" times than recommended by Airvac design literature[1], which recommended that ... "the valve open for a total time equal to twice the time required to admit the sewage."

The high transport velocities that can be reached in the two-phase flow of vacuum systems, relative to pumped systems, is indicated in Table 9. It has been observed that the turbulence in high-velocity vacuum-system transport disintegrates most sewage solids very effectively.

Vacuum System Valve and Pump Operation Frequencies--

The recorded frequencies of operation of vacuum valves, vacuum pumps and discharge pumps is presented in Table 10. As with the pressure system it should be kept in mind that valve operations must be multiplied by the evacuated volume of each sump, which are not the same for all sumps, to obtain the volumes of wastewater generated.

Considerable difficulty was encountered in obtaining data that was deemed reliable from the vacuum valve operation monitoring system. In some cases the monitoring system would not produce the desired indicating marks on the strip-chart recorder paper when valve operations were known to be occurring; at other times the monitoring system appeared to be producing spurious indicating marks on strip-chart channels which were believed to be not operating. For example vacuum valve No. 1 shows very infrequent operation, while water use data presented later in this section indicates that the resident was probably home during most of the monitoring periods. However, because there was no basis for differentiating between good and bad data, the data is presented as it was collected.

Table 10 shows an increase in the frequency of operation of the vacuum pumps during the year of monitoring. Deterioration in the efficiency of the pumps would result in the pumps running longer to re-establish vacuum. Leaks in the vacuum system (and possibly through the pumps) would result in more frequent operation of the pumps.

Vacuum System Wastewater Volumes--

The volumes of wastewater collected by the vacuum system, derived by multiplying the evacuated volume of sumps by the number of recorded valve operations is presented in Table 11. The volume of wastewater evacuated by operation of the discharge pumps is also shown in Table 11. Considering the questionable reliability of the vacuum valve operation data, discussed above, the wastewater volumes derived from operation of the discharge pumps is considered more reliable. The wastewater volumes calculated from the vacuum valve
greater than volumes calculated from the discharge pump operations.

As with the pressure system the average per capita wastewater generation is surprisingly low, generally being in the range of 115 to 189 liters (30 to 50 gallons) per capita day. However, the wastewater collected from individual vacuum valve installations varies considerably. The data from vacuum valve No. 1 is not considered reliable. The residence connected to vacuum valve No. 7 was vacant during most of the monitoring period. The residences connected to vacuum valves Nos. 2, 3, 4, and 8 have low to moderate per capita wastewater generation (relative to this project data) while the residence connected to valve No. 6 has relatively high per capita wastewater generation.

TABLE 10

VACUUM SYSTEM VALVE AND PUMP OPERATION FREQUENCY

		Operations per hour											
		Vacuum valve No./No. residences								Vacuum pump no.		Discharge pump no.	
Hour	Date	1/1	2/1	3/1	4/1	5/1	6/3	7/1	8/2	1	2	1	2
3- 4	Monday July 12, 1976 — PM									1	1		
4- 5										2	1		1
5- 6										1	2	1	
6- 7										1	1		1
7- 8										1	1		
8- 9										1	1	1	
9-10										1	1		1
10-11										2	2		
11-12										1	1	1	
12- 1	Tuesday July 13, 1976 — AM									1	1		
1- 2										1	1		1
2- 3										1	1		
3- 4										1	1	1	
4- 5										1			
5- 6										1	1		
6- 7										1	1		1
7- 8										1	1		
8- 9										1	2		
9-10										2	1	1	
10-11										1	2		1
11-12										1	1		
12- 1	PM									1	1	1	
1- 2										1	1		
2- 3										1			1
3- 4										1			
4- 5										1			

TABLE 10
(Cont.)

Hour	Date	Operations per hour: Vacuum valve No./No. residences 1/1	2/1	3/1	4/1	5/1	6/3	7/1	8/2	Vacuum pump no. 1	2	Discharge pump no. 1	2
12- 1	Monday February 14, 1977 PM		1	1		1	1		1	1	1		
1- 2					1		1			1	2		1
2- 3			1			1				2	1		
3- 4			1		1					1	1	1	
4- 5				1			1			1	1		
5- 6						1	2			1	1		
6- 7			2		1		2			1	1		1
7- 8							1			1	1		
8- 9			2							1	1		
9-10					1		1			1		1	
10-11				1	1					1	1		
11-12							1			1	1		
12- 1	Tuesday February 15, 1977 AM									1	1		
1- 2					1		1				1		1
2- 3							1			1	1		
3- 4							2			1	1		
4- 5										1			
5- 6							1				1		
6- 7										1	1		
7- 8			1		1		1		1	1		1	
8- 9					1					1	2		
9-10					1		1			1	1		
10-11					2					1	1		1
11-12		1			1	1	3			3	1	1	
12- 1	PM			1							1		
1- 2			1				1			2	1		
2- 3						1				1	1		1
3- 4					1		1			1	1		
4- 5							3		1	1	2	1	
5- 6					2		1			2	1		
6- 7			1		1		1			1	1		1
7- 8							1			1	2		
8- 9									1	1			
9-10			1		1		1			1	2	1	
10-11										1	1		
11-12										1			

TABLE 10
(Cont.)

Hour	Date	Operations per hour: Vacuum valve No. / No. residences								Vacuum pump no.		Discharge pump no.	
		1/1	2/1	3/1	4/1	5/1	6/3	7/1	8/2	1	2	1	2
12- 1	Wednesday February 16, 1977 — AM			1			1			1	1		
1- 2							1				1		
2- 3					1		1			2	1		1
3- 4											1		
4- 5										1			
5- 6					1		1		1	1	2		
6- 7			1							1			
7- 8				1			1			1	2	1	
8- 9					1					1	1		
9-10					2	1	1		1	2	1		1
10-11					4					1	2		
11-12				1	2	1	1			1	1	1	
12- 1	PM				1		1			2	2		2
1- 2		1	1							2	1	1	
2- 3				1		1	2		2	1	1		
3- 4							1				1		1
4- 5				1	1		1			1	1	1	
5- 6			1	1	2		1			2	2		
6- 7				1			1		1	1			1
7- 8										1	1		
8- 9			1		1					1	1		
9-10							1			1	1		
10-11											1	1	
11-12				1			1			1	1		
12- 1	Thursday February 17, 1977 — AM			1			1			1	1		
1- 2			1				1			1	1		
2- 3							1			1			
3- 4											1		1
4- 5										1	1		
5- 6							1			1			
6- 7											1		
7- 8					2		1		1	2	1		
8- 9				1						1	1		1
9-10					4	1	1			2	2		
10-11		1		1	1				1		1	1	1
11-12			1		1		1			2	1		

TABLE 10
(Cont.)

Hour	Date	Operations per hour: Vacuum valve No./No. residences								Vacuum pump no.		Discharge pump no.	
		1/1	2/1	3/1	4/1	5/1	6/3	7/1	8/2	1	2	1	2
12- 1	Thursday February 17, 1977 PM			1						1	2	1	
1- 2					1	1	2		1	2	2	1	1
2- 3					3					1	1		
3- 4							1			1	1		
4- 5					1					1	1	1	1
5- 6					1	1	1		1	2	1	1	
6- 7							1			1	2		
7- 8				1	1				1	2	1		1
8- 9			1				1			1	1		
9-10										1	1		
10-11				1			1				1	1	
11-12							1			1	1		
12- 1	Friday February 18, 1977 AM			1			1			1	1		
1- 2											1		
2- 3					1						1		1
3- 4							1			1	1		
4- 5							1			1	1		
5- 6										1	1		
6- 7					1		1				1		
7- 8										1	1		
8- 9				2	3		1		1	1	2	1	
9-10		2			1			1		1	1		1
10-11		3							2	1	1	1	
11-12					2		1	6	2	2	1		
12- 1	PM			1	1	1		1		1	1		
1- 2			1							1	1		1
2- 3					1	1					1		
3- 4					5			1		2	2		
4- 5					1			1		1		1	
5- 6							5			1	2		
6- 7							4			1	1		1
7- 8					1		1			2	1		
8- 9											1		
9-10					1		1			2	1		
10-11							1				1	1	
11-12									1	1	1		

TABLE 10
(Cont.)

Hour	Date	Operations per hour: Vacuum valve No./No. residences 1/1	2/1	3/1	4/1	5/1	6/3	7/1	8/2	Vacuum pump no. 1	Vacuum pump no. 2	Discharge pump no. 1	Discharge pump no. 2
12- 1	Saturday February, 19, 1977 AM						1			1			
1- 2										1	1		
2- 3											1		
3- 4							1			1	1		
4- 5					1					1			1
5- 6							1			1	1		
6- 7											1		
7- 8					1		1			1	1		
8- 9					8	1			1	2	1	1	
9-10			1		1	5	1		5	2	4		
10-11				1			1			1			1
11-12					1					1	1		
12- 1	PM						1		1	1	1		
1- 2							1		2	1	1	1	
2- 3					1		2		1	1	1		
3- 4					4	1			1	1	2		1
4- 5					1		1			1	1		
5- 6			1				1		1	1		1	
6- 7					1					1	1		
7- 8				1	1		5		1	1	2		1
8- 9					2					1	1		
9-10						1	1		1	1			
10-11					1		1			1	1	1	
11-12									1	1	1		
12- 1	Sunday February 20, 1977 AM										1		
1- 2							1			1	1		
2- 3		1					1		1	1	1		
3- 4					1					1			
4- 5							1	1		1	1		1
5- 6					1						1		
6- 7						1				1	1		
7- 8					1		1		2	2	1		
8- 9					2		1			1	1	1	
9-10			1		1				1	1	1		
10-11							1		1	1	1		
11-12					1	1				1	1		1

TABLE 10 (Cont.)

Hour	Date	Operations per hour: Vacuum valve No. / No. residences								Vacuum pump no.		Discharge pump no.	
		1/1	2/1	3/1	4/1	5/1	6/3	7/1	8/2	1	2	1	2
12- 1	Sunday February 20, 1977 PM				1		1			1	1		
1- 2							1			1	1		
2- 3									1		1		
3- 4					1		1		1	2	1	1	
4- 5					1		1			1	2		
5- 6					1		1		1	1	1		1
6- 7						1	1		1	1			
7- 8					1		1			1	1	1	
8- 9				1			1			1	1		
9-10							1				1		
10-11										1	1		
11-12							1			1			
12- 1	Monday February 21, 1977 AM				1		1		1	1	1		1
1- 2				1							1		
2- 3							1			1	1		
3- 4									1	1	1		
4- 5							1			1			
5- 6			1								1		
6- 7					2	1	1		2	2	1	1	
7- 8											1		
8- 9					2		1		1	1	1		
9-10			1		4	1	1	1		2	2		1
10-11					5		1			2	1	1	
11-12							1			1	1		
12- 1	PM								1		1		
1- 2							1			1	1		1
2- 3			2			1	1	1		1	1		
3- 4				1			3			1		1	
4- 5					1		3		1	1	2		
5- 6			2							1	1		1
6- 7					1		6			2	1		
7- 8							1			1	1	1	
8- 9						1			1	1	1		
9-10							1				1		
10-11					1				1	1	1		1
11-12							1			1	1		

TABLE 10 (Cont.)

Hour	Date	Operations per hour: Vacuum valve No. / No. residences								Vacuum pump no.		Discharge pump no.	
		1/1	2/1	3/1	4/1	5/1	6/3	7/1	8/2	1	2	1	2
12- 1	Tuesday February 22, 1977 — AM									1			
1- 2							1				1		
2- 3										1	1		
3- 4							1			1			
4- 5									1		1		
5- 6					1		1			2	1		
6- 7						1					1	1	
7- 8					2		1		1	1			
8- 9				1	5	1	1			2	2		1
9-10					2				1	1	1		
10-11					1		2	1		1	1	1	
11-12							1			1	1		
12- 1	Tuesday February 22, 1977 — PM		1	1	1	1			1	1	1		1
1- 2							1			1	1		
2- 3							1				1		
3- 4							2			1	1		
4- 5					6		1	1	1	2	1	1	
5- 6			1								1		1
6- 7						1	1			1	1		
7- 8			1						1	1	1		
8- 9					1		1			1	1	1	
9-10			1		1	1	1			1	1		
10-11									1	1			
11-12				1			1			1	2		1
12- 1	Wednesday February 23, 1977 — AM									1			
1- 2							1			1	1		
2- 3									1		1		
3- 4							1			1			
4- 5					1						1		
5- 6									1	1	1		
6- 7					2		1			1	1		
7- 8						1	1		1	1	1	1	
8- 9				1	2		2		1	2	1		
9-10					1	1				1	1		1
10-11													
11-12													

TABLE 10 (Cont.)

Hour	Date	Operations per hour: Vacuum valve No. / No. residences 1/1	2/1	3/1	4/1	5/1	6/3	7/1	8/2	Vacuum pump no. 1	Vacuum pump no. 2	Discharge pump no. 1	Discharge pump no. 2
9-10	Tuesday March 8, 1977 — AM				1	1	1						
10-11							2	1	1				
11-12					1		1						
12- 1	PM				1	1	1		1				
1- 2					1		1						
2- 3					1		1						
3- 1			1					1	1				
4- 5					1		2						
5- 6													
6- 7						1	1						
7- 8					1								
8- 9							1						
9-10					1		1						
10-11								1					
11-12							1						
12- 1	Wednesday March 9, 1977 — AM												
1- 2							1						
2- 3									1				
3- 4						1	1						
5- 6				1			1		1				
6- 7					1								
7- 8					2		5		2				
8- 9					2		1						
9-10					1	1		1					
10- 1					1		1		1				
11-12													
12- 1	PM				2		1						
1- 2							1		1				
2- 3						1	1	1					
3- 4			1										
4- 5									1				
5- 6					1		1						
6- 7							2						
7- 8					1		3						
8- 9					1				1				
9-10				1			1						
10-11					1								
11-12							1						

TABLE 10
(Cont.)

Hour	Date	Operations per hour: Vacuum valve No. / No. residences: 1/1	2/1	3/1	4/1	5/1	6/3	7/1	8/2	Vacuum pump no. 1	Vacuum pump no. 2	Discharge pump no. 1	Discharge pump no. 2
12- 1	Thursday March 10, 1977 AM		1										
1- 2	Thursday March 10, 1977 AM						1		1				
2- 3	Thursday March 10, 1977 AM					1							
3- 4	Thursday March 10, 1977 AM												
4- 5	Thursday March 10, 1977 AM				1				1				
5- 1	Thursday March 10, 1977 AM												
6- 7	Thursday March 10, 1977 AM						1						
7- 8	Thursday March 10, 1977 AM				1								
8- 9	Thursday March 10, 1977 AM						5		1				
9-10	Thursday March 10, 1977 AM				2		1		1				
10-11	Thursday March 10, 1977 AM				1		1	1					
11-12	Thursday March 10, 1977 AM				5				1				
12- 1	Thursday March 10, 1977 PM												
1- 2	Thursday March 10, 1977 PM					1	1						
2- 3	Thursday March 10, 1977 PM		1	2									
9-10	Tuesday April 26, 1977 AM				1		3			3			
10-11	Tuesday April 26, 1977 AM			2	1		1		1	3		1	
11-12	Tuesday April 26, 1977 AM			1	1					1			1
12- 1	Tuesday April 26, 1977 PM		1				1			2			
1- 2	Tuesday April 26, 1977 PM					1	1			1			
2- 3	Tuesday April 26, 1977 PM						1		1	2		1	
3- 4	Tuesday April 26, 1977 PM			1			1			1			
4- 5	Tuesday April 26, 1977 PM			2			1			2			
5- 6	Tuesday April 26, 1977 PM		1	1			1			2			1
6- 7	Tuesday April 26, 1977 PM						1			1		1	
7- 8	Tuesday April 26, 1977 PM						1		1	2			
8- 9	Tuesday April 26, 1977 PM					1				2			
9-10	Tuesday April 26, 1977 PM			1			1			1		1	
10-11	Tuesday April 26, 1977 PM						1			1			
11-12	Tuesday April 26, 1977 PM									2			

TABLE 10
(Cont.)

Hour	Date	Operations per hour: Vacuum valve No. / No. residences								Vacuum pump no.		Discharge pump no.	
		1/1	2/1	3/1	4/1	5/1	6/3	7/1	8/2	1	2	1	2
12- 1	Wednesday April 27, 1977 — AM						1			1			
1- 2							1		1	2			
2- 3							1			1		1	
3- 4										1			
4- 5									1	2			
5- 6					1		1			2			
6- 7										1			
7- 8			1				4		2	3			1
8- 9						1				1		1	1
9-10			1						1	2			
10-11			1						1	2			1
11-12					1			1		2			
12- 1	Wednesday April 27, 1977 — PM		1							2		1	
1- 2						1	1		1	1			
2- 3							2			1			
3- 4				1			1			2			1
4- 5						1	1		1	1			
5- 6				1			1		1	3			
6- 7			1	2						1		1	
7- 8			1				1			1			
8- 9							1			2			1
9-10							1		1	2			
10-11					1		1			2			
11-12							1			2			
12- 1	Thursday April 28, 1977 — AM						2			1		1	
1- 2										2			
2- 3							1			1			
3- 4										2			
4- 5							1			1			
5- 6							1			1			
6- 7										2			
7- 8			1				1		1	2			1
8- 9					1	1				2		1	
9-10				1			4		3	2			
10-11			1				1		1				

TABLE 10
(Cont.)

Hour	Date	Operations per hour: Vacuum valve No. / No. residences: 1/1	2/1	3/1	4/1	5/1	6/3	7/1	8/2	Vacuum pump no. 1	Vacuum pump no. 2	Discharge pump no. 1	Discharge pump no. 2
9-10	Tuesday May 17, 1977 AM									1	2		
10-11										3	3		
11-12						1	1			3	4		1
12- 1	PM		1		1				1	5	4		
1- 2							2			4	5	1	
2- 3							1			4	4		
3- 4							1	1	4	5	4		1
4- 5			1			1	2			5	5		
5- 6			1				3			5	4	1	
6- 7							1			4	4		1
7- 8							1			3	3		
8- 9				1			1		1	4	5		
9-10										5	4		
10-11							1			4	4		
11-12							1			2	3	1	
12- 1	Wednesday May 18, 1977 AM						1			4	3		
1- 2							1		1	4	4		
2- 3							1			4	3		
3- 4										4	4		1
4- 5										3	3		
5- 6							1			3	3		
6- 7			1							4	5		
6- 7			1							4	5		
7- 8				1		1	1		1	4	2	1	
8- 9			1				1			3	4	1	1
9-10						1	1			4	3		
10-11			1						1	4	4	1	
11-12							1			4	4		
12- 1									1	3	2		

TABLE 10
(Cont.)

Hour	Date	Operations per hour: Vacuum valve No. / No. residences 1/1	2/1	3/1	4/1	5/1	6/3	7/1	8/2	Vacuum pump no. 1	2	Discharge pump no. 1	2
10-11	Thursday July 7, 1977 AM							1					
11-12													
12- 1	PM			1			1						
1- 2						1	2	1					
2- 3					1		2						
3- 4					1		2	1					
4- 5							4						
5- 6							5						
6- 7					1								
7- 8					1		1						
8- 9				1									
9-10			1				1						
10-11						1	2						
11-12							1						
12- 1	Friday July 8, 1977 AM												
1- 2					1		1						
2- 3							1						
3- 4							1						
4- 5					1								
5- 6					1		1						
6- 7					1								
7- 8					2		2						
8- 9					2		1						
9-10					1								
5- 6	Wednesday July 13, 1977 PM						6			3	2	1	
6- 7				1		3				2	2		1
7- 8							1			2	2	1	
8- 9							1			2	2		
9-10					1		1			2	2		
10-11							1			2	2		1
11-12							1			2	2		

TABLE 10
(Cont.)

		Operations per hour											
		Vacuum valve No. / No. residences								Vacuum pump no.		Discharge pump no.	
Hour	Date	1/1	2/1	3/1	4/1	5/1	6/3	7/1	8/2	1	2	1	2
12- 1	Thursday, July 14, 1977 — AM						2			2	2		
1- 2										1	2		
2- 3							1			2	1		
3- 4							1			1	2	1	
4- 5										2	1	1	1
5- 6					1		1			2	2		
6- 7				1						1	2		
7- 8							1			3	2	1	
8- 9							1			2	2		
9-10					1		3	1		2	3		1
10-11							4			3	2	1	
11-12							1			2	2	1	1
12- 1	Thursday, July 14, 1977 — PM						1			1	1	1	
1- 2					1					2	2		
2- 3							1			1	2		1
3- 4							1			2	1		
4- 5					1		6	1		3	3	1	1
5- 6					1		1			2	3		
6- 7										2	2	1	
7- 8							1			2	1		
8- 9					1		2			3	3		
9-10										1	2		1
10-11							1			2	2		
11-12							1			2	2		
12- 1	Friday, July 15, 1977 — AM						2			3	2		
1- 2							2			1	2	1	
2- 3				1			1			2	1		
3- 4										2	2		
4- 5							1			1	2		
5- 6										2	2		
6- 7							1			2	2		1
7- 8					1					2	2		
8- 9					1		1			3	3		
9-10					2		5	1		3	2	1	
10-11					1		2			2	3	1	

TABLE 11
VACUUM SYSTEM WASTEWATER VOLUMES

Date/Time	Unit	Vacuum Valve No./No. Residences 1/1	2/1	3/1	4/1	5/1	6/3	7/1	8/2	No. Valve Operations and Wastewater Volume	No. Vacuum Pump Operations	No. Discharge Pump Operations	Wastewater Volume from Discharge Pump Operations	Wastewater Volume per Capita
Monday	No. Valve Operations	0	7	3	5	3	10	0	1	29				
February 14, 1977	Volume/Residence liter	0	435	133	208	193	1173	0	51	2195	27	4	1514	65.8
12:01 PM to	Volume/Residence gal	0	115	35	55	51	310	0	14	580			400	17.4
11:59 PM (12 hours)														
Tuesday	No. Valve Operations	1	4	1	12	2	19	0	3	42				
February 15, 1977	Volume/Residence liter	53	250	45	500	129	2230	0	154	3361	47	8	3028	131.7
	Volume/Residence gal	14	66	12	132	34	589	0	41	888			800	34.8
Wednesday	No. Valve Operations	1	4	8	16	3	16	0	5	53				
February 16, 1977	Volume/Residence liter	53	250	354	666	193	1878	0	257	3653	51	11	4164	181.0
	Volume/Residence gal	14	66	94	176	51	496	0	68	968			1100	47.8
Thursday	No. Valve Operations	2	3	6	15	3	15	0	5	49				
February 17, 1977	Volume/Residence liter	102	186	266	625	193	1760	0	257	3388	52	12	4542	197.5
	Volume/Residence gal	27	49	70	165	51	465	0	68	895			1200	52.2
Friday	No. Valve Operations	5	1	4	18	2	18	6	6	60				
February 18, 1977	Volume/Residence liter	256	62	177	749	129	2112	390	309	4187	47	8	3028	131.7
	Volume/Residence gal	68	16	47	198	34	558	103	82	1106			800	34.8
Saturday	No. Valve Operations	0	2	2	23	8	19	0	15	69				
February 19, 1977	Volume/Residence liter	0	124	89	958	515	2230	0	772	4686	48	8	3028	131.7
	Volume/Residence gal	0	33	23	253	136	589	0	204	1238			800	34.8
Sunday	No. Valve Operations	1	1	1	12	3	16	1	9	44		6		
February 20, 1977	Volume/Residence liter	53	63	44	500	193	1878	65	463	3259	44		2271	98.7
	Volume/Residence gal	14	17	12	132	51	496	17	122	861			600	26.1

TABLE 11, Continued
VACUUM SYSTEM WASTEWATER VOLUMES

Date/Time	Unit	Vacuum Valve No./No. Residences 1/1	2/1	3/1	4/1	5/1	6/3	7/1	8/2	No. Valve Operations and Wastewater Volume	No. Vacuum Pump Operations	No. Discharge Pump Operations	Wastewater Volume from Discharge Pump Operations	Wastewater Volume per Capita
Monday	No. Valve Operations	0	6	2	17	4	23	2	9	53				
February 21, 1977	Volume/Residence liter	0	372	89	708	257	2699	130	463	4713	47	9	3407	148.1
	Volume/Residence gal	0	98	23	187	68	713	34	122	1245			900	39.1
Tuesday	No. Valve Operations	0	4	3	20	5	2	17	2	7				
February 22, 1977	Volume/Residence liter	0	253	133	833	322	1995	130	360	4023	44	8	3028	131.7
	Volume/Residence gal	0	67	35	220	85	527	34	95	1063			800	34.8
Wednesday	No. Valve Operations	0	0	1	6	2	6	0	4	19				
February 23, 1977	Volume/Residence liter	0	0	44	250	129	704	0	206	1332	17	2	757	32.9
12:01 AM to	Volume/Residence gal	0	0	12	66	34	186	0	54	352			200	8.7
11:00 AM (11 hours)														
Tuesday	No. Valve Operations	0	1	1	15	5	23	5	7	57				
March 8, 1977	Volume/Residence liter	0	62	44	625	322	2699	326	352	4429				
9:00 AM to	Volume/Residence gal	0	16	12	165	85	713	86	93	1170				
Midnight (15 hours)														
Wednesday	No. Valve Operations	0	1	2	13	3	7	49						
March 9, 1977	Volume/Residence liter	0	62	89	541	193	2347	195	360	3785				
	Volume/Residence gal	0	16	23	143	51	620	52	95	1000				
Thursday	No. Valve Operations	0	2	2	10	2	10	1	5	32				
March 10, 1977	Volume/Residence liter	0	124	89	146	129	1173	65	257	2252				
Midnight to	Volume/Residence gal	0	33	23	110	34	310	17	68	595				
3:00 PM (15 hours)														
Tuesday	No. Valve Operations	0	2	8	3	2	15	0	3	33				
April 26, 1977	Volume/Residence liter	0	124	168	125	129	1760	0	195	2498	26*	6	2271	98.7
9:00 AM to	Volume/Residence gal	0	33	44	33	34	465	0	51	660			600	26.1
Midnight (15 hours)														

TABLE 11, Continued
VACUUM SYSTEM WASTEWATER VOLUMES

Date/Time	Unit	Vacuum Valve No./No. Residences 1/1	2/1	3/1	4/1	5/1	6/3	7/1	8/2	No. Valve Operations and Wastewater Volume	No. Vacuum Pump Operations	No. Discharge Pump Operations	Wastewater Volume from Discharge Pump Operations	Wastewater Volume per Capita
Wednesday	No. Valve Operations	0	6	4	3	4	19	1	10	47				
April 27, 1977	Volume/Residence liter	0	372	177	125	257	2230	64	515	3740	40*	9	3407	148.1
	Volume/Residence gal	0	98	47	33	68	589	17	136	988			900	39.1
Thursday	No. Valve Operations	0	2	1	1	1	11	0	5	21		4		
April 28, 1977	Volume/Residence liter	0	124	44	42	64	1291	0	257	1825	16*		1514	65.8
Midnight to	Volume/Residence gal	0	33	12	11	17	341	0	68	482			400	17.4
11:00 AM (11 hours)														
Tuesday	No. Valve Operations	0	3	1	1	2	15	1	6	29				
May 17, 1977	Volume/Residence liter	0	186	44	42	129	1760	64	309	2536	99	6	2271	98.7
9:00 AM to	Volume/Residence gal	0	49	12	11	34	465	17	82	670			600	26.1
Midnight (15 hours)														
Wednesday	No. Valve Operations	0	3	1	0	2	8	0	4	18				
May 18, 1977	Volume/Residence liter	0	186	44	0	129	939	0	206	1503	90	5	1893	82.3
Midnight to	Volume/Residence gal	0	49	12	0	34	248	0	54	397			500	21.7
1:00 PM (13 hours)														
Thursday	No. Valve Operations	0	1	2	13	2	28	2	0	48				
July 7, 1977	Volume/Residence liter	0	62	89	541	129	3286	130	0	4232				
10:00 AM to Friday	Volume/Residence gal	0	16	23	143	34	868	34	0	1118				
July 8, 1977 (24 hours)														
Wednesday	No. Valve Operations	0	0	2	5	3	35	2	0					
July 13, 1977	Volume/Residence liter	0	0	89	208	183	4107	130	0	4724	94	16	6057	263.3
5:00 PM to Thursday	Volume/Residence gal	0	0	23	55	51	1085	34	0	1248			1600	69.6
July 14, 1977														
5:00 PM (24 hours)														
Thursday July 14, 1977	No. Valve Operations	0	0	1	7	0	15	1	0	24				
5:00 PM to Friday	Volume/Residence	0	0	44	291	0	1760	64	0	2161	75	6	2271	98.7
July 15, 1977	Volume/Residence	0	0	12	77	0	465	17	0	571			600	26.1
11:00 AM (18 hours)														

*Operation of only one vacuum pump recorded.

Vacuum System Resident Water Use--

Water recorded to have been used by homeowners connected to the vacuum system during the project monitoring period is presented in Table 12. Patterns of water use were similar to those observed in the pressure system. There was unrestrained use of water during summer months, up to many thousands of liters per day per residence, apparently for lawn irrigation. In contrast during winter months water use dropped to generally less than 1,000 liters (260 gallons) per residence.

ENERGY CONSUMPTION

Pressure System

The record of electrical energy used by the pressure system is presented in Table 13. It should be noted that Meter No. 1 totalized energy consumed by Pump Stations Nos. 1, 2, 3, and the pressure system monitoring station. Meter No. 2 totalized energy consumed by Pump Stations Nos. 4, 5, and 6. It is immediately apparent from Table 4 that Meter No. 2 indicates a relatively constant energy consumption near 2 kwh per day with occasional values up to 5 kwh per day. In contract, energy consumption indicated by Meter No. 1 varies from 2 to 17 kwh per day. The higher energy consumption indicated by Meter No. 1 can be accounted for by the heater and ventilating fan in the monitoring station. Increased energy consumption in the monitoring station can be correlated with hot weather in August and September and cold weather beginning in December. The heater and ventilating fan in the monitoring station were controlled by a thermostat and operated intermittently. Energy consumption by the heater and ventilating fan cannot be separated from pump energy consumption.

No explanation is apparent for the low energy consumption recorded by Meter No. 1 for the period September 9, 1976 to October 11, 1976. The low energy use indicated may have been caused by an error in reading the meter.

Each of the electrical control boxes contained a continuously energized 20-watt strip heater. Energy consumption of approximately 1.44 kwh per day should therefore be subtracted from each of the daily energy consumption figures for Meter No. 2 to obtain sump-pump energy consumption.

The energy consumption data for Meter No. 2, corrected for the strip heaters, indicated average energy consumption by each pump to be approximately .26 kwh per day. This represents a cost of less than $0.01 per day at current electrical prices in Bend.

TABLE 12

VACUUM SYSTEM PARTICIPATING RESIDENT WATER USE

Date	No. of Days	Water use - liters per day (Volume in liters times 0.264 equals volume in gallons)										
		Valve No. 1	Valve No. 2	Valve No. 3	Valve No. 4	Valve No. 5	Valve No. 6			Valve No. 7	Valve No. 8	
							a	b	c		a	b
8/ 9/76	31	14,330	16,960	4,220	13,900	1,780	4	3,650	960	1,190	880	2,770
9/ 9/76	31	10,680	9,880	4,050	9,600	1,470		2,180	5,780	230	1,360	930
10/11/76	32	5,860	9,200	1,760	21,270	1,300	50	1,610	310	110	620	540
10/12/76	1	1,530	3,650	2,270	5,550	1,420	130	910	170	400	1,810	510
10/13/76	1	7,700	2,860	11,270	13,310	740	140	310	170	200	400	420
10/14/76	1	1,300	2,240	170	5,320	1,020		450	140	60	620	340
10/15/76	1	11,210	37,040	570	12,260	1,950	260	540	400	230	930	850
12/13/76	59	1,500	1,360	80	1,360	960	100	310	110	310	760	
1/12/77	30	850	370	200	570	880	100	310	80	1,840	880	1,270
2/15/77	34	1,020	510	170		760	150	280	140	230	790	1,190
2/16/77	1	760	450	140		590	390	370	60	230	420	
2/17/77	1	1,130	480	510	7,990	740	340	340	140		540	340
2/18/77	1	1,780	540	420	510		500	1,360	110		480	310
2/19/77	1	7,560	230	590	3,710		280	230	140	200	510	590
2/20/77	1	9,480	12,320	200	850		350	340	80	1	790	370

Table 12 (Cont.)

Date	No. of Days	Water use - liters per day (Volume in liters times 0.264 equals volume in gallons)										
		Valve No. 1	Valve No. 2	Valve No. 3	Valve No. 4	Valve No. 5	Valve No. 6			Valve No. 7	Valve No. 8	
							a	b	c		a	b
3/10/77	18	852	395	115	2,244	775	388	274	140	148	—	357
4/12/77	33	3,570	3,651	871	2,955	1,336	370	620	102	163	1,015	419
5/16/77	34	6,485	16,027	4,343	20,631	10,077	397	1,526	94	169	1,392	1,866
6/16/77	31	10,019	10,640	5,075	19,049	10,323	388	1,949	61	134	2,718	2,396
7/11/77	25	17,991	18,418	11,909	15,740	9,276	0	4,427	39	—	944	552
7/12/77	1	19,152	18,971	35,245	26,443	789	0	4,860	83	—	2,065	344
7/13/77	1	—	24,967	4,320	5,724	1,665	0	691	49	113	1,295	400
7/14/77	1	31,718	19,178	9,149	31,715	11,234	0	1,748	38	276	1,484	683
7/15/77	1	20,409	13,798	6,850	2,092	710	0	1,424	22	83	986	525
7/16/77	1	31,201	—	12,627	20,927	1,348	26	5,732	49	170	951	548
7/17/77	1	27,625	18,804	13,001	22,214	7,273	0	5,056	4	0	789	306

TABLE 13

PRESSURE SYSTEM ENERGY CONSUMPTION

Period Ending	Number of Days	Meter No. 1 Pump Stations Nos. 1, 2, 3, & Monitoring Station (kwh/day)	Meter No. 2 Pump Station Nos. 4, 5, 6 (kwh/day)
8- 9-76	31	5.77	1.84
9- 9-76	31	5.39	2.00
10-11-76	32	0.19	2.09
10-18-76	7	1.86	2.14
10-19-76	1	3.0	3.0
10-20-76	1	4.0	2.0
10-21-76	1	3.0	2.0
10-22-76	1	3.0	2.0
10-23-76	1	7.0	5.0
10-24-76	1	3.0	3.0
10-25-76	1	3.0	2.0
10-26-76	1	4.0	2.0
12-13-76	48	7.63	2.31
1-12-77	30	16.16	2.47
2- 7-77	26	15.38	2.42
2- 8-77	1	17.0	3.0
2- 9-77	1	16.0	5.0
2-10-77	1	11.0	3.0
2-11-77	1	12.0	2.0
2-12-77	1	11.0	3.0
2-13-77	1	12.0	2.0
3-10-77	25	17.28	2.40
4-12-77	33	11.06	2.30
5-16-77	34	11.62	2.29
6-16-77	31	7.84	2.52
7-18-77	32	5.91	1.75
7-19-77	1	7.0	2.0
7-20-77	1	5.0	2.0
7-21-77	1	5.0	2.0
7-22-77	1	5.0	4.0
7-23-77	1	4.0	2.0
7-24-77	1	4.0	2.0

Energy consumption by the monitoring system would not be applicable to a nonresearch project. If pump control boxes were installed indoors, instead of outside, the strip heaters would probably be unnecessary.

Vacuum System

Electrical energy consumption by the vacuum system is tabulated in Table 14. As noted on Table 14, Meter No. 1 recorded energy consumption by the vacuum pumps, Meter No. 2 recorded energy consumption by the discharge pumps, and Meter No. 3 recorded energy consumption by the vacuum station fans, heaters and lights. The vacuum pumps consumed an average of approximately 7.5 kwh per day, with a range from 5.0 to 13.8 kwh per day. The period of highest energy consumption corresponds to the period shortly before Vacuum Pump No. 1 was rebuilt and perhaps resulted from loss of pump efficiency. The energy consumption data in Table 14 appears to show slightly more efficient operation during colder weather and an increase in energy consumed over the year of operation. Whether the increase in energy consumed resulted from development of leaks in the system or deterioration of pump efficiency was not determined.

The discharge pumps are recorded to have consumed an average of approximately 1.16 kwh per day with a range of .71 to 2.0 kwh per day. A range of energy consumption by the discharge pump could be expected because the pumps operate against varying heads depending on the vacuum in the system, in addition to the range of energy consumption that would have resulted from the variation in the volume of wastewater produced.

Station power consumption for fans, heaters and lights ranged from 3 to 14 kwh per day, with an average of approximately 6.27 kwh per day. Peaks of energy consumption by the vacuum station correspond to hot or cold weather. Only an insignificant part of energy consumption by the vacuum system can be credited to the monitoring system. Station heating and ventilating would be required whether the monitoring system were installed or not.

Average electrical energy consumption by the vacuum system apportioned between the eleven participating homeowners was approximately 1.36 kwh per household per day. This represents an average cost of approximately $0.04 per day, at current electrical prices in Bend.

TABLE 14

VACUUM SYSTEM ENERGY CONSUMPTION

Date	Number of days	Meter No. 1 Vacuum Pumps kwh/day	Meter No. 2 Discharge Pumps kwh/day	Meter No. 3 Station kwh/day
8- 9-76	31	7.39	1.71	5.52
9- 9-76	31	6.10	.71	3.71
10-11-76	32	5.97	.91	2.56
10-12-76	1	7.0	2.0	5.0
10-13-76	1	5.0	2.0	3.0
10-14-76	1	6.0	1.0	3.0
10-15-76	1	7.0	1.0	4.0
12-13-76	59	6.42	1.20	5.81
1-12-76	30	5.63	1.37	14.4
2-15-77	34	5.23	1.06	11.7
2-16-77	1	6.0	1.0	6.0
2-17-77	1	5.0	2.0	6.0
2-19-77	2	6.0	1.0	8.0
2-20-77	1	5.0	1.0	5.0
3-10-77	18	5.56	1.44	8.28
4-12-77	33	5.61	1.09	5.58
5-16-77	34	13.85	1.09	3.15
6-16-77	31	9.94	1.16	3.90
7-11-77	25	11.88	1.20	6.12
7-12-77	1	10.0	1.0	6.0
7-13-77	1	9.0	2.0	5.0
7-14-77	1	10.0	1.0	8.0
7-15-77	1	8.0	1.0	5.0
7-16-77	1	10.0	1.0	6.0
7-17-77	1	10.0	2.0	6.0

EFFLUENT AND SEWAGE CHEMICAL CHARACTERISTICS

Chemical characteristics of septic-tank effluent and sewage samples collected from the pressure and vacuum systems are tabulated in Tables 15 and 16. The samples were collected by apparatus described in Section 3. As described in Section 3 the sampling pump was electrically interconnected to operate whenever any of the low pressure system pumps or either of the vacuum system discharge pumps were operating, with intent to allow collection of representative, composited samples proportioned to wastewater flow rates.

A 24-hour composited sample was collected from each system on an approximately monthly basis. Samples were also composited for each system during succeeding six-hour periods over a 24-hour period during each of three intensive monitoring periods. The 24-hour diurnal study periods are indicated on Tables 15 and 16.

Temperature, pH, and dissolved oxygen were measured in fresh grab samples collected at the site. The remaining chemical characteristics were measured from composited samples, at the Bend wastewater treatment plant laboratory.

The average and extreme values of some of the chemical characteristic data from the septic tank effluent and raw sewage samples analyzed for this project are compared in Table 17 to similar data reported for septic tank effluent by EPA[4] and for raw domestic sewage by Metcalf and Eddy[7].

Temperature

The temperatures of both the septic tank effluent and the raw sewage apparently follow seasonal temperature fluctuations, which is to be expected considering that in both systems the sumps and pipes provide ample time for heat exchange with the air through the sump covers and with the soil. The raw sewage in the vacuum system was two to four degrees warmer than septic effluent from the pressure system in both extreme and average valves.

pH

With only a few exceptions the pH of the septic tank effluent were a few tenths of a pH unit below neutral while the pH of the raw sewage ranged up to 1.5 pH units above neutral.

TABLE 15
PRESSURE SYSTEM SEPTIC EFFLUENT CHARACTERISTICS

Time and Date of Sample Collection	Temperature °F	Temperature °C	pH	Dissolved Oxygen mg/l	Alkalinity (as $CaCO_3$) mg/l	Grease mg/l	Total Ortho Phosphate (P) mg/l	Total Kjeldahl Nitrogen (N) mg/l	Total Sulfide (S) mg/l	Suspended Solids mg/l	BOD_5 mg/l	COD mg/l
0900 August 17, 1976 to 0900 August 18, 1976	62	16.7	6.5	0.0	163.0	45.6	8.1	34.7	.06	39.0	160.0	172.3
0900 August 25, 1976 to 0900 August 26, 1976	58	14.4	6.5	0.3	174.0	72.6	9.4	33.6	1.03	35.0	212.5	273.8
DIURNAL STUDY: 0500 October 21, 1976 to 1100 October 21, 1976	56	13.3	6.6	0.9	174.5	73.9	8.1	36.5	1.02	17.0	128.8	202.6
DIURNAL STUDY: 1100 October 21, 1976 to 1700 October 21, 1976	62	16.7	6.7	0.9	185.5	71.6	8.3	41.2	1.08	30.0	173.8	210.9
DIURNAL STUDY: 1700 October 21, 1976 to 2300 October 21, 1976	56	13.3	6.7	1.2	159.0	118.3	7.0	32.2	1.09	31.0	93.8	170.5
DIURNAL STUDY: 2300 October 21, 1976 to 0500 October 22, 1976	52	11.1	6.5	0.0	157.0	63.5	6.9	30.1	1.18	45.0	151.3	257.8
0800 October 30, 1976 to 0800 November 1, 1976			7.1	0.0	163.0	43.8	10.7	33.3	1.62	31.3	157.5	231.0
0800 November 23, 1976 to 0800 November 24, 1976	56	13.3	6.8	0.0	217.0	34.3	7.4	42.5	2.13	36.0	117.5	196.5
0830 December 28, 1976 to 0830 December 29, 1976	44	6.7	6.6	1.3	216.0	47.6	9.5	42.3	3.08	16.0	267.0	171.6
0815 January 25, 1977 to 0830 January 26, 1977	38	3.3	6.6	0.0	203.5	48.5	11.1	46.0	1.05	33.0	198.0	210.0
DIURNAL STUDY: 1700 February 9, 1977 to 2300 February 9, 1977	52	11.1	6.9	0.5	250.0	133.7	14.7	46.8	1.18	34.0	182.0	673.5
DIURNAL STUDY: 2300 February 9, 1977 to 0500 February 10, 1977	52	11.1	7.1	5.6	224.5	93.8	12.3	41.2	1.14	26.0	182.0	631.5
DIURNAL STUDY: 0500 February 10, 1977 to 1100 February 10, 1977	60	15.6	6.8	0.0	204.5	68.4	12.2	37.2	1.21	36.0	143.0	415.3
DIURNAL STUDY: 1100 February 10, 1977 to 1700 February 10, 1977	54	12.2	7.2	0.0	247.0	71.0	14.0	47.9	1.21	39.0	195.0	380.4

TABLE 15
PRESSURE SYSTEM SEPTIC EFFLUENT CHARACTERISTICS, Continued

Time and Date of Sample Collection	Temperature		pH	Dissolved Oxygen mg/l	Alkalinity (as $CaCO_3$) mg/l	Grease mg/l	Total Ortho Phosphate (P) mg/l	Total Kjeldahl Nitrogen (N) mg/l	Total Sulfide (S) mg/l	Suspended Solids mg/l	BOD_5 mg/l	COD mg/l
	°F	°C										
0800 March 15, 1977 to 0800 March 16, 1977	48	8.9	6.6	0.0	210.0	59.00	10.9	44.2	4.70	30.0	165.0	244.2
0800 April 20, 1977 to 0800 April 22, 1977	58	14.4	6.6	0.0	200.0	48.7	10.1	42.85	2.45	33.0	146.3	213.3
0800 June 1, 1977 to 0700 June 2, 1977	56	13.3	6.6	0.0	241.0	53.8	12.4	50.0	5.35	49.0	120.1	196.2
0800 June 29, 1977 to 0700 June 30, 1977	64	17.8	6.6	0.0	229.5	54.9	10.8	46.5	1.5	46.0	95.0	195.6
1700 July 20, 1977 to 2300 July 20, 1977	68	20.0	6.7	0.0	213.0	62.5	11.6	43.4	1.57	39.0	124.0	287.0
2300 July 20, 1977 to 0500 July 21, 1977	62	16.9	6.8	0.0	220.0	51.2	11.4	44.5	1.5	46.0	144.0	241.0
0500 July 21, 1977 to 1100 July 21, 1977	70	21.1	6.7	0.0	213.0	62.0	11.5	40.5	2.32	56.0	158.0	271.0
1100 July 21, 1977 to 1700 July 21, 1977	68	20.0	6.4	0.3	222.0	52.6	10.9	42.3	1.4	53.0	139.0	227.0
Average	54.4	13.2	6.7	0.5	204.0	65.0	10.4	40.9	1.8	36.4	157.0	276.0

DIURNAL STUDY (rows 1700 July 20, 1977 through 1700 July 21, 1977)

TABLE 16

VACUUM SYSTEM SEWAGE CHEMICAL CHARACTERISTICS

	Time and Date of Sample Collection	Temperature °F	Temperature °C	pH	Dissolved Oxygen mg/l	Alkalinity (as $CaCO_3$) mg/l	Grease mg/l	Total Ortho Phosphate (P) mg/l	Total Kjeldahl Nitrogen (N) mg/l	Suspended Solids mg/l	BOD_5 mg/l	COD mg/l
	0900 August 16, 1976 to 0900 August 17, 1976	62	16.7	8.3	0.2		142.0	3.7	32.4	194.0	255.0	342.5
	0830 September 27, 1976 to 0800 September 28, 1976	63	17.2	6.6	0.3	123.0	57.3	5.1	29.0	166.0	225.0	382.9
DIURNAL STUDY	0500 October 14, 1976 to 1100 October 14, 1976	62	16.7	8.0	0.3	148.5	57.0	2.9	34.3	83.0	147.5	196.4
DIURNAL STUDY	1100 October 14, 1976 to 1700 October 14, 1976	62	16.7	7.9	0.6	123.5	202.0	2.9	28.4	107.0	183.8	296.3
DIURNAL STUDY	1700 October 14, 1976 to 2300 October 14, 1976	62	16.7	7.3	0.0	89.0	129.5	2.2	18.4	115.0	162.3	303.4
DIURNAL STUDY	2300 October 14, 1976 to 0500 October 15, 1976	60	15.6	7.5	2.8	108.0	172.4	2.7	25.7	82.0	180.0	229.9
	0830 November 22, 1976 to 0830 November 23, 1976	51	10.6	7.7	1.9	81.5	162.5	1.5	16.9	220.0	135.0	253.9
	0900 January 4, 1977 to 0900 January 5, 1977	48	8.9	8.5	0.5	148.0	67.0	3.8	32.8	164.0	163.0	286.7
	0800 January 18, 1977 to 0800 January 19, 1977	44	6.7	8.3	3.6	120.0	47.6	3.2	26.3	216.0	150.0	317.8
DIURNAL STUDY	1700 February 16, 1977 to 2300 February 16, 1977	45	7.2	7.8	0.2	113.0	154.5	3.1	23.0	102.0	251.0	611.0
DIURNAL STUDY	2300 February 16, 1977 to 0500 February 17, 1977	50	10.0	8.1	0.1	101.0	89.4	2.0	20.3	12.0	158.0	355.0
DIURNAL STUDY	0500 February 17, 1977 to 1100 February 17, 1977	44	6.7	8.5	0.5	125.0	104.3	2.7	31.5	98.0	183.0	429.4
DIURNAL STUDY	1100 February 17, 1977 to 1700 February 17, 1977	52	11.1	8.1	0.7	131.5	253.5	3.8	28.6	178.0	228.0	881.0

TABLE 16
VACUUM SYSTEM SEWAGE CHEMICAL CHARACTERISTICS, Continued

	Time and Date of Sample Collection	Temperature °F	Temperature °C	pH	Dissolved Oxygen mg/l	Alkalinity (as $CaCO_3$) mg/l	Grease mg/l	Total Ortho Phosphate (P) mg/l	Total Kjeldahl Nitrogen (N) mg/l	Suspended Solids mg/l	BOD_5 mg/l	COD mg/l
	0800 March 8, 1977 to 0800 March 9, 1977	50	10.0	8.5	2.00	144.5	57.6	2.7	26.9	153.0	177.0	356.8
	0800 April 27, 1977 to 0800 April 28, 1977	62	16.7	7.60	0.1	140.0	71.2	3.4	31.85	191.0	162.2	263.9
	0800 May 17, 1977 to 0800 May 18, 1977	56	13.3	8.5	0.5	125.0	54.5	2.6	28.35	171.0	189.4	234.8
	0800 July 7, 1977 to 0800 July 8, 1977	65	18.3	8.4	0.0	127.5	70.7	3.9	31.0	234.0	221.0	352.0
DIURNAL STUDY	1700 July 18, 1977 to 2300 July 18, 1977	66	18.9	6.6	0.0	137.5	161.3	4.7	27.6	369.0	233.0	575.2
DIURNAL STUDY	2300 July 13, 1977 to 0300 July 14, 1977	65	18.3	8.2	0.7	122.0	68.7	2.8	27.4	177.0	192.0	321.7
DIURNAL STUDY	0500 July 14, 1977 to 1100 July 14, 1977	65	18.3	8.0	0.0	160.0	85.2	3.3	43.3	197.0	125.0	221.4
DIURNAL STUDY	1100 July 14, 1977 to 1700 July 14, 1977	72	22.2	8.2	0.0	185.0	115.9	4.4	31.92	217.0	220.0	416.3
	Average	57.0	14.0	8.0	0.7	127.7	110.7	3.2	28.4	164.1	187.7	363.0

TABLE 17

COMPARISON OF CHEMICAL CHARACTERISTICS DATA
FOR SEPTIC TANK EFFLUENT AND RAW SEWAGE

Chemical Characteristics	Septic Tank Effluent Data		Raw Domestic Sewage Data	
	Bend R & D Project	EPA Data[9]	Bend R & D Project	Metcalf & Eddy[6]
Alkalinity mg/l as $CaCO_3$				
Average	204	-	127.7	100
Range	157 to 250	-	81.5 to 185.0	50 to 200
Grease mg/l				
Average	65	-	110.7	100
Range	34.3 to 133	-	57.0 to 172.4	50 to 150
Total Ortho Phosphate as P				
Average	10.4	14.6	3.2	10
Range	7.0 to 14.0	11.4 to 17.7	1.5 to 5.1	6 to 20
Total Kjeldahl Nitrogen as N				
Average	40.9	55.3	28.4	40
Range	30.1 to 50.0	48.9 to 61.6	16.9 to 43.3	20 to 85
Suspended Solids mg/l				
Average	36.4	54	164.1	200
Range	16 to 56	47 to 62	12.0 to 369.0	100 to 350
BOD mg/l				
Average	157.0	158	187.7	200
Range	93.8 to 267.0	142 to 174	125.0 to 255	100 to 300
COD (unfiltered) mg/l				
Average	276.0	360	363.3	500
Range	170.5 to 673.5	335 to 386	196.4 to 611.0	250 to 1000

Dissolved Oxygen

It is interesting to note that the septic tank effluent samples frequently had a trace of oxygen content, some over 1 mg/l. The anomolous reading of 5.6 mg/l on February 9-10, 1977 is viewed with some skepticism. The raw sewage in the vacuum collection tank generally, but not always, had a measured dissolved oxygen content, ranging from zero up to 3.6 mg/l. Not unexpectedly, the higher dissolved oxygen content in samples from both systems tend to occur during colder weather periods.

Alkalinity

The alkalinity of the raw sewage collected by the vacuum system ranged from 81.5 up to 185 mg/l (as $CaCo_3$) with an average of 127.7 mg/l. The alkalinity of septic tank effluent ranged from 157.0 up to 250.0 mg/l with an average of 204.0 mg/l. Metcalf and Eddy[7] characterize typical domestic sewage as having alkalinity ranging from 50 to 200 mg/l. Bicarbonate alkalinity of the Bend water supply was low; reported to be generally in the range of 10 to 60 mg/l (as $CaCO_3$). The natural waters from the Bend water supply apparently received additional alkaline buffering capacity from the wastewater pollutants. This phenomenon of apparent alkalinity increase is common in anaerobic digesters due to the titratability of volatile acids by the standard sulfuric acid. In order to determine the actual bicarbonate alkalinity the concentration of volatile acids (as $CaCO_3$) must be subtracted from the apparent alkalinity concentration. Volatile acids were not measured during this study.

Grease

Grease content in samples from the vacuum system averaged 110.7 mg/l, while grease content in septic effluent samples from the pressure system averaged only 65.0 mg/l. Metcalf and Eddy[7] characterize medium strength domestic sewage as having 100 mg/l grease. The results should not be interpreted to quantify a percentage of grease removal by the septic tanks in the pressure system, since initial grease content was not measured.

Phosphate

Total ortho-phosphate in the samples of septic tank effluent collected from the pressure system contained an average of 10.4 mg/l (as P) with variations from 7.0 to 14.0 mg/l, while the samples of raw sewage from the vacuum system contained an average of only 3.2 mg/l with phosphate with variations from 1.5 to 4.7 mg/l. The phosphate content in the pressure system effluent is typical of domestic sewage[4], and septic tank effluent[7]. The phosphate content in the vacuum system sewage is lower than typical. The only apparent explanation for the difference in the phosphate content of the septic tank effluent and raw sewage samples appears to be the difference in age and character of the residents of the two neighborhoods. Residents of the pressure system area were generally younger than in the vacuum system area. Housewives in the pressure system area may have used detergents containing phosphates more generously in laundering the clothing of children than housewives in the vacuum system area; and, although per capita wastewater production was low in both areas.

Nitrogen

Total Kjeldahl nitrogen in the samples collected from the pressure system averaged 40.9 mg/l (as N) with measured values ranging from 30.1 to 50.0 mg/l, compared to a reported average total nitrogen content of 55.3 mg/l for septic tank effluent. The Kjeldahl nitrogen in the vacuum system sewage samples averaged 28.4 mg/l nitrogen with values ranging from 18.4 to 43.3 mg/l. Metcalf and Eddy[7] reported typical medium strength domestic sewage to have a total nitrogen content of 40 mg/l.

Sulfide

Total sulfide in the septic tank effluent samples was measured to evaluate the potential for odors and formation of sulfuric acid in gravity sewers receiving the septic effluent discharge. Total sulfide was found to average 1.8 mg/l with a range of concentrations from .06 to 5.35. At the slightly acid pH of the septic effluent most of the sulfide would have been in the form of non-ionized gaseous hydrogen sulfide[10]. No objectionable odors were noted near the discharge manhole. The septic tank effluent was sufficiently diluted by the gravity sewer flow to prevent any acid formation from hydrogen sulfide.

Suspended Solids

Suspended solids measured in the septic tank effluent samples averaged 36.4 mg/l with a range from 17.0 to 56.0 mg/l, compared to an average of 54 mg/l[4] reported to be typical of septic tank effluent. Suspended solids in the raw-sewage samples from the vacuum systems were measured to average 164.1 mg/l with a range of 12.0 to 369.0 mg/l, or slightly less than the average for typical domestic sewage reported by Metcalf and Eddy[7].

BOD

The BOD of the septic tank effluent samples collected from the pressure system averaged 157.0, in close agreement with the average septic tank effluent BOD value reported by EPA[4]. The average BOD of the raw sewage samples collected from the vacuum system was 187.7 mg/l, slightly less than the BOD of 200 mg/l reported by Metcalf and Eddy[7] for average domestic sewage.

COD

The COD of the septic tank effluent averaged 276.0 mg/l with a range from 170.5 to 673.5 mg/l. The average was low and the extremes wider than data reported by EPA[4]. The COD of the raw sewage from the vacuum system averaged 363.3 mg/l with values ranging from 196.4 to 611.0 mg/l. The average and both extreme values were lower than the typical values reported by Metcalf and Eddy[7], again indicating that the vacuum system sewage was dilute relative to typical average values.

COMPARISON OF PRESSURE AND VACUUM SYSTEM COSTS

The following is a comparison of estimated costs for hypothetical pressure and vacuum sewage collection systems serving residences typical of the Bend R & D project. The cost estimates are derived from the Bend project data and are adjusted, as explained in the following, to allow for differences in the two areas served. Each home is assumed to have their own pump sump or vacuum valve. The cost figures derived are reduced to the annual cost per residence, relative to 1976 cost levels. Labor is assumed to cost $10.00 per hour. Amortization of capital costs are based on a 20-year payback period and 7 percent interest rates. The comparison of pressure and vacuum system costs are summarized in Table 18.

Potential System Size

Both the pressure and vacuum systems constructed in Bend had the potential to serve up to approximately 50 homes, although only eleven homes were actually connected to each system. Costs for the hypothetical systems which are applicable to the total system are therefore apportioned among the potential systems' capacity of 50 homes.

TABLE 18

COMPARISON OF PRESSURE AND VACUUM SYSTEM COSTS

Cost Item	Pressure System	Vacuum System
House Service Lines 16.8 m (55 ft)/residence	$ 289.00	$ 289.00
Collection Lines 39.3 m (131 ft)/residence	1,100.00	1,420.00
Pressure System Pump Station	2,114.00	
Vacuum Sump-Valve Pit-Valve		1,181.00
Vacuum Station		845.00
Vacuum System Discharge Line		20.00
Pressure Pump Repair or Replacement at 10 years. Present Worth	100.00	
Vacuum Pump Repair or Replacement at 10-year Interval. Present Worth		45.00
Present Worth of Total Capital Cost	3,603.00	3,800.00
Annual Amortization 20 years @ 7%	340.00	359.00
Annual Operation and Maintenance Costs	30.00	50.00
Energy Costs	4.00	12.00
Total Annual Cost Per Residence	$ 374.00	$ 421.00

Excavation

Costs for excavation of the pressure and vacuum system pipe trenches averaged $12.30 per meter ($3.75 per foot) and $19.36 per meter ($5.90 per foot) respectively. Trenches for both systems averaged approximately 1.0 m (3.2 feet deep). The vacuum pipe trenches may have required extra effort to excavate for trap assemblies and to maintain the downward slope of the lines. However, there was no way to differentiate the extra cost for the vacuum system configuration from the greater cost caused by more rock encountered in the vacuum system trenches.

House Service Lines

The hypothetical pressure and vacuum systems should have house service lines of similar average length. House service lines in the Bend pressure system averaged 10.7 m (35 feet) in length; house service lines in the vacuum system averaged 22.6 m (74 feet) in length. The difference was considered to be due to differences in the site's housing patterns, instead of differences inherent in the two systems. In both the pressure and vacuum systems the house service lines were constructed of 10.2-cm (4-inch) diameter PVC pipe and buried approximately .76 m (2.5 feet) deep. The hypothetical systems are assumed to have house service lines averaging 16.8 m (55 feet) long costing $6.56 per meter ($2.00 per foot) for excavation and $10.66 per meter ($3.25 per foot) for pipe installation for an average cost of $289.00 per residence.

Collection Lines

The pressure system in Bend averaged 28.3 m (93 feet) of collection line per house while the vacuum system averaged 51.2 m (168 feet) of collection line per house. As with the length of house service line, the difference in the length of the collection lines was considered to be due to differences in the housing density rather than any inherent difference in the two systems. The hypothetical pressure and vacuum systems will be considered to have an average of 39.3 m (131 feet) per house, with an average excavation cost of $15.81 per meter ($5.00 per foot).

The pressure system used 5.1-cm (2-inch) diameter, Class 160, PVC pressure pipe, with an estimated installation cost of $9.84 per meter ($3.43 per foot). It should be noted that the terrain in which the pressure system was installed did not require use of air release valves, which could have added as much as $1.63 per meter ($.50 per foot) if one pressure relief valve had been required. The estimated price per foot includes the line isolation valve and cleanouts. Cost to the average residence in the hypothetical pressure system for excavation and installation of the collection pipe is $1,100.00.

The vacuum system used 7.62-cm (3-inch) diameter, Schedule 40, PVC pipe. The installation cost included piping through the collection sumps and valve pits and five trap and cleanout assemblies. The pipe has an estimated installation cost of $19.20 per meter ($5.85 per foot). Cost to the average residence in the hypothetical vacuum system for excavation and installation of the collection pipe is $1,420.00

Pressure System Pump Station

The pump stations for the Bend pressure system cost $1,436.00 each plus an estimated $978.00 for electrical hookup, which included the alarm and alarm telemetry system and the power distribution system, but not the pump operation monitoring system. An additional $300.00 per residence is deducted from the electrical system cost to arrive at the cost for the hypothetical pressure system, which would receive power from house circuits and would have local alarms only. Cost per residence for pump station for the hypothetical pressure system is $2,114.00.

Vacuum Sump - Valve Pit - Valve

The vacuum system sumps and valve pit combinations for the Bend vacuum system cost $681.00 each installed plus $500.00 for each valve. Pipeline costs through the valve pit were included in collection pipe costs. The high water alarm system will be included in electrical system costs.

Vacuum Station

Costs for the vacuum station in the Bend project were: $11,310.00 for the station structure and piping, $25,300.00 for station equipment and $8,924.00 for the system electrical hookup, including the sump high water alarm and alarm telemetry system, but not including the valve operation monitoring equipment. As with the pressure system an additional $300.00 per residence is deducted from the electrical costs to arrive at estimated costs for the hypothetical vacuum system, which does not include the elaborate alarm system included in the Bend project. The hypothetical vacuum station therefore has an estimated total cost of $42,234.00. As noted before the cost of the hypothetical vacuum station can be divided among a potential system capacity of 50 residences for an average cost of $845.00 per residence.

Vacuum System Discharge Lines

A vacuum system will require some length of line to discharge into a gravity sewer. The discharge line for the Bend vacuum system costs approximately $6,620.00. However, to make an equitable comparison of the Bend pressure and vacuum systems the cost of the discharge line should be largely discounted because the pressure system was located adjacent to the gravity interceptor. Assuming that the hypothetical vacuum system has a discharge line costing $1,000.00 and apportioning the cost among 50 residences results in a cost of only $20.00 per residence.

Parts Repair and Replacement

Some of the equipment of the pressure and vacuum system will undoubtedly require major repair and/or replacement before the 20-year design period used for this analysis has passed. However, the data available is inadequate to make a very accurate forecast of the costs that will be incurred. Specifically the length of operating experience from the Bend project is inadequate to forecast future equipment failure problems.

The pumps in a pressure system appear to be the major equipment item most likely to fail during the lifetime of a pressure system. Preliminary results of a study of existing STEP and grinder pump systems indicates that the mean time between service calls (MTBSC) for any single pump ranges from three to seven years for different systems installed[3]. However, most of the pumps had been installed less than ten years. The service calls were caused by a variety of problems, many of which could have been detected by a preventative maintenance program. Labor cost for any major pump repair task very quickly equals the cost of a new pump.

For this analysis of the hypothetical pressure system it will be assumed that pumps with the average cost of the pumps used on the Bend project will be replaced every 10 years for a present worth cost of $100.00. Labor costs and other miscellaneous repair will be included in the following under the category of Maintenance.

An estimate of the life of components of the vacuum system is considerably more uncertain than for the pressure system. As noted before the sliding vane vacuum pumps have a poor record of reliability for this application, but the Bend project has not provided sufficient experience to judge whether the vacuum pump problems can be classified as "start-up" problems, are due to the small size of the Bend vacuum system, improper pump application, or whether the problems are typical of vacuum systems generally. For this analysis it is assumed that the vacuum pumps will need to be replaced at the end of 10 years. The present worth of replacing the two vacuum pumps at the end of 10 years divided among 50 residences is approximately $45.00 per residence.

On the Bend project problems with the vacuum valves have originated in the pneumatic controller, not in the valve itself. Airvac representatives report that the vacuum valves operate through 200,000 to 400,000 cycles before failure in laboratory tests. The vacuum valve life should be adequate for a 20-year design period if the laboratory data is applicable to field conditions. The Bend project experience to date has not indicated that the valves and controllers will not last through a 20-year design period, but has indicated that malfunction can be caused by any particle of debris that may enter the controller.

Maintenance

Based on the performance of the Bend pressure system we would recommend that the pressure system pump stations and the pumps be inspected annually as a preventative maintenance procedure. It may be desirable to hose down grease buildup periodically although there was no apparent need at the end of the first year of operation. Otherwise no maintenance service is recommended except when an alarm indicates a failure. It is estimated that each pump station would receive one man hour per year of routine inspection and maintenance, plus five man hours of major repair and maintenance once every five years for an average annual cost of $20.00 per year. The septic tank of a STEP pressure system will need periodic inspection and cleaning, at an estimated annual cost of $10.00 per residence.

Like the pump sumps the vacuum sump, valve pit and valve installations should receive an annual preventive maintenance inspection and hosing down of grease buildup in the collection sump if needed. Otherwise maintenance should be done when an alarm indicates failure. Three man hours per year of routine inspection and maintenance, plus five man hours of major repair once every five years is estimated at an annual average cost of $40.00 per year per vacuum valve installation.

The vacuum station should receive inspection at least twice weekly. Approximately 50 man hours per year are estimated for maintenance of the vacuum station. However, when the vacuum station maintenance is apportioned among the potential system size of 50 homes only one-half hour per year per residence results, for an estimated cost of $ 10.00.

Energy

The average energy cost for each residence in the pressure system was less than $.01 per day if the energy consumed by the control box strip heater was not included and approximately $.03 per day if the strip heater energy was included. The strip heaters are not considered necessary if the control boxes were placed inside the residence. The average energy cost for each residence in the vacuum system was approximately $.04 per day. Energy costs for the hypothetical systems are estimated to be $4.00 per year per residence in the pressure system and $12.00 per year per residence for the vacuum system costs.

Discussion

The cost estimates presented in Table 18 indicate that the hypothetical pressure and vacuum systems may have approximately competitive total annual costs. However, it should be understood that costs could vary widely for specific site applications. For example, air release valves would add to the cost of a pressure system if they were needed. The cost of vacuum system collection line installation is indicated to be significantly higher than for pressure system collection lines, and could make vacuum system less attractive in a sparsely settled area.

A fundamental difference in pressure and vacuum systems which is not reflected in Table 18 may be as significant as the cost estimates indicated in Table 18. The major cost of a pressure system is the pump sump, which does not need to be installed until the residence is ready for occupation. By comparison the vacuum station is a major cost component of a vacuum system and must be the first item installed. Although the vacuum station costs per residence may become relatively small when apportioned among the ultimate number of residences connected, the initial residences connected may bear a high capital cost load until the system potential size is reached. Similarly a major portion of repair and maintenance costs estimated for the vacuum system occur in the vacuum station and can be apportioned among connected residences. If a large number of residences are connected the cost per residence may be small; if a small number of residences are connected the cost per residence may be quite high.

The reader is warned against accepting the figures in the above cost comparison for literal application to a proposed project of any size. The figures are based, in part, on contractor costs which, in this case, were the first experience of the contractor. Other figures are hypothetical based on individual judgment. Anyone attempting a cost comparison between pressure and vacuum sewers and gravity sewers must recognize the need for thorough study and evaluation of the conditions peculiar to the specific project.

SECTION 5

DESIGN CONSIDERATIONS

GENERAL

There is a considerable volume of literature available which narrates the development of low pressure sewer technology. An account of the development of vacuum sewer technology is somewhat less readily available. This report does not attempt to repeat or summarize the design information that is available in the sources listed in the references and bibliography section. This chapter discusses alternative design concepts considered and experience gained during design, construction and operation of the Bend pressure and vacuum systems.

It should be understood that system design is a process of weighing the relative benefits and disadvantages of a multitude of possibilities. A rejected alternative may not necessarily be wrong but may be outweighed by other considerations for the specific application. Conversely, the selected design is seldom able to satisfy all desired criteria.

LOW PRESSURE SEWER TECHNOLOGY

As stated before, this report will not attempt to present a comprehensive summary of low pressure sewer technology which is available from sources listed in the bibliography section. The paper "Status of Pressure Sewer Technology" by J. F. Kreissl [6] is probably the most current and comprehensive summary of low pressure sewer design information available. Copies of the paper can be obtained from the U. S. Environmental Protection Agency Technology Transfer Program.

In approaching the design of a low pressure sewer system, there are several preliminary decisions to be made. Included among these are:

1. Collection of raw sewage using a grinder pump or collection of septic tank effluent using a sump pump. (STEP)

2. Type of pumps - Both centrifugal and semipositive displacement grinder pumps are being used in low pressure sewage systems. Most effluent pumps being used are centrifugal units.

Several systems using grinder pumps have been installed, operated, and reported upon. Data on grinder pump operation was therefore available. One of the initial goals of the Bend project was to collect data from a low pressure system collecting septic tank effluent. Design of the Bend pressure system therefore focused on use of centrifugal pumps, without grinders, collecting septic tank effluent.

VACUUM SEWER TECHNOLOGY

As with the pressure system, this report will not attempt to present a comprehensive analysis of vacuum system technology. However, vacuum system technology has not been as widely published as has pressure system technology. The principal sources of information on vacuum systems have been literature distributed by the companies selling vacuum systems and equipment. Probably the most current and comprehensive summary of vacuum sewer information is in the paper "Vacuum Sewer Technology" by I. A. Cooper and J. W. Rezek[2]. Copies of this paper are available from the U. S. Environmental Protection Agency Technology Transfer Program.

At the present time, there are two major companies marketing vacuum systems across the United States: Colt-Envirovac and Airvac. Although there are a number of differences in design concept between the two companies, one fundamental difference concerns the valves marketed by the two companies. Colt-Envirovac markets a descendant of the Liljendahl toilet valve developed in Sweden. The principal feature of the Colt-Envirovac valve is that it was developed as a toilet valve, has the potential for significant reduction of flush water requirements, and is applicable to the separation of "black" water (containing fecal wastes) and "grey" water (not containing fecal waste).

Airvac markets a 7.62-cm (3-inch) diameter valve designed for collecting raw sewage (combined black water and grey water). The Airvac valve was specified for the Bend vacuum system.

INSTITUTIONAL CONSIDERATIONS

Pressure and vacuum systems require a departure from normal institutional relationships typical of gravity sewer systems. Gravity systems historically have an established division of responsibility. A city or sewer district generally owns and maintains sewer lines up to private property. Property owners generally maintain service sewers and plumbing inside the property line, within restrictions established by plumbing, sewer, and building codes. The municipality has authority to enforce code restrictions to the degree the situation warrants. Gravity sewer systems are relatively simple in their operation, i.e., sewage flows down grade as long as the channel is not obstructed or overloaded. Sewage lift stations are installed when needed.

In contrast, pressure and vacuum systems incorporate increased mechanical complexity and a wider range of modes of failure. The need for a more complex range of prompt, reliable maintenance response is correspondingly increased. Since either pump sumps and pressure lines or vacuum valves and lines may require installation on private property, easements for installation and maintenance may be required.

It is not considered advisable to leave maintenance of either low pressure pump stations or vacuum valves to either the homeowner or a plumber selected at random by the homeowner. Standardized parts and repair and maintenance procedures are considered necessary to maintain the integrity of the system. It is considered advisable that before extensive vacuum or pressure systems are installed, an institutional structure with responsibility and authority for maintenance of the system be established.

FEASIBILITY OF MULTI-HOME SERVICE BY A SINGLE PUMP STATION OR VACUUM VALVE

Either a minimum-sized low pressure pump station or a single vacuum valve installation generally have the capacity to handle much more sewage than generated by a single home. Therefore, it appears that considerable savings could be obtained by connecting several homes to one pump station or vacuum valve.

The Bend pressure and vacuum sewer systems incorporated this concept. Groups of one, two, and three homes were connected to single pump stations or vacuum valves. These installations worked satisfactorily. There does not appear to be any technical reason for not installing multi-house connections to single pump stations or vacuum valves. However, multi-home installations may encounter several problems of a nontechnical nature.

One of the problems of a multi-house pressure-sewer installation is how to meter and pay for electrical energy. It appears most feasible to power the pumps through house circuits and accumulate the energy consumption on the house meters. However, in a multi-house installation energy consumed would appear on the meter of only one homeowner, and presents the problem of how to apportion costs between the homeowners sharing the pump station.

A metering system which would accumulate energy consumption for each pump would require a transformer and meter at each pump station. Very little energy would be recorded; a large amount of effort would be needed to reach the meters and prepare billings. Another option is to accumulate several pumps' energy consumption on a centrally located meter, as was done on the Bend project. However, this approach requires a distribution line from the central meter to each of the pumps being served.

It does not appear feasible to meter the energy used by pumping systems other than on the meters of the house circuits. A formula for apportioning the cost would need to be agreed upon by the participating homeowners before installing a multi-home pump station.

Energy consumption by a vacuum system is localized at the receiving station and presents a simpler problem of power metering.

Another possible problem of multi-home sewage collection sumps is assigning charges to the responsible individual if damage occurs as a result of negligent acts, such as flushing material that will plug or damage the system. This is not considered to be a major problem with septic tank effluent pumping systems, which will have solids removed by the septic tank, or with a 7.6-cm (3-inch) diameter pipe vacuum system which has capacity to handle most solids which can be flushed through normal plumbing fixtures. The ability to assign responsibility for pump stoppage has been recounted to be a desirable feature in a private system pumping raw sewage with small pumps which could be stopped by sanitary napkins or articles of clothing [3].

It is possible that if one home of a multi-home collection sump installation were installed at a lower level than the other homes and if the pump and alarm system failed, sewage could back up into the plumbing of the lower home. Claims by the flooded individual that damage resulted from negligence of another homeowner or the sewer utility might result. It should be noted that this is speculation; such an event did not occur on the Bend project. However, as described in Section 3 the Bend project incorporated fail-safe overflow lines to the existing subsurface disposal system, which might not be allowed on a nonresearch installation. Because of the fail-safe nature of the Bend system the homeowners were largely unaware of equipment failures that did occur and therefore did not have any major reactions to the failures.

The discussion above of the problems that might be encountered in operating a multi-home collection sump system is presented for consideration. It is felt that there is not sufficient experience to make firm recommendations.

ALARM SYSTEMS

It is considered desirable to provide an alarm system to indicate failure of a pressure or vacuum system to enable prompt repair action. Most failures will result in high water in sewage collection sumps. Therefore, the most versatile alarm system would be triggered by high water in collection sumps. Hopefully, a high-water alarm system would permit repair of any failed component before hydraulic storage capacity in the sump, and septic tank if used, is filled and sewage backs up into house plumbing. The smaller the available hydraulic storage volume, the more critical would be the response time. The concept of adding additional hydraulic storage volume in house sewer lines has been proposed on some projects.

Oregon subsurface disposal regulations require use of mercury float switches for control of sump pumps because hermetically sealed float switches are considered, by DEQ, to be less prone to failure from corrosion or grease buildup than other water-level sensors. Mercury float switches were specified for sump pump controls and high-water alarm sensors on the Bend project to be compatible with this regulation.

The Bend project incorporated high-water alarms in both pressure and vacuum system collection sumps. Both the pressure and vacuum systems also included alarm circuitry which identified the location of each collection sump experiencing high water conditions. This capability was included as a part of the monitoring program for the Bend project but may not be practical for systems serving a large number of homes. The wire network carrying the alarm signals back to central monitoring points could become very extensive and would be subject to failures and maintenance costs.

A less elaborate alarm system than that used on the Bend project could consist of a switch actuated by high water in the collection sump and an alarm indicator light installed in a conspicuous place in the home. An alarm light placed where it would be visible from the street would also allow police to inform maintenance personnel in the event of failure when the homeowner is absent.

A pressure system failed condition which might not result in a high-water alarm can be caused by a pump discharge check valve sticking in open position as occurred in the Bend pressure system. The sump with the open check valve would be filled with sewage whenever any other pump operated. The pump with the failed valve would then operate until the sump is again emptied. If the sump pump could counter system back pressure, high-water alarm conditions might never be reached. The frequent pump operation might not be noticed. It may be desirable to place a pump running light in a conspicuous place where the homeowner can note unusually high frequency of pump operation. Additional reliability can also be added to a pressure system by double check valves on the pump discharge lines.

The Bend vacuum system included a high-water alarm in the main collecting tank and a low vacuum alarm on the vacuum reserve tank. The need for an alarm to indicate vacuum pump oil system failure was mentioned in Section 4.

To place the above discussion of alarm system in perspective, it should be noted that gravity sewers can and occasionally do fail by plugging, with the result that sewage backs up into house plumbing. No one has seriously proposed alarm systems for failure of gravity sewers. It is considered that some degree of alarm capability is desirable to indicate mechanical failure in pressure or vacuum systems, but attempting to achieve complete assurance that sewage will never back up into house plumbing does not appear practical. Additional operating experience is needed to define the optimum alarm system for pressure and vacuum sewage collection systems.

PRESSURE SYSTEM SUMP CONFIGURATION

As noted in Section 4 care needs to be taken in design of pressure system pump sump configurations to allow for repair and maintenance. The optimum design may include trade-offs of the cost of extra repair and maintenance effort against the cost of more elaborate equipment.

Removal and replacement of the pump appears to be the most probable and most frequent repair and maintenance task. It is highly desirable that the pump can be removed and replaced in the sump from the ground surface and while the sump is full of liquid. However, in preliminary cost estimating procedures for the Bend project, guide-rail and slide-away coupling systems were quoted to cost up to $200.00 each. It appeared feasible to consider pumping liquid from the sumps into a container in the event of failure and using a mechanical coupling system which would have required maintenance personal to enter the sump to uncouple the pump. The sump could not have been manually uncoupled from the surface because of the 0.91-m (3-foot) pipe burial requirement at Bend. The guide-rail and slide-away coupling systems were placed on the project bid documents as an optional add-deduct item. The add-deduct price for the guide-rail and slide-away coupling systems on the beginning bid was only $50.00 for each sump, the guide-rail and slide-away coupling systems were included in the constructed sump configuration.

The guide-rail and slide-away coupling systems used at Bend have performed satisfactorily, but devices for uncoupling sump pumps are undergoing continued development by pump manufacturers. The systems used at Bend have probably been superseded on the market by better and less expensive equipment. For example, a pump coupling system which uses an inverted U-fitting on the pump discharge pipe, which hooks into a mating rubber gasketed fitting on the discharge line, has been advertized on a grinder pump system by the F. E. Myers Co.[10].

As described in Section 4, a check valve failed on the Bend pressure system. The operator noted that check valves installed in the verticle pipe run were difficult to service in that the valve could not be replaced from the top of the sump. The flooded sump had to be emptied into another container to prevent contamination of the ground, so that a maintenance person could enter the sump to remove the check valve. The sump is cramped in space and is an unpleasant place to work. These objectionable conditions might be improved if the check valve were placed in the horizontal pipe run, near the point the discharge pipe intersects the sump wall. (see Figure 3). However, the horizontal pipe run would still be difficult to reach from the ground surface when a 0.91-m (3-foot) deep pipe buried is required, as at Bend, and the sump would still need to be emptied to a level to expose the valve for service. Another design alternative is to place the check and gate valve or valves outside of the sump in a separate valve pit. Some systems have used double check valves, and some systems have used gate valves on both sides of the check valve. These options, of course, add cost. Designers should consider costs and advantages of alternatives for each application.

SUMP COVERS

Sump covers, for both pressure and vacuum systems, are items that appear to have received little comment in available literature. However, sump covers are a troublesome item that resists standardization and may require unique treatment on each project.

Because the sump covers are the interface between the sump and the outside environment, they may need to meet a variety of design criteria. Security and strength versus ease of entry may present conflicting requirements. The cover should provide adequate strength for the expected traffic load, which may range from foot traffic to heavy vehicle traffic in a single project depending on where the sump is located. The cover should also provide security against entry by unauthorized persons and against vandalism. On the other hand the cover locking device should allow entry by maintenance personnel without undue effort and should resist physical abuse and corrosion. The cover should be aesthetically compatible with the site. And finally, as in all designs, costs must be balanced against desirable design options.

Various sump-cover materials were considered during the design phase of the Bend project (cast iron, steel plate, precast concrete, fiberglass). The sump-cover specification was written as a performance specification. The sump covers proposed and accepted were fabricated from 0.64-cm (1/4-inch) thick steel plate bolted to nuts imbedded in the sump flanges, as described in Section 3. All of the sumps and valve pits were located in lawn areas. The steel plates were satisfactory in that they provided adequate strength for lawn or light vehicle traffic. Although heavy, the covers could be handled by one workman. And, although the pressure system sumps were corroding under breaks in the protective coating, the steel plate is probably thick enough to last through the design period.

Fiberglass covers are being used on sumps in another pressure system in Bend and are reported to be giving satisfactory service.

The system of bolting the sump covers to nuts imbedded in the sump covers to nuts imbedded in the sump flanges was less than satisfactory, but with some modifications is the best system we have to recommend. The bolts and imbedded nuts are simple and inexpensive to fabricate, will provide adequate security against unauthorized entry in most applications, and can provide sufficient closing force to contain the escape of odorous gases. The bolts and nuts should be of at least 1.3 cm (1/2 inch) diameter to withstand physical abuse and should be stainless steel to withstand corrosion. The sump cover should either be keyed or the bolt pattern should be symmetrical, to aid in easy replacement. The sump rim should be above ground level to minimize fouling the nuts with debris.

The top elevation of the sumps in the Bend project, relative to the ground surface, varied from below to several inches above the ground surface. Problems occurred with sump covers which were placed below ground level. As noted before, debris tended to foul the threads of bolts and nuts on covers that were below ground level much more than if the cover were slightly above grade. One pressure system sump cover was installed slightly below grade and covered with bark chips. As described in Section 4 this resulted in bark-chip debris falling into the sump during a maintenance operation and subsequent plugging of the check valve.

The sumps and valve pits in the Bend project were all installed in lawn areas. The sump covers received a variety of imaginative treatments by the homeowners to minimize the aesthetic impacts. One vacuum sump cover and valve pit cover were incorporated into a rock garden. An arrangement of lawn figurines was placed on another vacuum sump and valve pit cover. A lawn table was placed on top of another sump cover. It was concluded that with some care and imagination in placing the sumps and incorporating them into the landscaping that they need not be aesthetically detractive.

COMPARISON OF PRESSURE VACUUM AND GRAVITY SEWERS

A nonquantative comparison of pressure, vacuum, and gravity sewer systems is presented in Table 19. The limitation of a comparison such as that presented in Table 16 should be understood. The three systems do not have completely analogous components which may be compared without some distortion of the compared categories. Any specific site would require a different design approach for each system and utilize a different group of components for each system.

TABLE 19

COMPARISON OF PRESSURE, VACUUM, AND GRAVITY SEWER SYSTEMS

ITEM	PRESSURE SYSTEM	VACUUM SYSTEM	GRAVITY SYSTEM
1. Capabilities and Limitations	Permits installation on widely varying terrain. Lifts and length of line limited by pump capability. Technology still developing.	Total lift limited to less than approximately 4.5 m (15 feet) by use of atmospheric pressure as motive force. Maximum allowable length of line not well defined by present state of technology. Probably less than 1200 m (4000 feet).	Downhill transport only. Lift stations required if terrain does not permit downhill slope. No limit on length of line.
2. Trench Requirements	Pipeline follows ground profile at depth needed to provide mechanical and freeze protection. Narrow trench adequate. Pipe can be assembled above ground. Line and grade not critical.	Pipeline follows ground profile with series of abrupt lifts follows by downhill slopes. Depth of bury is to provide mechanical and freeze protection. Narrow trench is adequate. Pipe can generally be assembled above ground. Line and grade not critical but lift and trap assemblies and tributary intersection assemblies require care in design and placement.	Trench cuts must be deep enough to provide downhill grade and uniform line and grade between manholes. Trenches must generally be wide enough to allow assembling pipe in the trench.
3. Pipe	Small diameter. Typically 3.17 to 10.16 cm (1¼ to 4 inch) diameter. Class 125 to Class 200 PVC.	Small diameter. 7.62 cm (3 inch) diameter. Schedule 40 PVC recommended.	Generally 15.24 or 20.32 cm (6 or 8 inch) minimum diameter. Variety of materials. $5.00 to $10.00 per foot installed.
4. Pipeline Appurtenances	Air release valve assembly at high points in line. Cleanouts (if deemed necessary). Valves to isolate branch lines for service.	Lift and trap assemblies. Cleanouts (if deemed necessary).	Manholes or cleanouts every 90 to 100 m (300 to 400 feet).
5. Sewage Moving Force	Pump station at each house (or group of houses).	Sump and vacuum valve installation at each house (or group of houses). Vacuum station having the following equipment: Station housing Vacuum pumps Collection tanks Discharge pumps Standby engine generator (if required)	Gravity. Lift stations and force mains, if needed.

TABLE 19. (Continued)

ITEM	PRESSURE SYSTEM	VACUUM SYSTEM	GRAVITY SYSTEM
6. Sequence of Installation	Pump stations and lines extended as area develops	Vacuum station must be installed initially. Sumps' vacuum valves and lines extended as area developes.	Lines extended as area develops.
7. Operation and Maintenance	Replace pump (or other components) when failure occurs. Recommend periodic check of pump station. Hosing down grease buildup periodically may prove to be desirable. Energy consumption to operate pumps. Higher potential for damage by other construction activities than gravity system. Leaks may go undetected and contaminate groundwater.	Replace vacuum valve or valve controller when failure occurs. Recommend daily check of vacuum station, periodic check of valves. Hosing down grease buildup in sump periodically may prove to be desirable. Energy consumption to operate vacuum and discharge pumps. Higher potential for damage by other construction activities than gravity system. Undetected small leaks may increase power consumption of vacuum pumps and may be difficult to locate and repair.	Periodic cleaning of sewer. Pump station maintenance and operation costs if included. If leaks develop infiltration will increase treatment costs. Infiltration may occur through leaks in dry weather, possibly causing groundwater contamination.
8. Estimated System Life	Insufficient data for reliable estimates. Pumps - 8 to 10 years average life. PVC pressure mains - 20 to 50 years. PVC pressure lines should have a life of 20 to 50 years.	Insufficient data for reliable estimates. Airvac vacuum valves - 200,000 to 400,000 cycles. Vacuum pumps - 10 to 20 years. Discharge pumps - 20 years. PVC vacuum lines - 20 to 50 years.	Gravity sewers - 50 years or more.

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16. ABSTRACT

A pressure sewer system collecting domestic septic tank effluent and a vacuum system collecting raw domestic sewage were constructed in the City of Bend, Oregon. Each of the systems collected sewage from eleven houses and discharged into existing gravity sewer mains. Groups of one, two and three houses were served by single collection sump/vacuum valve or collection sump/pump combinations. The systems were operated and monitored for a period of approximately one year. The systems were evaluated for construction costs, operation and maintenance costs, reliability, operating characteristics, and chemical characteristics of collected sewage and septic effluent.

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