

EVALUATION OF SHALLOW-PLACED LOW PRESSURE DISTRIBUTION
SYSTEMS IN SOILS marginally suited for
ON-SITE WASTE TREATMENT

by

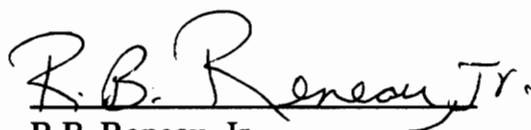
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EVALUATION OF SHALLOW-PLACED LOW PRESSURE DISTRIBUTION
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M. Marian Ijzerman

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(ABSTRACT)

Two shallow-placed low pressure distribution (LPD) systems were evaluated in soils that were marginally suited for a conventional on-site wastewater disposal system (OSWDS) because of low hydraulic conductivity and shallow depth of soil to bedrock. The soils used for this study were Edom (fine, illitic, mesic, Typic Hapludult) and Penn-Bucks soil (fine-loamy, mixed, mesic, ultic Hapludult). In the Edom soil, the LPD system was installed with four subsystem designs operating: a narrow trench design with a design loading rate of 17.5 Lpd/m², and three designs based on Virginia regulations with design loading rates of 9.0 Lpd/m², 4.5 Lpd/m², and 5.7 Lpd/m². In the Penn-Bucks soil, the LPD system was installed with three subsystem designs operating: a narrow trench design with a design loading rate of 30.6 Lpd/m², and two designs based on Virginia regulations with design loading rates of 14.3 Lpd/m², and 7.3 Lpd/m².

The evaluation was conducted under different moisture and temperature conditions (summer of 1989, and the winter of 1990), and focused on the fate and transport below each system of two antibiotic resistant *Escherichia coli* strains and two host-specific bacteriophage strains. The potential loss of NO₃⁻-N through the biological process of denitrification was also examined.

In the Edom soil, a narrow trench design, and designs based on the Virginia regulation all removed > 99.9% of the bacterial and viral tracers during the summer of 1989, and > 99% during the winter of 1990 throughout a 152 cm depth. The potential loss of NO_3^- -N in the Edom soil by denitrification was estimated to be 38%.

In the Penn-Bucks soil, the narrow trench design failed within six months of installation because the effluent loading rate was too high to permit infiltration through the silty clay loam soil, once biological clogging developed with the subsequent decrease in infiltrative capacity. The lower Virginia loading rate was more effective at microbial retention with > 99.9% removal throughout a 114 cm depth in both the summer of 1989 and the winter of 1990. The normal Virginia loading rate removed >99% of the bacterial and viral tracers throughout a 102 cm depth in both the summer of 1989 and the winter of 1990. The overall loss of NO_3^- -N in the Penn-Bucks soil through denitrification was estimated at 67%.

I dedicate the contents of this thesis
to my Lord who has walked me
through to its completion.

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Chapter I

INTRODUCTION

A. Rationale

In the United States, on-site wastewater disposal systems (OSWDS) apply the largest volume of wastewater directly to soil (95). There are four counties in the U.S. which are served by greater than 100,000 OSWDS with an additional 23 counties served by 50,000 to 100,000 OSWDS (31). In 1980, 20.9 million residences nationwide utilized subsurface absorption systems or cesspools to treat 14×10^9 L of wastewater (68).

In 1980, 34% of the two million homes in Virginia used some type of OSWDS to dispose of domestic wastewaters. This represents 238 million liters of wastewater produced per day from 10% of the homes in urban areas (121,000) and 75% of the rural homes (497,000) in Virginia (82). The number of OSWDS is increasing, with the Virginia Department of Health receiving 40,000 new applications for OSWDS per year (personal communication, Virginia Department of Health).

Groundwater supplies over 100 million Americans with drinking water. In rural areas, 90-95% of the drinking water is from ground water sources (95). Individuals who depend heavily on groundwater as their potable water supply also depend primarily on OSWDS as their sole means of disposal of domestic wastewater. In Virginia, the majority of the OSWDS are conventional gravity flow systems. These systems can provide effective treatment where there are soils of sufficient depth and

permeability (40). Unfortunately, in some regions of Virginia, soils suitable for a conventional system are limited (84).

With the rapid suburban expansion around many metropolitan areas in the U.S., many conventional gravity-fed OSWDS have been placed on soils classified as marginally suited or as unsuited for the effective purification of wastewater (39). Thus, the combination of high septic tank density on "poor" soils has resulted in OSWDS being identified as a major contributor to groundwater contamination (45, 63, 87, 95). The U.S. Environmental Protection Agency (EPA) (1977) has designated areas with a septic tank density of greater than $15.2/\text{km}^2$ as areas of potential contamination problems (95). From 1971-1982, there were 399 waterborne outbreaks and 86,050 cases of waterborne disease reported, and these resulted in three deaths (24).

Most contaminants in septic tank effluent are potentially waterborne and are thus of primary concern. Bacteria and viruses are the major biological contaminants due to their relatively small size and subsequent ease of movement through the soil pore system (13, 68). The illnesses most frequently transmitted through contaminated groundwater of bacterial and viral origin include: acute gastroenteritis of undetermined etiology, hepatitis A, shigellosis, and viral gastroenteritis (24). Nitrogen is the primary chemical of concern because of the mobility of NO_3^- -N through the system (12). Nitrate (NO_3^- -N) is the agent responsible for infant methemoglobinemia, and it has also been implicated as one of the factors responsible for the accelerated eutrophication of surface waters (23, 61).

In response to the need for an environmentally safe method of disposal of domestic wastewater on-site, the Low Pressure Distribution (LPD) system was developed (41). The LPD system was designed and developed in North Carolina to overcome the soil restrictions which inhibit the successful use of conventional gravity-fed

OSWDS. The LPD system functions by incorporating pressure-dosed distribution and narrow trenches (19). The LPD distribution system has been successfully used on sites which have 1) seasonal shallow or perched groundwater, 2) soils with hydraulic restrictive horizons at shallow depths, 3) sandy soils with high permeability, and 4) sites with steep slopes (17).

B. Objectives

This research focuses on the suitability of two shallow-placed LPD systems in soils where conventional OSWDS have failed, as evidenced by surface ponding. One of the LPD systems is located in Rockingham County, VA, where the site restriction is low soil hydraulic conductivity. The other LPD system is located in Prince William County, VA, where the site restrictions are shallow depth of soil to bedrock and a low soil hydraulic conductivity.

The suitability of the LPD system was evaluated under two extreme moisture and temperature conditions, with respect to loading rates at each location, by:

- 1) evaluating the fate and transport of bacterial and viral tracers, and
- 2) evaluating the potential for NO_3^- -N removal by the biological process of denitrification.

Chapter II

REVIEW OF RELATED LITERATURE

The number of cases of groundwater contamination are increasing in areas primarily dependent on groundwater for domestic uses, so the use of OSWDS for the treatment and disposal of domestic wastewater is receiving more attention. The increasing dependence on groundwater as a source of potable water has spurred efforts to protect the quality of this limited resource (95).

In 1980, 20.9 million residences (24.1% of the total in the U.S.) applied approximately 14×10^9 L of domestic wastewater via OSWDS to soils each day (68). In the U.S. there are four counties with more than 100,000 OSWDS, and an additional 23 counties with more than 50,000 OSWDS (31). While the relative percentage of new homes using OSWDS has decreased over the past several years, the total number of OSWDS is increasing at a rate of about 0.5 million per year (95). With suburban expansion around metropolitan areas into once rural areas, the possibility for the exposure of large numbers of individuals to untreated drinking water increases (39). Suburban growth also frequently exceeds the expansion of municipal facilities into newly subdivided localities since the costs of installing municipal sewage service are generally prohibitively high especially in rural areas; the only solution is to install the more affordable OSWDS (96).

Individuals who rely on OSWDS as their sole means of disposal of domestic wastes may also depend primarily on groundwater as their potable water supply (63). Groundwater supplies over 100 million Americans with drinking water daily. In rural areas, 90-95% of the drinking water is from ground water sources (95). It

has been estimated that by the year 2000, the nation's use of groundwater is expected to increase to 33% of the total water used (45). Noncommunity and individual water systems can generally obtain adequate quantities of water from groundwater sources and often use the water without treating it. It is therefore not surprising that contaminated, untreated groundwater is a major cause of outbreaks and illnesses which occur in these water systems (24). Cabelli (15) reported that waterborn outbreaks from noncommunity water systems were more than double those from community systems.

Poorly functioning OSWDS have been implicated as a major source of groundwater contamination (45, 63, 87, 95). The use of contaminated, untreated, or inadequately treated groundwater was responsible for 51% of all waterborn outbreaks and 40% of all waterborn illnesses reported in the U.S. between 1971-82 (24). Illnesses caused by drinking water contaminated by OSWDS include gastroenteritis, hepatitis, and typhoid (24). In 1972, five cases of typhoid occurred in a residential area of Washington State. When a dye was flushed through the OSWDS of a suspected carrier, it was detected 36 hrs later in several wells in the area. *Salmonella typhi*, the causative agent of typhoid, was isolated from the well water (95). An outbreak of 98 cases of hepatitis A (infectious hepatitis) in Arkansas was traced to the use of commercial pellet ice. The ice was made of water found to be heavily contaminated with fecal coliform bacteria. A dye study traced the contamination to an OSWDS serving a home occupied by persons who had recently been infected with hepatitis (95). A Norwalk-like agent was responsible for over 400 cases of gastroenteritis at a resort camp in Colorado. It was found, using dye tracers, that the camp tap water was contaminated with effluent from an OSWDS located 15.2 m above the spring supplying the camp (95).

The most notable cause of NO_3^- -N contamination of groundwater is the release

of wastewaters at or near the surface of the earth. These wastewaters may originate from OSWDS, waste stabilization ponds, privies, or leaky sewers (64). Calculations of the N input by OSWDS indicate that the supply of N to groundwater of typical rural OSWDS is insignificant when the density of residences is less than one per 0.2 hectare (89). However, in areas of higher population densities, conventional OSWDS supply significant quantities of NO_3^- -N to groundwater supplies. The population of Kootenai County, ID has nearly doubled from 35,332 since 1970. This rapidly growing county, which depends almost entirely on conventional OSWDS, threatens the Rathburn Prairie aquifer. Monitoring reveals a significant increase in NO_3^- -N concentrations (6-12 mg NO_3^- -N/L) a significant increase above historical background concentrations of less than 1 mg NO_3^- -N/L measured in 1970 (63).

Nitrogen poses the greatest threat to groundwater sources because of the mobility of NO_3^- -N in soil (12). Contamination of drinking waters with NO_3^- -N increases the risks of methemoglobinemia and the formation of carcinogenic nitrosamines (68). Infants are generally more susceptible to methemoglobinemia because an infant's total fluid intake per body weight is three times that of an adult (23). Methemoglobinemia results when NO_3^- -N, primarily consumed from contaminated water, is reduced in the gastrointestinal tract to NO_2^- -N. This reacts with the hemoglobin of red blood cells, yielding methemoglobin, which results in an impairment of oxygen transport in the body (1). Most reported cases have been associated with drinking water containing 22 mg NO_3^- -N/L; as a result, the World Health Organization and various countries have established standards for the quality of water to be less than 10 mg NO_3^- -N/L (1). It is estimated that about 1% of the U.S. population using public water supplies are consuming NO_3^- -N in excess of the EPA limit, primarily from groundwater systems (22)

A. Biological Contaminants

1. Bacteria

The principal pathogens found in sewage are bacteria, protozoa, helminths (intestinal worms), and viruses (28). Bacteria (750 nm) and viruses (18-25 nm) pose the greatest health risk because they are small enough to move within the pore system of most soils (13, 68). Protozoa and helminths are of lesser concern because the transport of these organisms through a soil pore system is unlikely due to their relatively large size (13).

Pathogenic enteric bacteria *Escherichia*, *Salmonella*, *Shigella*, *Vibrio*, and *Yersinia* are common constituents of wastewater (62). Soil filtration appears to be the main mechanism for removal of bacteria (33, 34). Butler, *et al.* (14) reported that the greatest removal of bacteria, using a sandy soil, occurred on the biological mat 0.5 cm below the soil surface used for effluent infiltration. The straining of bacteria at the soil surface appears to be the main limitation in the travel of bacteria through soils. When suspended particles, including bacteria, accumulate on the soil surface, they become part of the filter system (47). Bower, *et al.* (6) reported that most fecal coliform bacteria were immobilized in the top 3 to 4 cm of soil below basins intermittently flooded with secondary sewage effluent. Schaub and Sorber (76) also indicated that when wastewater was applied by rapid infiltration, the enteric indicator bacteria were readily concentrated on the soil surface mat. Similar results have also been reported by Reneau and Pettry (66).

Macropore flow through saturated, strongly structured soils or soils of the sandy textural class may promote pathogen travel over long distances with minimal treatment (68). Cogger and Carlile (20) reported that effluent treatment was poorest

around systems that were continuously saturated with groundwater. Fecal coliform movement was reported to occur as deep as 2.0 to 2.5 m beneath some systems, but no wells deeper than 2.5 m were placed near the systems, so the full extent of vertical movement is not known. Stewart and Reneau (83) monitored the extent of fecal coliform movement away from septic drainfields in two poorly drained Coastal Plain soils with seasonally high, fluctuating water tables. Horizontal movement of up to 10 m was detected, with average fecal coliform concentrations of less than 3 MPN/100 ml. Other investigators tracing the transport patterns of fecal microorganisms under saturated flow conditions reported similar findings (38, 54, 55, 65, 66).

Unsaturated flow differs markedly from saturated flow. In unsaturated flow, most of the effluent moves through the smaller pores (micropores) because the driving force is not gravity, but matric potential or capillary attraction under which only the smallest pores contain effluent. Movement of the liquid is relatively slow and allows contact time between the effluent, soil particles, and soil microorganisms (40).

The efficiency of unsaturated flow conditions at removing biological contaminants has been well documented (68). Hansel and Machmeier (40) reported that bacterial contaminants can be adequately removed within 0.9 to 1.2 m under unsaturated conditions. Magdoff, *et al.* (52) support this claim by reporting that fecal indicator bacteria were not detected in any column effluent percolating through 60 cm of fill over 30 cm of silt loam. Brown, *et al.* (11) reported that fecal coliforms were detected only occasionally in the leachate water samples drawn from undisturbed soil cores 120 cm below the septic tile line. Ziebell, *et al.* (98) reported a 300 fold decrease in bacteria numbers 38 cm below the trench bottom and 30 cm laterally in sandy soils.

2. Viruses

Of the viruses that infect man, more than 110 different types are excreted in feces and urine many of which are transmitted to man by the fecal-oral route (35). It has been reported that one million virus particles per gram of feces and concentrations as high as 463,500 infectious virus particles per litre have been detected in raw sewage (32). Viruses in human waste include the entero, adeno, reo, cytomegalo, reo-like viruses, and hepatitis (53).

Viruses found in domestic wastewater are a greater health problem for humans than bacteria because the dose required to cause sickness is much less than with bacteria (62). Ward and Akin (90) have recently reviewed the literature on minimum infectious dose of human viruses. The results indicate that relatively low numbers of viruses, one or two plaque forming units (PFU), are capable of causing infections.

Viruses are infectious agents that possess either RNA or DNA. They are colloidal shaped particles ranging in size from 20-200 nm and are encased in a protein coat (33). The amphoteric nature of the external viral proteins plays a critical role in their behavior within the soil matrix (27). Soils contain a variety of colloidal particles including clay minerals and organic matter. Thus the soil matrix offers a large active surface area which enables sorptive interactions to take place (4).

Unlike bacteria, where filtration at the soil water interface appears to be the main mechanism of removal, adsorption is the dominant mechanism of virus removal by soils (33, 34). Two general theories have been proposed for the mechanism of viral adsorption to solids. Carlson, *et al.* (18) found that bacteriophage T2 adsorption to natural clay particles was highly dependent on the concentration of cations present in solution. It was shown that the maximum

adsorption of T2 was about ten times greater for a divalent cation than for a monovalent cation at the same concentration in solution. This led them to conclusions that a clay-cation-virus bridge is operating to link the two negatively charged particles. Thus a reduction in the cation concentration results in a breakdown of the bridging effect and desorption of the virus.

Schaub, *et al.* (74) proposed that the fixation of multivalent cations onto the ionizable groups on the virus particles is accompanied by a reduction of the net charge of the particle. This reduction of the electric charge on the particle allows the solid and virus to come close enough for intermolecular Van der Waals forces to interact.

Factors influencing the adsorption phenomena will not only determine the efficiency of virus removal but also their long term behavior in soil (33). Adsorption within soil systems is influenced by clay content and type, ion species, and ionic strength (18). Drewry and Eliassen (26) conducted work with bacteriophage T1, T2, and f2 in nine different soils from California and Arkansas. They found that virus adsorption increased with an increase in cation concentration and clay content. Schiffenbauer and Stotzky (77) reported that the adsorption of coliphage T7 (96%) to montmorillonite was greater than that of T1 (84%), but that the adsorption of both coliphages to kaolinite was the same (99%).

The adsorption phenomena is further complicated by the fact that all viruses are not biochemically identical, and adsorptive behaviour may vary (33). Goyal and Gerba (36) compared the adsorption of a number of different strains of human enteroviruses and bacteriophages to nine different soils. Greater than 90% of all viruses adsorbed to a sandy loam soil except echovirus type 1, 12, and 29 and the simian rotavirus (SA-11). Of the five bacteriophages studied, f2 and ϕ x174 adsorbed the least. They concluded that adsorption was dependent on type and strain of virus, and soil type.

It has been demonstrated conclusively that virus association with solids does not result in inactivation. In fact, virus survival may be prolonged (4, 28). Schaub and Sagik (75) demonstrated that enterovirus particles are not inactivated when adsorbed to clays or organic colloids. Using two encephalomyocarditis viruses (Columbia SK and Mangovirus), they showed that plating of clay-bound virus suspensions on L cell monolayers resulted in plaque formation. In addition, the infectivity of clay adsorbed mengovirus administered either orally or intracerebrally was shown. Moore, *et al.* (58) also reported infectivity in plaque assay of particulate association of polio type 1 (Mahoney) and coliphages T2 and T7.

Many studies have been conducted which deal with the transport of indicator organisms through soil in order to determine their impact on environmental quality. Even though numerous reports of extensive travel distances have been reported (70, 91), most viruses die within 3 m of their source (8, 32). Lance, *et al.* (48) reported that poliovirus type 1 (LSc) was not detected below the 160 cm depth in columns filled with calcareous sand. They also reported that most of the viruses were adsorbed in the top 5 cm of the soil. Landry, *et al.* (51) reported that 96% of the guanidine-resistant strain of poliovirus LSc 2ab was adsorbed within the first 25 cm of the soil. Less than 0.22% were observed in core filtrates (75 cm). Brown, *et al.* (11) in a two year lysimeter study in which they utilized three undisturbed soils (sandy loam, sandy clay, and clay subsoils), concluded that fecal coliforms were detected only occasionally in the leachate water samples drawn from the soil 120 cm below the septic line. It should be noted that Brown, *et al.* (11) used ceramic cups in the study, which most likely reduced the fecal coliform population by filtration.

Virus persistence in soils is well documented. Melnick, *et al.* (56) reported enteric virus survival for 25-125 days in soil. Wellings, *et al.* (91) reported that poliovirus was found surviving at least 28 days in a Florida cypress dome used for

sewage effluent discharge. Yeager and O'Brien (97) reported that poliovirus type 1 and coxsackievirus B1 persisted in soils for at least 180 days at 4°C. Bitton, *et al.* (5) reported poliovirus 1 and echovirus 1 survival for up to 35 days.

Wellings, *et al.* (91) reported that soil-retained viruses that had the potential to survive for long periods could under certain environmental conditions be released and move into groundwater systems. Desorption of viruses has been reported when solutions of much lower ionic strength (rainfall or distilled water) were flushed through soil systems (68). Duboise, *et al.* (27) studied the movement of poliovirus I (Chat) through a sandy forest soil using several regimens of loading of either dechlorinated effluent or distilled water. Simulated cycles of rainfall and effluent applications indicated that poliovirus applied in effluents may move considerable distances through the soil after rainfall. Wellings, *et al.* (91) reported both vertical and lateral movement of viruses discharged into a cypress dome after heavy rains when no effluent was being applied. They reported that in an earlier study undertaken in St. Petersburg, FL, a burst of virus was demonstrated in both the 10 and 20 ft monitoring wells after 28 inches of rainfall fell over a three month period. These results indicated that reducing the ionic strength of the soil solution caused desorption and movement of viruses through the soil (48).

B. Chemical Contaminants

1. Nitrate

a. Nitrification

Nitrate (NO_3^- -N) is considered the single most important ion associated with septic tank effluent. NO_3^- -N contamination of groundwater in excess of 10 mg/L is considered toxic (Standard Methods 1989)(2), and contamination of surface waters at much lower concentrations may contribute to eutrophication of surface waters (61).

Septic tank effluent averages 40 to 80 mg N/L and is approximately 25% organic N and 75% soluble NH_4^+ -N (86). When aerobic conditions exist in soil, NH_4^+ -N is quickly biologically oxidized to NO_3^- -N. If an anaerobic environment follows, biological reduction of NO_3^- -N to N gas may result, provided a usable source of carbon exists (61).

Nitrification is the biological transformation of reduced N compounds to oxidized N compounds (1). It is generally believed that the organisms responsible for this transformation are *Nitrosomonas*, and to a lesser extent *Nitrosospira*, and *Nitrosococcus* (oxidize NH_4^+ -N ions to NO_2^- -N), and *Nitrobacter* (oxidizes NO_2^- -N ions to NO_3^- -N) (16).

The pioneering work of Winogradsky established that nitrification is typically associated with the metabolism of chemoautotrophic bacteria (78). These organisms have the capacity to utilize carbon dioxide as their sole source of carbon; the energy for cell synthesis is obtained by the first group from the oxidation of NH_4^+ -N ions, and the other by the oxidation of NO_2^- -N (1). These organisms are strict aerobes, thus making oxygen an obligate requirement (78). Nitrification is considered not to

occur in significant amounts at redox values lower than +200 mV (37). Viable counts of nitrifiers in soil range from 10^3 to 10^5 organisms/g, but much higher numbers (10^7 to 10^8 organisms/g) have been found in high NH_4^+ -N environments (37).

In OSWDS, nitrification has been reported to occur in well-aerated soils beneath the trenches of drainfield systems. Whelan (93) investigated the suitability of using calcareous sands (Xeropsamment) for treatment of septic tank effluent. Most of the NH_4^+ -N in the effluent was oxidized to NO_3^- -N in the unsaturated zone just below the slime layer. Walker, *et al.* (88) also reported that when sand was used as the medium for disposal of septic tank effluent, virtually complete nitrification of NH_4^+ -N to NO_3^- -N occurred in the unsaturated subcrust soil within 2 cm from the crust. Whelan and Barrow (92) also reported similar findings.

Butler, *et al.* (14) suggest that the organic constituents of conventional OSWDS are filtered out within the first few centimeters of soil. This retards the movement of water and results in a thin saturated zone surrounded by an unsaturated zone. If sufficient oxygen enters the unsaturated zone, the NH_4^+ -N will be oxidized to NO_3^- -N (12). Thus in OSWDS, oxygen diffusion to the treatment zone is the most rate-limiting factor in the formation of inorganic N present (68). Sikora and Corey (79) noted that coarser, strongly-aggregated soils should favor nitrification, while fine-textured, poorly aggregated soil would limit nitrification.

The moisture status of the soil has a marked influence on NO_3^- -N production because the moisture level affects the aeration regime of the soil (78). The optimum level varies with different soil, but NO_3^- -N generally appears most readily at one-half to two-third the soil moisture-holding capacity (1).

The rate of nitrification is also markedly affected by the pH and temperature in the surrounding soil (78). The rate of nitrification decreases greatly below pH 6.0 and becomes negligible below 5.0. In terms of temperature, the rate of nitrification

is very slow below 5°C and above 40°C. The optimum lies between 30°C and 35°C (1).

Under conditions where NH_4^+ -N is the dominant inorganic N form under OSWDS due to the anaerobic conditions present, the transport of NH_4^+ -N to ground water may occur (68). The movement of NH_4^+ -N is highly dependent upon the chemical and physical composition of the soil (68). Brown, *et al.* (12) reported that septic fields have the potential to saturate the available exchange sites of a sandy soil with NH_4^+ -N. After saturation, the NH_4^+ -N moves downward with the leachate water. Downward NH_4^+ -N movement was measured at 100 cm/yr in a sandy loam soil and at 25 cm/yr in a sandy clay and clay soil.

Groundwaters below OSWDS that are placed on well-drained soils where nitrification occurs immediately below the OSWDS are potentially at risk of NO_3^- -N contamination (68). Whelan (93) reported that within a calcareous sand, NO_3^- -N was present in the soil solution up to concentrations of 50 mg/L down to a depth of 8 m. Walker, *et al.* (89) estimated that 33 Kg NO_3^- -N/yr per family of four would leach into the groundwater below a sandy soil. Walker, *et al.* (89) reported sands to have NO_3^- -N concentrations greater than 10 mg/L adjacent to subsurface adsorption fields. In these well-drained systems, 0.2 ha down gradient would be needed for NO_3^- -N concentrations in the top layer of the ground water to be diluted to less than 10 mg/L. Thus in well aerated sands, the only active mechanism of lowering the NO_3^- -N concentration is by dilution.

OSWDS that utilize both aerobic and anaerobic conditions appear to have promise in dealing with the NO_3^- -N problem. Reneau (67) reported that nitrification appeared to take place between 1.5 and 5.0 m from the drainfield and was probably active at the aerobic upper portion of the saturated zone. As effluent moved toward the tile drainage system, the NO_3^- -N produced moved into the un-

derlying anaerobic zone and was denitrified. Cogger and Carlile (20) reported that effluent treatment was poorest around systems that were continuously saturated with groundwater with average levels of 7.3 mg/L NH_4^+ -N, 1.0 mg/L NO_3^- -N. Systems that were seasonally saturated generally performed better with average levels of 2.3 mg/L NH_4^+ -N, 2.0 mg/L NO_3^- -N.

b. Denitrification

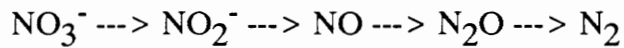
Denitrification is the biological reduction of N oxides (NO_3^- , NO_2^- , NO, N_2O) to a gaseous form of N (1). Facultative anaerobic bacteria use oxidized N compounds to replace oxygen as a terminal electron acceptor in respiration (30). The pathway of denitrification is dependent upon (29):

1. presence of bacteria possessing the metabolic capacity to denitrify,
2. readily available carbon source to act as an electron donor,
3. anaerobic conditions or limited oxygen availability, and
4. nitrogen oxides such as NO_3^- -N, NO_2^- -N, nitrogen oxide (NO), or nitrous oxide (N_2O) to serve as electron acceptors.

Nitrates can be reduced via two different pathways. Assimilatory NO_3^- -N reduction is the reduction of NO_3^- -N to the NH_4^+ -N form, which eventually is used for amino acid synthesis within the cell (1). Dissimilatory NO_3^- -N reduction is the process whereby nitrous oxides are used as electron sinks which are used as a nutrient source and subsequently released to the environment (37).

The ability of bacteria to reduce N-oxides in a dissimilatory manner is widespread among soil microbes (30). More than 40% of all soil genera contain isolates capable of reducing NO_3^- -N to NO_2^- -N, but the more significant further reductive steps leading to denitrification are restricted primarily to bacteria of the

genera *Bacillus*, *Micrococcus*, and *Pseudomonas*. It is not uncommon to find 10^5 isolates of denitrifiers/g of soil (37):



The key factor in determining whether or not denitrification will occur is the rate of oxygen diffusion. At redox levels of +200 mV, the normal utilization of oxygen as a terminal electron acceptor is inhibited, and dissimilatory NO_3^- -N reduction is activated (37). In soil environments, the water regime largely determines the redox levels, and substantial denitrification occurs in water-logged soils. Some denitrification occurs in well-drained soils because these contain water-filled anaerobic microenvironments where the diffusion of oxygen is limited (30). Nitrate losses do not usually occur at moisture levels below 60% of the water-holding capacity (1).

The rate of denitrification is also controlled largely by the pH, temperature, and type and supply of a readily available C source. Denitrification occurs rapidly if the soil pH is above 6.0 and slowly if the pH is below 5.5 (50). Bremner and Shaw (10) reported that denitrification rates increased rapidly with temperature over a 2-25°C temperature range, but proceeded at a slower rate above 25°C. Denitrification is slower in soils low in C when compared to soil rich in organic matter (1). Bremner and Shaw (9) observed that a maximal loss of N occurred when the ratio of C to N was 2:1 or 3:1. Bremner and Shaw (10) observed little or no gaseous loss of N from submerged soils containing less than 1% C. Readily decomposable compounds such as simple sugars or organic acids are oxidized quickly and are more stimulatory than higher C:N materials such as straws or grasses (10).

C. Low Pressure Distribution Systems

1. Conventional Design

In the U.S., the majority of the OSWDS are of the conventional gravity flow design. This system is composed of a septic tank, a distribution box, and a subsurface soil absorption system. The waste moves by gravity flow 1) from the house to the septic tank, 2) from the septic tank to the distribution box, and finally, 3) from the distribution box out to the laterals located throughout the soil absorption system (68).

The septic tank is an anaerobic system composed of a number of facultative bacteria whose primary function is the hydrolysis of complex proteins, carbohydrates, and fats. Approximately 80% of the suspended solid reduction can be attributed to hydrolysis by bacteria and the settling of solids. Coliform bacteria and enteric virus counts still remain very high and rely on the soil absorption phase to reduce their levels (98).

On-site wastewater systems can provide effective treatment where there are soils of sufficient depth and permeability. Soils that are considered suitable for the installation of a conventional on-site system should have a percolation rate no faster than 0.04 min/cm and no slower than 24 min/cm. Also, there must be no seasonal high water table or other barrier closer than 0.9 m to the bottom of the treatment system (40). Unfortunately, as much as half of the soils in many areas of the U.S. are not suited for the installation of a conventional gravity fed soil absorption system (73).

The problem of poorly functioning gravity on-site systems is widespread. It is estimated that of the homes presently served by conventional OSWDS, half will not

function satisfactorily over their 15-20-year design (73). The high failure rate is a result of the placement of these systems on steep slopes, in soils with restrictive horizons, stoniness, and shallowness to bedrock associated with landscapes which are aesthetically and/or economically pleasing for development (81).

A large percentage of failures can be attributed to the smearing of trench bottoms and sides during construction. If the infiltrative surface is smeared or compacted, thus eliminating the larger pores, the infiltration rate of the effluent into the soil will be reduced by several orders of magnitude (3).

Healy and Laak (43) estimated that 75% of all on-site systems failed due to hydraulic overloading. Nonuniform distribution resulting from unequal dispersal from the distribution box results in localized overloading over the entire length of the absorption area. This localized overloading results in small areas receiving a continuous trickle of effluent. Eventually biological clogging occurs and reduces the infiltration rate at that point, forcing the effluent to travel along the bottom of the absorption area until it reaches an unclogged area. This phenomenon is classically termed "creeping failure" (59). This continues until the entire bottom area is clogged and hydraulic failure occurs.

Many systems fail due to the development of hydraulically restrictive layers. Bouma (8) showed that a clogging layer, formed from the accumulation of metabolic products of soil bacteria and to a lesser degree suspended solids, inevitably forms in most on-site absorption fields. This clogging layer forms at the soil-gravel interface and extends into the soil an average depth of 2-cm. Some degree of clogging can enhance wastewater renovation by producing an unsaturated flow regime below the clogged layer (79). As a result, the effluent moves slowly through this zone, providing additional time for physical and biochemical reactions to provide treatment (86). But excessive clogging can reduce the liquid infiltration

rate to a point where hydraulic failure of the system occurs (60).

2. Low Pressure Design

In response to the demand for an environmentally acceptable and economical means of disposing of domestic wastewaters, on-site alternatives to the conventional soil absorption system have evolved (41). The LPD system was designed and developed in North Carolina in response to intense land development in areas not suited for the conventional gravity system. The LPD attempts to overcome soil conditions too restrictive for the conventional system by incorporating pressure-dosed distribution, shallow placement, and narrow trenches (19). Since 1977, North Carolina has installed more than 2000 LPD systems (17).

The LPD system is composed of a septic tank, pump chamber, and a pressure distribution network. The domestic tank effluent flows by gravity into a pump chamber where a submersible pump conveys the effluent to the trenches one or two times a day. The trenches are typically 15-45 cm deep, which allows the effluent to be introduced into the best aerated, most permeable, and most biologically active soil horizons. It also provides the maximum separation distance to restrictive soil conditions (19).

The pressure distribution network overcomes hydraulic failures typical of poorly functional conventional systems by distributing effluent equally to all parts of the absorption system (19). Even more importantly, it provides a dosing and resting regime which is likely as important as uniform distribution in retarding clogging and increasing field longevity (60).

Since clogging occurs mainly under anaerobic conditions (44), dosing periodically

will allow the infiltrative surface to be exposed to air between doses (7). This "resting" phase allows the soil to drain and reaerate, thus encouraging rapid degradation of the clogging mat. This will extend the life of the absorption system by keeping the clogging mat resistance to a minimum (60).

The LPD system was designed to overcome several soil and site limitations that prohibit the successful operation of a conventional gravity-fed soil absorption system. These conditions are (17):

- 1) seasonally shallow or perched groundwater,
- 2) restrictive horizons at shallow depths (*i.e.*, clayey subsoils or bedrock),
- 3) rapidly permeable sands, and
- 4) steeply sloped sites.

Stewart and Reneau (84) studied the performance of a shallowly-placed low pressure OSWDS in a Typic Ochraquult with a fluctuating high water table. In spite of large numbers of fecal coliforms present in the septic tank effluent (44,700 MPN /L), few coliforms were present at 1.5 m below the OSWDS. They attributed this decline to uniform septic tank effluent distribution, placement of the OSWDS in the more biologically active and aerobic soil horizons, and the maximization of unsaturated flow.

In terms of nitrogen removal, Stewart and Reneau (84) also reported large accumulations of NO_3^- -N beneath the OSWDS in the aerobic zone, and limited vertical and horizontal movement was observed. The limited movement was attributed to denitrification, which was apparently active during periods of high water table levels. The energy source for denitrification, they proposed, came from a combination of soil organic matter, fresh carbon sources supplied by the grass cover, and carbon present in the septic tank effluent.

Cogger and Carlile (20) conducted an 18 month field evaluation of 15 conventional and alternative LPD systems in soils with high water tables. Comparison of the LPD systems and the continuously saturated conventional systems suggests that improved treatment can be provided by the LPD under high water table conditions. At a distance of 1.5 m from the systems, the nitrogen composition below the conventional system was NH_4^+ -N 10.3 mg/L and NO_3^- -N 1.3 mg/L, while for the LPD system the nitrogen levels were reported as NH_4^+ -N 3.4 mg/L and NO_3^- -N 2.0 mg/L. In addition, the median fecal coliform counts were higher around the conventional gravity-fed system when compared with the LPD systems (1300 MPN/L vs 560 MPN/L).

Yahner, *et al.* (94) provide a summary of a five year monitoring effort on alternative systems in Indiana. Thirteen LPD systems with shallow trench depths were installed to overcome soil and site limitations for a conventional system. Soil limitations were: 1) the presence of dense, compacted loam or clayey loam glacial till or fragipan (Bx) horizon above 914 mm, 2) seasonal high water tables, perched above the compact, dense limiting layers, and 3) slow permeability in the subsoil B horizon. All of the systems performed successfully, that is, there was no interruption to sewage flow from the home, no effluent surfaced within the system, and there was no consistent passage of untreated effluent into any of the system monitoring wells.

Chapter III

MATERIALS AND METHODS

A. Low Pressure Distribution Systems

One experimental low pressure distribution (LPD) system was installed in Rockingham Co. on an Edom (fine, illitic, mesic Typic Hapludult) soil, and a second in Prince William Co., Va. on a Penn-Bucks (fine-loamy, mixed, mesic ultic Hapludult) soil considered to be marginally suited for a conventional gravity-fed OSWDS. Soil descriptions for the Rockingham Co. site can be found in Table 1. Soil descriptions for the Prince William Co. site can be found in Tables 2, 3.

In LPD systems, the household effluent is first treated in a conventional septic tank, after which the clarified effluent flows by gravity to a pump chamber. The pump chamber contains a submersible pump which is preset to deliver a specified volume of effluent to the laterals within the distribution system. The equalization of flow across the entire distribution system is assured by pressurized distribution. Flow is equalized by accounting for differences in the elevation and the frictional headloss between the laterals, and adjusting the number and size of the distribution holes so that each lateral discharges an equal volume of effluent per unit of lateral length. This pressurized system also allows for a dosing and resting phase to occur.

Presently in Virginia, the trenches of LPD systems must be installed at least 45 cm deep. The two experimental LPD systems focus on the suitability of installing the trenches at a maximum of 30 cm deep in the most biologically active upper soil horizon. The trenches were placed on the contour, and the laterals were placed

Table 1. Profile description for the Edom soil located in Rockingham Co., Va. for all four subsystems.

0-10 cm, loamy fill material located over the experimental systems.

Ap 10-35 cm, dark brown (10YR 4/3) to a dark yellowish-brown (10 YR 4/4) silt loam; weak, very fine granular structure; very friable (moist).

B1t 35-56 cm, yellowish-red (5YR 5/6) silty clay loam; moderate medium subangular block structure; firm; few oxide concretions.

B2t 56-91 cm, yellowish-red (5YR 5/6) clay; common brownish-yellow (10YR 6/8) mottles; strong medium subangular blocky; firm; few fine oxide stains and concretions.

B3 91-119 cm, red (2.5YR 5/6); yellowish-red (5YR 5/6), brownish-yellow (10YR 6/8) clay; moderate fine subangular blocky structure; many oxide concretions and stains.

C 119-175 cm, yellowish-red (5YR 5/6) brownish-yellow (10YR 6/6), and yellow (10YR 7/6) silty clay with strongly weathered shale fragments; many oxide stains and concretions; at deeper depths, common light brownish-gray (10YR 6/2) mottles. Solumn depth varied from 90 to 120 cm. Depth to bedrock varied from 120 cm to greater than 175 cm.

Table 2. Profile description for the Penn-Bucks soil located in Prince William Co. for Subsystems 1 and 2.

0-10 cm, fill material over the experimental systems.

Ap 10-22 cm, dark reddish-brown (5YR 3/4) silt loam; weak, fine and medium, granular structure; friable, slightly sticky and slightly plastic; few shale fragments.

B2t 22-48 cm, reddish-brown (2.5YR 5/4) to red (2.5 YR 4/6) silty clay loam; fine and medium subangular blocky structure; slightly sticky and slightly plastic; large percentage of shale fragments present.

C 48-73 cm, dark reddish brown (2.5YR 3/4) very shaley silty clay; massive; firm, slightly sticky and slightly plastic. Large percentage of shale fragments present; with some oxide coatings.

Cr 73 cm, Triassic shale.

Texture in the B horizon ranged from silty clay loam to silty clay. Depth to hard rock varied from 50 to 90 cm at this site. A saturated zone was common in the lower part of the Bt horizon. Also some light gray (7.5YR 7/0) coating present on some of the shale fragments in the C horizon. Also some oxide coating present on the shale fragments.

Table 3. Profile description for the Penn-Bucks soil located in Prince William Co. for Subsystem 3 and the reserve.

0-10 cm, fill material over the experimental system.

Ap 10-20 cm, dark reddish-brown (5YR 3/4) silt loam; weak, fine and medium, granular structure; friable, slightly sticky and slightly plastic; few shale fragments.

B2t 20-40 cm, dark reddish-brown (2.5YR 3/4) to reddish-brown (2.5YR 4/4) silty clay loam; fine and medium subangular blocky structure; slightly sticky and slightly plastic.

C 40-56 cm, reddish-brown (2.5YR 4/4) and yellowish loam (10YR 5/4) very shaley silty loam; massive; firm, slightly sticky and slightly plastic; large percentage of shale fragments present.

Cr 57 cm, Triassic shale.

Depth to bedrock varied from 60 to 90 cm at the site.

level in the trenches to assure an even distribution of effluent. All laterals were underlain with 15.2 cm of gravel, with 5.1 cm of gravel covering the laterals. The gravel was covered by mirafi cloth and then backfilled with 15 cm of fill material. The systems were then graded to a slightly convex shape in order to aid in surface water runoff.

On the site chosen in the Edom soil for the installation of the shallow-placed LPD system, the soil percolation rate was estimated at 47.2 min/cm, and the site was restricted by low soil hydraulic conductivity (Table 4). The shallow-placed LPD system was installed with four different subsystem designs, each receiving a different loading rate. Subsystem 1 was installed according to Cogger, *et al.* (19) with an effective trench bottom design loading rate of 17.5 Lpd/m². These trenches were prepared using a trenching machine and have a trench width of 20.3 cm with a center to center spacing of 1.5 m. Subsystem 2 was installed according to Virginia State regulations (21) with a trench bottom design loading rate of 9.0 Lpd/m². These trenches were prepared using a backhoe and have a trench width of 0.6 m with a center to center spacing of 1.8 m. Subsystem 3 and Subsystem 4 were multiples of the Virginia State rate and have a trench bottom design loading rate of 4.5 Lpd/m² and 5.70 Lpd/m², respectively. These trenches were also prepared using a backhoe and have a trench width of 0.6 m with a center to center spacing of 1.8 m (Table 5 and Appendix A).

The site chosen in Penn-Bucks soil for the installation of the shallow-placed LPD system had an estimated percolation rate of 35.4 min/cm (Table 4). The shallow-placed LPD system was installed with three different subsystem designs. Each subsystem received a different loading rate. Subsystem 1 was installed according to Virginia State regulations (21) with an effective trench bottom design loading rate of 14.3 Lpd/m². These trenches were prepared using a backhoe and have a trench

Table 4. Site descriptions for Rockingham Co. and Prince William Co. Va.

County	Soil Type	Soil Restrictions	Perc. Rate (min/cm)
Rockingham	Edom	low hydraulic conductivity	47.2
Pr. William	Penn-Bucks	shallow depth to bedrock: low hydraulic conductivity	35.4

Table 5. The actual loading rates and the design loading rates for all subsystems in both the Edom and Penn-Bucks soils.

Soil Type	Design Flow (Lpd)	Actual Flow (Lpd)	Subsystem	Design Loading Rate (Lpd/m ²)	Actual Loading Rate (Lpd/m ²)
Edom	1135.6	427.0	1	17.5	6.5
			2	9.0	5.3
			3	4.5	1.6
			4	5.7	2.0
Penn-Bucks	1135.6	632.2	1	14.3	7.7
			2	30.6	16.7
			3	7.3	4.1

width of 0.6 m with a center to center spacing of 1.8 m. Subsystem 2 was installed according to Cogger, *et al.* (19), with an effective trench bottom design loading rate of 30.6 Lpd/m². These trenches were prepared using a trenching machine and have a trench width of 20.3 cm with a center to center spacing of 1.5 m. Subsystem 3 was a multiple of the Virginia State regulation with an effective trench bottom design loading rate of 7.3 Lpd/m². These trenches were prepared with a backhoe and have a trench width of 0.6 m with a center to center spacing of 1.8 m (Table 5 and Appendix A).

The following monitoring equipment was installed at each location on all subsystems:

1. Sampling wells: 3.2 to 5.1 cm schedule 40 Polyvinyl chloride pipe (PVC) pipe with a cap covering the bottom end. A series of 0.6 cm holes were placed around the pipe 15.2 cm from the cap. Screen mesh (fiberglass screening, standard size) was placed over the holes to inhibit soil from entering the well. At the Rockingham Co. site, the wells were placed at 30.5, 45.7, and 152.4 cm below trench bottom. At the Prince William Co. site the wells were placed at various depths below the trench bottom. Water samples were collected from these wells by applying a vacuum to a sample bottle with a bilge pump.
2. Solution samplers: 5.1 cm Fasco tubing was fitted with a 100 kPa high flow ceramic cup (2.5 μ m pore size) fitted to the bottom end of the pipe. At the Rockingham Co. site, the solution samplers were placed at 30.5, 45.7 cm below trench bottom. At the Prince William Co. site, the solution samples were placed at 15.2 and 30.5 cm below trench bottom. Water samples were collected from these solution samplers by applying a vacuum to a sample bottle with a bilge pump.
3. Tensiometers: 1.3 cm Schedule 40 Electrical Conduit PVC pipe was fitted with a

100 kPa standard ceramic cup (2.1 μm pore size) to the bottom end of the pipe. The tensiometers were filled with a 50/50 water - ethylene-glycol solution mixture, and a rubber septum was placed at the top of the pipe. At both the Edom and Penn-Bucks soil sites, the tensiometers were placed at 15.2 and 30.5 cm below trench bottom. Soil matric potentials were determined with a tensiometer.

4. Soil access wells: 15.2 cm thin wall PVC pipe set at the trench bottom level. Soil samples were obtained from the soil access wells.
5. Stage recorders: The recorders charted water levels within the trenches. Diagrams of the monitoring equipment in each subsystem can be found in Appendix B.

B. Soil Physical Properties

Particle size analysis, following the procedure outlined by Day (25), and hydraulic conductivities, following the procedure of Klute (46), as well as bulk density values (Tables 6, 7) were determined for soil samples collected from the site chosen for the installation of the LPD system in Edom and Penn-Bucks soils.

Table 6. Particle size analysis, bulk density, and hydraulic conductivities determined for the Edom soil site.

Subsystem	Depth (cm)	Particle Size Analysis sand silt clay %	Bulk Density (g/cm ³)	Hydraulic Conductivity value (cm/hr)	Hydraulic Conductivity rating
1	10-20	4 71 25	76.1	1.5	v. rapid
	21-38	ND 63 37	6.1	1.2	moderate
	39-74	ND 54 46	5.0	1.5	moderate
	75-116	10 40 50	7.2	1.6	m. rapid
	117-140	8 24 68	0.1	1.7	v. slow
140-191	ND 43 57	-	-	-	
2	15-33	8 70 22	4.0	1.4	moderate
	34-46	8 67 25	1.5	1.6	m. slow
	47-61	ND 48 52	4.3	1.6	moderate
	62-91	ND 39 61	2.5	1.7	moderate
	92-122	ND 38 62	2.2	1.5	m. slow
	122-142	ND 53 47	1.1	1.5	moderate
3	10-35	17 58 25	1.9	1.3	v. rapid
	35-56	ND 62 38	1.8	1.4	m. slow
	56-91	ND 34 66	2.4	1.5	moderate
	91-119	ND 34 66	0.9	1.6	m. slow
	119-175	2 45 53	2.4	1.6	moderate

Table 7. Particle size analysis, bulk density, and hydraulic conductivities determined for the Penn-Bucks soil site.

Subsystem	Depth (cm)	Particle Size Analysis % sand silt clay			Bulk Density (g/cm ³)	Hydraulic Conductivity value (cm/hr)	Conductivity rating
1	5-20	20	53	27	1.4	71.6	v. rapid
	21-48	14	51	35	1.6	6.8	m. rapid
	49-74	24	41	35	1.5	14.8	rapid
2	10-23	18	58	24	1.5	10.8	m. rapid
	24-48	46	31	23	1.6	1.6	m. slow
	49-74	16	58	26	1.6	1.4	m. slow
3	10-22	44	44	12	1.4	10.4	v. rapid
	22-48	25	53	22	1.5	2.1	moderate
	48-73	44	43	13	1.4	2.6	moderate

C. Microbial Tracer Studies

1. Bacterial Preparation

a. Summer 1989

Spontaneously-resistant mutants of an *Escherichia coli* strain (American Type Culture Collection ATCC, 25922) were selected with the gradient plate procedure (56), for resistance to 100 $\mu\text{g}/\text{ml}$ Spectinomycin and 100 $\mu\text{g}/\text{ml}$ Sodium Azide (Sigma Chemical Co., St. Louis, Mo). The strain was inoculated into 250 ml Erlenmyer flasks containing 100 ml Trypticase Soy Broth (Difco Laboratories, Detroit, MI) and incubated for 24 hrs at 37^oC. This 24-hr-old culture was transferred to 4 L Erlenmyer flasks containing 3 L of Nutrient Broth (BBL Micro. Systems, MD) and incubated for 12 hr at 30^oC. The 12-hr-old culture was transferred to 3 L polypropylene containers, placed on ice in Lifoam 24.6 L coolers, and transported to the field.

Population counts of the *E. coli* culture were determined by serial diluting 10 ml of the culture into 90 ml bottles of Proteose Peptone, and plating 0.1 ml onto Eosin Methylene Blue agar (Difco Laboratories, Detroit, MI) amended with 100 $\mu\text{g}/\text{ml}$ Spectinomycin and 100 $\mu\text{g}/\text{ml}$ Sodium Azide. The plates were incubated for 24 hr at 37^oC, after which colonies were counted. The population of the *E. coli* culture used was 7.8×10^6 colony forming unit (cfu) per milliliter.

b) Winter 1990

An *Escherichia coli* strain was isolated from a pump chamber effluent sample by plating the effluent on Eosin Methylene Blue agar and isolating a colony which produced the characteristic green sheen only produced by *E. coli* on this medium.

Spontaneously-resistant mutants of this *E. coli* strain were selected with the gradient plate procedure (56), for resistance to 100 $\mu\text{g}/\text{ml}$ Nalidixic Acid and 100 $\mu\text{g}/\text{ml}$ Sodium Azide (Sigma Chemical Co., St. Louis, Mo) was determined. The strain was inoculated into 250 ml Erlenmyer flasks containing 100 ml of Trypticase Soy Broth and incubated for 24 hr at 37°C. This 24 hr old culture was transferred to 4 L Erlenmyer flasks containing 3 L of Nutrient Broth and incubated for 12 hr at 30°C. The 12 hr old culture was transferred to 3 L polypropylene containers, placed on ice in Lifoam 24.6 L coolers and transported to the field.

Population counts of the *E. coli* culture was determined by serial diluting 10 ml of the culture into 90 ml bottles of Proteose Peptone, and plating 0.1 ml onto Eosin Methylene Blue agar amended with 100 $\mu\text{g}/\text{ml}$ Nalidixic Acid and 100 $\mu\text{g}/\text{ml}$ Sodium Azide. The plates were incubated for 24 hr at 37°C, after which colonies were counted. The population of the *E. coli* culture used was 2.0×10^7 cfu/ml.

2. Viral Preparation

a) Summer 1989

A phage stock of *Escherichia coli* strain f2 (ATCC 15766-B1) was prepared by inoculating 100 ml of Trypticase Soy Broth with 1 ml of the host *E. coli* (ATCC 12435) strain and incubated at 37°C. Once the culture was in the actively multiplying stage (approx. 2 hr), 0.1 ml of the bacteriophage strain f2 was added, and the culture was incubated at 37°C for 18 hr.

A 100 ml, 12 hr old, *E. coli* host (ATCC 12435) culture was transferred to 4 L Erlenmyer flasks containing 3 L of Nutrient Broth. The flasks were incubated at 30°C for 2 hr in order to allow the culture to enter an actively growing stage. Fifteen milliliters of the bacteriophage f2 stock culture was added per 4 L flasks and incubated at 30°C for 12 hr. The phage was transferred to 3 L polypropylene containers, placed on ice in Lifoam 24.6 L coolers, and transported to the field.

Populations counts of the bacteriophage culture were made by serial diluting 10 ml of culture into 90 ml bottles of Proteose Peptone. A plaque assay was done by placing 50 ml of the diluted culture into 50 ml of a 50°C solution of double-strength Trypticase Soy Agar along with 3 ml of a 2-hr-old *E. coli* host (ATCC 12435) culture. The mixture was swirled and evenly distributed into 3 petri plates (100 x 15mm - Baxter Healthcare Corp., McGaw Park, IL). The plates were incubated at 37°C for 24 hr, after which the plaques formed by the bacteriophage were counted. The initial bacteriophage f2 population was determined to be 1.0×10^4 plaque forming units (pfu) per milliliter.

b) Winter 1990

An *Escherichia coli* bacteriophage T-1 (Biology Dept., VPI&SU) stock was prepared by inoculating 1.5 ml of a 12-hr-old culture of the host *Escherichia coli* Strain B (Biology Dept., VPI&SU) into 150 ml of Trypticase Soy Broth. The culture was incubated at 37°C with shaking at 250 oscillations per minute for 2 hr. One and a half milliliters of a previously prepared phage stock of phage T-1 (1.0×10^6 pfu/ml) was added and incubated on a shaker at 150 oscillations per minute for 12 hr.

Thirty milliliters of a 12-hr-old host culture of *E. coli* Strain B was inoculated in a 4 L flask of Nutrient Broth and incubated at 30°C for 2.5 hr in order to allow the culture to enter an actively growing stage. Twenty-five milliliters of the T-1 phage stock was added per flask, and the flasks were incubated at 30°C for 12 hr. The bacteriophage culture was placed in 3 L polypropylene containers, and transported to the field on ice in Lifoam 24.6 L coolers.

Population counts of the bacteriophage T-1 culture were determined by serial diluting 10 ml of the culture into 90 ml bottles of Proteose Peptone. A plaque assay was done by placing 50 ml of the diluted culture into a 50°C solution of double-strength Trypticase Soy Agar along with 3 ml of a 2-hr-old host *E. coli* Strain B culture. The mixture was swirled and evenly divided into three petri plates and incubated at 37°C for 4-6 hr. The plaques formed by the bacteriophage were counted. The initial population was determined to be 1.0×10^7 pfu/ml.

3. Field Study

The LPD systems were shut off two to three days in advance of introduction of the biological tracers, in order to allow the pump chamber to fill with a sufficient volume of effluent. The effluent then became the medium whereby the tracer microorganisms would be added to the systems.

Six liters of each bacterial and viral tracer strain were poured into the pump chamber at both the Rockingham Co. and Prince William Co. locations. Thirty minutes was allocated for the thorough mixing of the organisms in the pump chamber during which time the sampling wells at each location were evacuated.

The systems were turned on manually and allowed to dose until the effluent level in the pump chamber was just above the 'low-water' float. Thus approximately 2271 L of effluent were pumped from the chamber at Rockingham Co., and 1268 L at Prince William Co. The system did not dose again during the entire tracer study.

Water samples were collected by applying a vacuum to a 250 ml polypropylene bottle with the use of a bilge pump from every sampling well at 24, 48, and 72 hrs after the initial dosing of the bacterial and viral tracers (only at Rockingham Co. were water samples taken at 816 hr). All sampling wells were pumped dry after each sampling period. The samples were placed on ice in Lifoam 24.6 L coolers and transported back to the lab (VPI&SU) and analysed within 48 hr.

4. Tracer Detection

a) Bacterial Tracer

Fifty milliliters of a clean water sample was millipore filtered (Cellulosic, White Grid, 0.45 Micron, 47mm) with the aid of a prefilter. The filter was placed on 100 mm Eosin Methylene Blue agar petri plates (50 x 9mm -Falcon HAWG-04750) amended with the appropriate strength of antibiotics. The plates were incubated at 37°C for 24 hr, after which colony counts of the antibiotic-resistant *E. coli* were recorded Fig. 1.

For water samples containing dispersed materials, a most-probable-number (MPN) procedure was used from Hartel and Hagedorn (42). Ninety-six well (12 row) microtiter plates (Falcon 3072) were inoculated with a solution of double-strength lactose broth (Difco Laboratories, Detroit MI), 0.04% Bromthymol Blue (Sigma Chemical Co., St. Louis Mo), and 20 µg/ml of each of the appropriate antibiotics. A 50-200 µl, eight channel micropipette (VWR Scientific, Bridgeport NJ) delivered 50 µl of lactose broth solution to the first row of wells and 200 µl of solution to the remaining 11 rows.

The micropipette discharged 50 µl of water sample into the first row of wells, producing a 1:1 dilution. All subsequent dilutions were 1:5. The last row of wells was uninoculated with sample and used as a control.

The plates were incubated at 37°C for 48 hr, after which the yellow positive wells were counted and converted to MPN values by using the three-column MPN code of Rowe, *et al.* (71) Fig. 2.

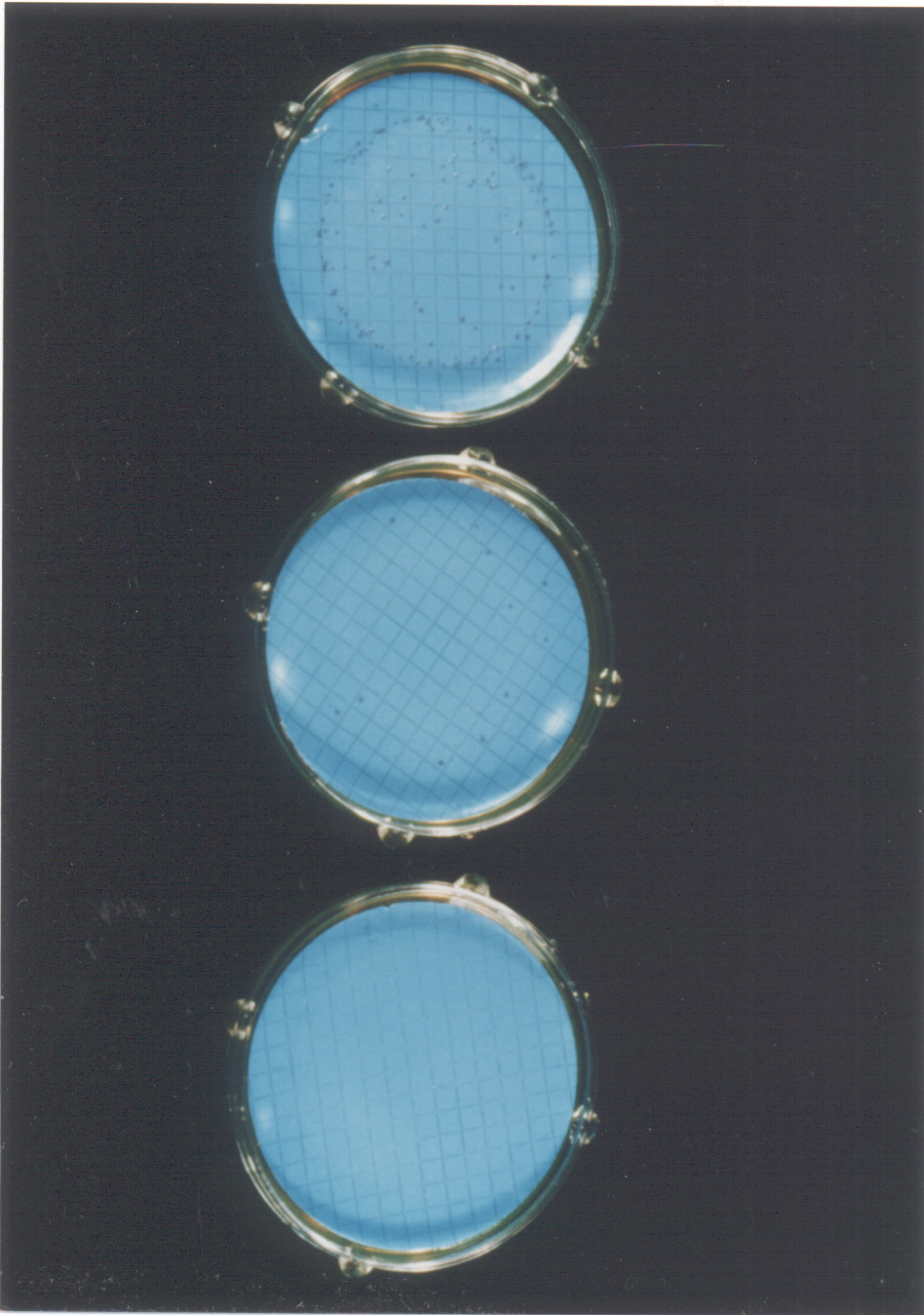


Fig. 1. The recovery technique used to isolate the bacterial tracer from water samples collected during the summer, 1989, and winter, 1990.

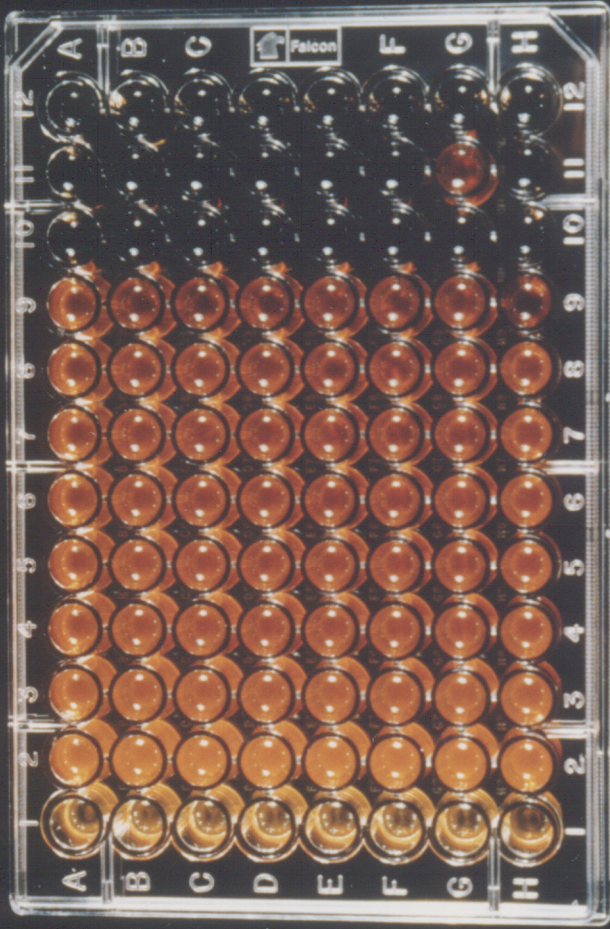


Fig. 2. The 96-well-microtiter plate technique used in the recovery of the bacterial tracer from dirty water samples in the summer, 1989, and winter, 1990.

b) Viral Tracer

A 50 ml water sample was millipore filtered (Cellulosic, White Grid, 0.45 Micron, 47mm) with the aid of a prefilter. This surface sterilized water sample was added to 50 ml of a 50°C double-strength Trypticase Soy Agar solution. Three milliliters of a 2-4-hour-old host culture of *E. coli* was added. The mixture was swirled and poured evenly into three petri plates (100 x 15mm - Falcon) and incubated for 6-24 hr (depending on the bacteriophage strain used) at 37°C. Plaques formed by the bacteriophage were then counted Fig. 3.

5. Bacterial and Viral Analyses

The bacterial and viral counts were organized into designated categories for each season, soil, subsystem, time, and depth on the advice of a statistics consultant (VPI&SU). The categories are based on a 50 ml water sample. The categories are as follows: 1; 0 cfu 2; 1-50 cfu 3; 51-100 cfu 4; > 101 cfu for bacteria and 1; 0 pfu 2; 1-50 pfu 3; 51-100 pfu 4; 101-1000 pfu 5; 1001-10000 pfu 6; > 10000 pfu for viral counts.

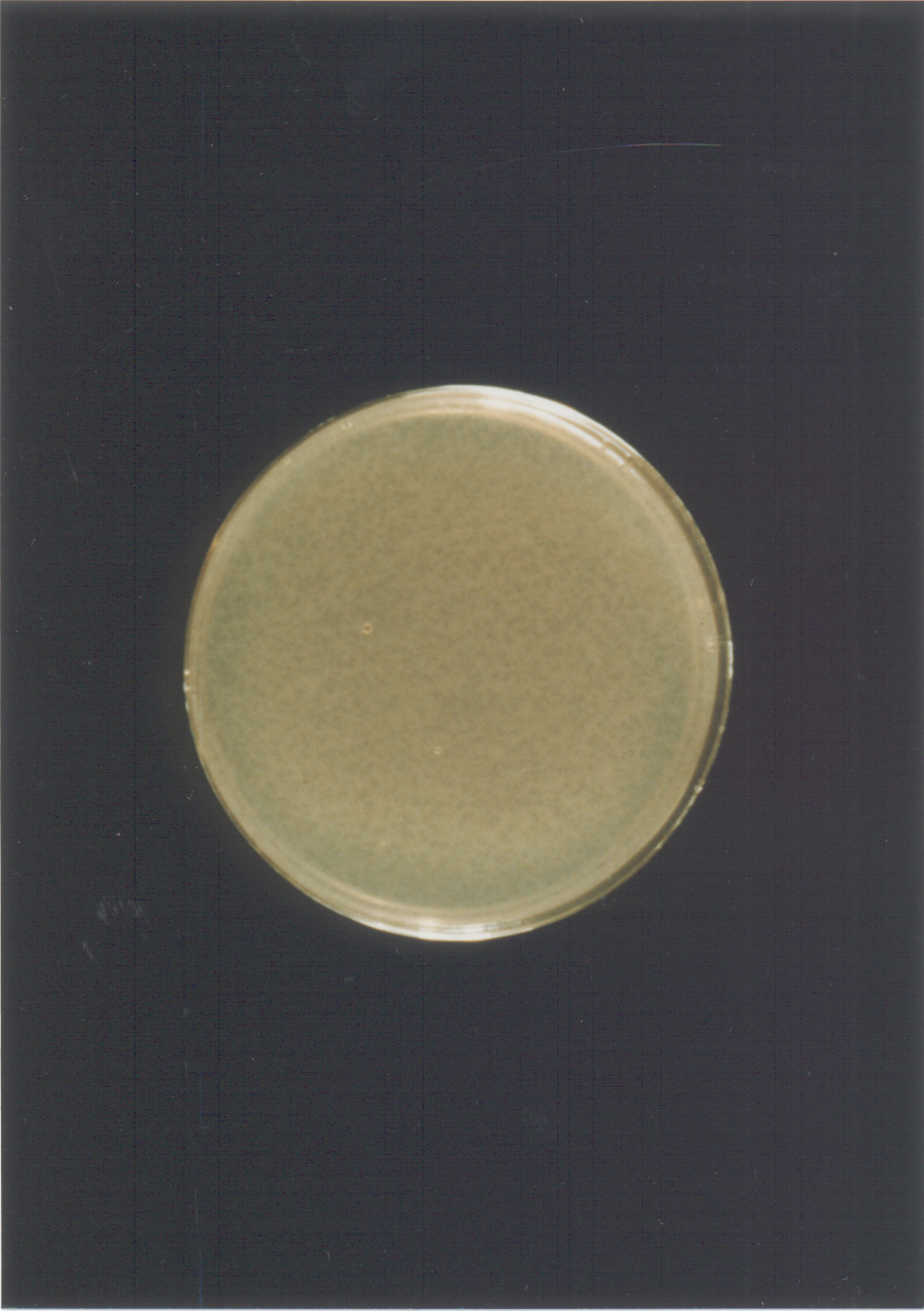


Fig. 3. The plaque assay used in the recovery of the viral tracer from water samples collected during the summer, 1989, and winter, 1990.

D. Denitrification Studies

The denitrification studies are based on the acetylene blocking technique (85). Acetylene blocks the final transformation of N_2O to N_2 by inhibiting the enzyme nitrous oxide reductase. This procedure will provide an estimate of the actual field denitrification rates. This study will also investigate if the samples are carbon or nitrogen limited (85).

For both the summer and winter studies, two 30.5 cm soil cores were taken from two soil access wells per subsystem from both the Edom and Penn-Bucks soils. Samples were obtained using a 2.5 cm sampling probe sampler fitted with a 2.5 cm acrylic tube insert. The samples were placed on ice in Lifoam 24.6 L coolers and transported back to the lab (VPI&SU). The denitrification study was initiated within 12 hr of the sample collection.

The two soil cores from each of the wells were split into 0-15.2 cm and 15.2-30.5 cm segments, and placed in 710 ml whirl-pak bags (VWR Scientific, Bridgeport NJ) and mixed thoroughly. Percent moisture was determined for each sample by weighing 5 g samples of moist soil into aluminum weighing dishes and drying at $105^{\circ}C$ for 24 hr. Dry weights were obtained once dried.

Two treatments were used in the denitrification study:

1. 0: no amendment.
2. Glucose: 2.0 ml of glucose added from a 1.4 M $C_6H_{12}O_6$ stock solution.

Ten grams of soil were placed in 125 ml Erlenmeyer flasks per treatment. Each treatment was replicated three times.

An air-tight rubber septum was inserted into the neck of each flask. The flask was flushed with helium gas (He) for 1 min at a flow rate of > 10 L/min in order to create an anaerobic environment, while equalizing the pressure in order to keep the

flask at atmospheric pressure. Ten milliliters of gas were removed and replaced with 10 ml of acetylene gas ($\text{CH}\equiv\text{CH}$). The flasks were incubated at 20°C for approximately 48 hr. One-half milliliter gas samples were removed from each flask and analyzed for the presence of nitrous oxide (N_2O) at approximately 7, 24, and 48 hrs. The analysis was made on a Varian 3700 Gas Chromatograph equipped with an electron capture detector. A glass 2.0 m column pre-packed with Porapak-Q was used with an inlet temperature of 60°C , a column/oven temperature of 50°C , and a detector temperature of 350°C . Argon gas (Ag) with 10% methane was used as the carrier. The peaks were integrated using a 3390A Hewlett Packard Integrator. Good separation of the N_2O peak had been observed under these conditions with a retention time of approximately 1.3 minutes.

The N_2O produced was determined on a μg of $\text{N}_2\text{O}/\text{g}$ of dry soil basis by accounting for the N_2O dissolved in water using the equation of Tiedje (85). The data was corrected for unequal variances using a Variance Stabilizing Model (Statistics Dept., VPI&SU). This model determined that a log transformation raised to the power 0.2 was needed in order to stabilize the variances.

Analysis of variance (ANOVA) was performed on N_2O produced by season, soil, subsystem, depth, and time using the General Linear Models (GLM) procedure of SAS (SAS Institute, 1982) (72). Mean separations between treatments were performed by Duncan's Multiple Range Test (SAS Institute Staff, 1982) when the overall F-test was significant at $P < 0.05$.

E. Chemical Analyses

Groundwater and pump chamber samples were collected monthly by applying a vacuum to a sample bottle using a bilge pump. The samples were transported back in 250 ml polypropylene acid washed bottles on ice in Lifoam 24.6 L coolers. NO_3^- -N, NH_4^+ -N, TKN, and Cl^- determinations were made within 48 hours after sampling.

The effluent samples were filtered (0.45 μm pore size) with the use of a prefilter. NO_3^- -N, NH_4^+ -N, and TKN determinations were performed on an Orion continuous-flow autoanalysis colorimeter AC 100 equipped with Orion Autoanalysis Pump AP-200, analytical cartridge, and an Orion Scientific AR 200 plotter. Cl^- determinations were made using the coulometric titration procedure on a Haakebuchler Digital Chloridometer.

NO_3^- -N, NH_4^+ -N, TKN, and Cl^- values were obtained on a $\mu\text{g}/\text{ml}$ basis. The NO_3^- -N, NH_4^+ -N, TKN, and Cl^- values were statistically analyzed using SAS (SAS Institute Staff, 1982) (72) from which means were generated by soil, subsystem, and depth.

F. Soil Matric Potentials

Monthly soil matric potentials (ψ_m) were determined at both sites on a monthly basis.

The soil ψ_m determinations were divided into two seasons: 1) Summer 1989, which included the months of May, June, August, and September, and 2) Winter 1990, which included the months of November, January, February, and March.

The matric potentials were statistically analysed using SAS (SAS Institute Staff, 1982) (72) from which means were generated by season, soil, subsystem, and depth.

RESULTS AND DISCUSSION

A. Hydraulic Performance

Hydraulic failure of a OSWDS results from the inability of the system to accept the daily sewage flow, it is most commonly identified by ponding of partially-treated effluent on the soil surface (3). Hydraulic overloading may result from saturated conditions below the disposal field or development of a slowly permeable clogging mat that reduces the infiltrative capacity of the soil. Under saturated conditions, effluent can move rapidly through macropores and escape treatment due to inadequate effluent-soil contact time. Cogger and Carlile (20) reported that effluent treatment was poorest around systems that were continuously saturated.

In the Edom soil, the narrow trench design (19), the Virginia State regulation design (21), and the multiples of the Virginia State regulation design all functioned satisfactorily with respect to hydraulic performance. Moist, unsaturated conditions were present beneath the four subsystems, with an average ψ_m of -54 and -68 kPa in the summer and winter, respectively. As expected, even drier conditions were present between the trenches, with an average ψ_m of -74 kPa and -98 kPa in the summer and winter, respectively, for all the subsystems (Tables 8, 9).

Satisfactory performance was especially evident during the winter months when the soil moisture was expected to approach saturation, thereby making effluent disposal from each subsystem more difficult. The ψ_m values indicated that the soil beneath and between the trenches of the four subsystems remained similar to those

Table 8. Soil matric potentials determined for the Edom soil, below and between the trenches of all four subsystems in the summer, 1989[#].

Subsystem	Loading rate (Lpd/m ²)	Depth below trench (cm)	Mean Pressurehead (kPa)	
			Below	Between
1	17.5	15.2	-65.9	--
		30.5	-65.3	-91.2
		45.7	-67.3	-69.8
2	9.0	15.2	-52.0	--
		30.5	-68.2	-65.5
		45.7	-67.0	-78.7
3	4.5	15.2	-38.1	-14.5
		30.5	-40.5	--
		45.7	-49.0	-95.9
4	5.7	15.2	-49.9	--
		30.5	-50.1	-99.3
		45.5	-37.4	-80.7

[#] May, June, July, and September.

Table 9. Soil matric potentials determined for the Edom soil, below and between the trenches of all four subsystems in the winter, 1990[#].

Subsystem	Loading rate (Lpd/m ²)	Depth below trench (cm)	Mean Pressurehead (kPa)	
			Below	Between
1	17.5	15.2	-66.8	--
		30.5	-76.2	-104.6
		45.7	-44.8	-105.6
2	9.0	15.2	-64.9	--
		30.5	-65.4	-94.6
		45.7	-98.5	-103.4
3	4.5	15.2	-54.9	-76.5
		30.5	-76.2	--
		45.7	-83.5	-98.0
4	5.7	15.2	-57.3	--
		30.5	-71.9	-105.2
		45.7	-60.2	-95.7

[#] November, January, February, and March.

obtained during the summer period (Tables 8, 9). However, the summer of 1989 received much higher than normal rainfall.

All four subsystems demonstrated satisfactory hydraulics and showed no sign of failure. However, the actual loading rate of each subsystem was approximately one-third of the designed loading rate (Table 5). Thus, each subsystem actually possessed an increased soil volume area to dispose and treat of the effluent entering the trenches compared with recommended rates. These reduced application rates were also conducive to overcoming the soil restriction of low hydraulic conductivity (Table 6).

In the Penn-Bucks soil, the narrow trench design (19) failed within six months of installation, as evidenced by surface ponding of effluent. This was an indication that the effluent loading rate was too high to permit infiltration through the silty clay loam soil, once biological clogging developed with the subsequent decrease in infiltrative capacity. Effluent application to this subsystem was discontinued, and the effluent was rerouted to the reserve area in February, 1989.

The Virginia State regulation design (21) functioned satisfactorily hydraulically as evidenced by the low ψ_m values beneath the subsystem and even drier conditions measured between the trenches in both seasons (Tables 10, 11). This low ψ_m indicated that moist, unsaturated conditions were present beneath the subsystem with even drier conditions present between the trenches. The lower Virginia loading rate functioned very satisfactorily hydraulically, as evidenced by the lower ψ_m values below and between the trenches, as compared to the higher Virginia loading rate for both seasons. These low ψ_m values indicated that drier conditions existed both below and between the trenches of this subsystem (Tables 10, 11).

Both loading rates (Virginia regulation and the lower Virginia) performed successfully with respect to hydraulic performance, because it was probably enhanced

Table 10. Soil matrix potentials determined for the Penn-Bucks soil, below and between the trenches for both subsystems in the summer, 1989.

Subsystem	Loading rate (Lpd/m ²)	Depth below trench (cm)	Mean Pressurehead (kPa)	
			Below	Between
1	14.3	15.2	-78.9	--
		30.5	-77.4	-81.3
3	7.3	15.2	-148.4	--
		30.5	-121.1	-204.6

May, June, July, and September.

Table 11. Soil matrix potentials determined for the Penn-Bucks soil, below and between the trenches for both subsystems in the winter, 1990.

Subsystem	Loading rate (Lpd/m ²)	Depth below trench (cm)	Mean Pressurehead (kPa)	
			Below	Between
1	14.3	15.2	-80.2	--
		30.5	-94.1	-91.4
3	7.3	15.2	-92.1	--
		30.5	-96.9	-114.4

November, January, February, and March.

by the lower-than-design loading rate (Table 5). The reduced loading rates that were actually applied were also conducive to overcoming the soil restriction of low hydraulic conductivity present at this site (Table 7).

In both the Edom and Penn-Bucks soils, the soil restrictions limiting the successful use of OSWDS appeared to be overcome by applying a low volume of effluent to a relatively large treatment area. This leads to the possibility of increasing the trench treatment area, while reducing the effluent loading rates to as low as possible, thereby ensuring successful hydraulic performance. Increasing the trench width from 60 cm to 90 cm would reduce the cost of the system and allow more flexibility with respect to alternating aerobic and anaerobic conditions.

B. Microbial Tracer Studies

1. Edom Soil

In all four subsystems, the bacterial tracer was observed more often at levels > 100 colony forming units (cfu) per 50 ml than the viral tracer below the trench bottom for both the summer and winter seasons (Tables 12-19). Additionally, both the bacterial and viral tracers were transported to the 152 cm depth in all subsystems, although the number of each tracer observed was always greater in the winter than in the summer (Tables 12-19).

During the 816 hr summer observation period, the bacterial tracer was reduced to levels of 0-50 cfu/50 ml while the viral tracer was reduced to levels of 0 pfu/50 ml at all depths (Tables 12, 14, 16, 18). During the 816 hr winter observation period, in Subsystem 1, only the viral tracer was reduced to low levels (0-50 pfu/50 ml) at all depths, while the bacterial tracer remained at levels > 100 cfu/50 ml at the 31 and

Table 12. Bacterial and viral tracers enumerated for Subsystem 1 with a design loading rate of 17.5 lpd/m² in the Edom soil during the summer, 1989#.

Time (hr)	Depth Below Trench (cm)	Bacteria##				Viruses###						
		1	2	3	4	1	2	3	4	5	6	
24	30.5	0	1	0	1	1	1	0	0	0	0	0
	45.7	1	0	0	1	0	2	0	0	0	0	0
	152.4	0	1	0	1	2	0	0	0	0	0	0
48	30.5	0	1	0	1	2	0	0	0	0	0	0
	45.7	0	2	0	0	2	0	0	0	0	0	0
	152.4	0	2	0	0	2	0	0	0	0	0	0
72	30.5	1	1	0	0	2	0	0	0	0	0	0
	45.7	1	1	0	0	2	0	0	0	0	0	0
	152.4	1	0	0	1	2	0	0	0	0	0	0
816	30.5	2	0	0	0	2	0	0	0	0	0	0
	45.7	1	1	0	0	2	0	0	0	0	0	0
	152.4	1	1	0	0	2	0	0	0	0	0	0

Bacterial and viral tracers applied at 1.4 x 10⁸ cfu/m² and 1.9 x 10⁵ pfu/m², respectively.

Bacteria: 1. 0 2. 1-50 3. 51-100 4. >100.

Viruses: 1. 0 2. 1-50 3. 51-100 4. 101-1000 5. 1001-10000 6. >10000.

Table 13. Bacterial and viral tracers enumerated for Subsystem 1 with a design loading rate of 17.5 Lpd/m² in the Edom soil during the winter, 1990[#].

Time (hr)	Depth Below Trench (cm)	Bacteria ##				Viruses ##						
		1	2	3	4	1	2	3	4	5	6	
24	30.5	0	0	0	2	1	0	0	0	0	0	1
	45.7	0	0	0	2	0	0	0	0	0	0	2
	152.4	0	0	2	0	1	1	0	0	0	0	0
48	30.5	0	0	0	2	0	1	0	1	0	0	0
	45.7	0	0	0	2	0	0	0	0	0	2	0
	152.4	0	1	1	0	1	1	0	0	0	0	0
72	30.5	2	0	0	0	2	0	0	0	0	0	0
	45.7	1	0	0	1	2	0	0	0	0	0	0
	152.4	0	0	2	0	0	2	0	0	0	0	0
816	30.5	0	0	0	2	1	1	0	0	0	0	0
	45.7	0	0	0	2	0	2	0	0	0	0	0
	152.4	0	2	0	0	1	1	0	0	0	0	0

Bacterial and viral tracers applied at 3.7 x 10⁸ cfu/m² and 1.9 x 10⁸ pfu/m², respectively.

Bacteria: 1. 0 2. 1-50 3. 51-100 4. >100.

Viruses: 1. 0 2. 1-50 3. 51-100 4. 101-1000 5. 1001-10000 6. >10000.

Table 14. Bacterial and viral tracers enumerated for Subsystem 2 with a design loading rate of 9.0 Lpd/m² in the Edom soil during the summer, 1989#.

Time (hr)	Depth Below Trench (cm)	Bacteria ##				Viruses ###							
		1	2	3	4	1	2	3	4	5	6		
		CFU/50 ml				PFU/50 ml							
24	30.5	0	0	0	2	0	2	0	0	0	0	0	0
	45.7	0	0	0	2	0	2	0	0	0	0	0	0
	152.4	0	2	0	0	1	1	0	0	0	0	0	0
48	30.5	0	0	0	2	1	1	0	0	0	0	0	0
	45.7	0	0	0	2	2	0	0	0	0	0	0	0
	152.4	0	2	0	0	2	0	0	0	0	0	0	0
72	30.5	1	0	0	1	1	1	0	0	0	0	0	0
	45.7	0	1	0	1	2	0	0	0	0	0	0	0
	152.4	1	1	0	0	2	0	0	0	0	0	0	0
816	30.5	2	0	0	0	2	0	0	0	0	0	0	0
	45.7	1	1	0	0	2	0	0	0	0	0	0	0
	152.4	2	0	0	0	2	0	0	0	0	0	0	0

Bacterial and viral tracers applied at 7.4 x 10⁷ cfu/m² and 9.5 x 10⁴ pfu/m², respectively.

Bacteria: 1. 0 2. 1-50 3. 51-100 4. >100.

Viruses: 1. 0 2. 1-50 3. 51-100 4. 101-1000 5. 1001-10000 6. >10000.

Table 15. Bacterial and viral tracers enumerated for Subsystem 2 with a design loading rate of 9.0 Lpd/m² in the Edom soil during the winter, 1990#.

Time (hr)	Depth Below Trench (cm)	Bacteria #				Viruses ###								
		1	2	3	4	1	2	3	4	5	6			
24	30.5	0	0	0	2	0	0	0	0	0	0	0	0	2
	45.7	0	0	0	2	0	0	0	0	0	0	0	0	2
	152.4	0	0	2	0	1	1	0	0	0	0	0	0	0
48	30.5	0	0	0	2	0	0	0	0	0	0	0	2	0
	45.7	0	0	0	2	0	0	0	0	0	0	0	2	0
	152.4	0	0	1	1	0	1	0	0	0	0	0	0	1
72	30.5	0	0	0	2	0	0	0	0	0	1	1	0	0
	45.7	0	0	0	2	0	0	2	0	0	0	0	0	0
	152.4	0	0	2	0	2	0	0	0	0	0	0	0	0
816	30.5	0	0	0	2	0	0	0	0	0	2	0	0	0
	45.7	1	0	0	1	0	0	0	0	0	2	0	0	0
	152.4	0	0	0	2	2	0	0	0	0	0	0	0	0

Bacterial and viral tracers applied at 1.9 x 10⁸ cfu/m² and 9.5 x 10⁷ pfu/m², respectively.

Bacteria: 1. 0 2. 1-50 3. 51-100 4. >100.

Viruses: 1. 0 2. 1-50 3. 51-100 4. 101-1000 5. 1001-10000 6. >10000.

Table 16. Bacterial and viral tracers enumerated for Subsystem 3 with a design loading rate of 4.5 Lpd/m² in the Edom soil during the summer, 1989#.

Time (hr)	Depth Below Trench (cm)	Bacteria #				Viruses ###						
		1	2	3	4	1	2	3	4	5	6	
24	30.5	0	0	0	2	0	2	0	0	0	0	0
	45.7	0	0	0	2	0	2	0	0	0	0	0
	152.4	0	1	0	1	2	0	0	0	0	0	0
48	30.5	0	1	0	1	2	0	0	0	0	0	0
	45.7	2	0	0	0	2	0	0	0	0	0	0
	152.4	1	1	0	0	2	0	0	0	0	0	0
72	30.5	1	0	0	1	2	0	0	0	0	0	0
	45.7	0	0	0	2	2	0	0	0	0	0	0
	152.4	1	0	1	0	2	0	0	0	0	0	0
816	30.5	1	1	0	0	2	0	0	0	0	0	0
	45.7	1	1	0	0	2	0	0	0	0	0	0
	152.4	2	0	0	0	2	0	0	0	0	0	0

Bacterial and viral tracers applied at 3.7 x 10⁷ cfu/m² and 4.8 x 10⁴ pfu/m², respectively.

Bacteria: 1. 0 2. 1-50 3. 51-100 4. >100.

Viruses: 1. 0 2. 1-50 3. 51-100 4. 101-1000 5. 1001-10000 6. >10000.

Table 17. Bacterial and viral tracers enumerated for Subsystem 3 with a design loading rate of 4.5 Lpd/m² in the Edom soil during the winter, 1990#.

Time (hr)	Depth Below Trench (cm)	Bacteria ##				Viruses ###						
		1	2	3	4	1	2	3	4	5	6	
24	30.5	0	0	0	2	0	0	0	0	0	1	1
	45.7	0	0	0	2	0	0	0	1	1	0	0
	152.4	0	2	0	0	1	0	0	1	0	0	0
48	30.5	0	0	2	0	0	1	0	1	0	0	0
	45.7	0	0	0	2	0	2	0	0	0	0	0
	152.4	0	1	0	1	0	1	0	0	0	1	1
72	30.5	2	0	0	0	2	0	0	0	0	0	0
	45.7	2	0	0	0	2	0	0	0	0	0	0
	152.4	0	1	1	0	2	0	0	0	0	0	0
816	30.5	0	0	0	2	0	0	1	0	1	0	0
	45.7	0	0	0	2	0	1	0	1	0	0	0
	152.4	0	1	0	1	2	0	0	0	0	0	0

Bacterial and viral tracers applied at 9.5 x 10⁷ cfu/m² and 4.8 x 10⁷ pfu/m², respectively.

Bacteria: 1. 0 2. 1-50 3. 51-100 4. >100.

Viruses: 1. 0 2. 1-50 3. 51-100 4. 101-1000 5. 1001-10000 6. >10000.

Table 18. Bacterial and viral tracers enumerated for Subsystem 4 with a design loading rate of 5.7 Lpd/m² in the Edom soil during the summer, 1989#.

Time (hr)	Depth Below Trench (cm)	Bacteria #				Viruses #					
		CFU/50 ml				PFU/50 ml					
		1	2	3	4	1	2	3	4	5	6
24	30.5	1	0	0	1	0	2	0	0	0	0
	45.7	0	1	0	1	0	2	0	0	0	0
	152.4	2	0	0	0	2	0	0	0	0	0
48	30.5	1	0	0	1	2	0	0	0	0	0
	45.7	2	0	0	0	2	0	0	0	0	0
	152.4	2	0	0	0	2	0	0	0	0	0
72	30.5	0	2	0	0	2	0	0	0	0	0
	45.7	0	2	0	0	2	0	0	0	0	0
	152.4	1	0	0	1	2	0	0	0	0	0
816	30.5	0	2	0	0	2	0	0	0	0	0
	45.7	0	2	0	0	2	0	0	0	0	0
	152.4	1	1	0	0	2	0	0	0	0	0

Bacterial and viral tracers applied at 4.7 x 10⁷ cfu/m² and 6.0 x 10⁴ pfu/m², respectively.

Bacteria: 1. 0 2. 1-50 3. 51-100 4. >100.

Viruses: 1. 0 2. 1-50 3. 51-100 4. 101-1000 5. 1001-10000 6. >10000.

Table 19. Bacterial and viral tracers enumerated for Subsystem 4 with a design loading rate of 5.7 Lpd/m² in the Edom soil during the winter, 1990[#].

Time (hr)	Depth Below Trench (cm)	Bacteria ##				Viruses ##							
		1	2	3	4	1	2	3	4	5	6		
		CFU/50 ml				PFU/50 ml							
24	30.5	0	0	0	2	0	1	0	1	0	0	0	0
	45.7	0	0	0	2	0	0	0	0	0	0	1	1
	152.4	0	0	1	1	0	2	0	0	0	0	0	0
48	30.5	0	0	0	2	0	1	0	0	0	0	1	0
	45.7	0	0	0	2	0	0	0	0	2	0	0	0
	152.4	0	2	0	0	0	2	0	0	0	0	0	0
72	30.5	0	1	0	1	0	1	0	1	0	0	1	0
	45.7	0	0	0	2	0	1	0	1	0	1	0	0
	152.4	0	1	1	0	1	1	0	0	0	0	0	0
816	30.5	0	1	0	1	0	2	0	0	0	0	0	0
	45.7	0	0	0	2	0	1	1	0	0	0	0	0
	152.4	0	2	0	0	1	1	0	0	0	0	0	0

Bacterial and viral tracers applied at 1.2 x 10⁸ cfu/m² and 6.0 x 10⁷ pfu/m², respectively.

Bacteria: 1. 0 2. 1-50 3. 51-100 4. >100.

Viruses: 1. 0 2. 1-50 3. 51-100 4. 101-1000 5. 1001-10000 6. >10000.

46 cm depths below the trench bottom (Table 13). In Subsystem 2, the viral tracer decreased to levels of 51-100 pfu/50 ml or less at all depths, while the bacterial tracer remained at levels > 100 cfu/50 ml at all depths (Table 15). In Subsystem 3, the viral tracer remained at levels > 100 pfu/50 ml only at the 31 and 46 cm depths, while the bacterial tracer remained at levels > 100/50 ml at all depths below the trench bottom (Table 17). In Subsystem 4, the viral tracer was reduced to levels less than 100 pfu/50 ml at all depths, while the bacterial tracer remained at levels > 100 cfu/50 ml only at the 31 and 46 cm depths below the trench bottom (Table 19).

Bacterial and viral transport below OSWDS is highly influenced by the moisture regime present below the disposal field. Under saturated conditions, effluent flows through macropores and is afforded minimal treatment (if any) due to the relatively low effluent-soil contact time. Biological contaminants have been shown to move considerable distances under saturated conditions as compared to unsaturated flow. Romero (70) concluded that a distance of 15 to 30 m was necessary for the removal of biological contaminants under saturated conditions. In contrast, under unsaturated conditions, effluent moves through micropores where a high level of treatment is afforded by the soil due to the prolonged contact times. Romero (70) concluded that most biological contaminants can be adequately removed in less than three meters, or approximately one-tenth the distance required for removal under saturated flow conditions.

During the summer months, all four subsystems functioned very similarly with respect to microbial retention. Moist, unsaturated conditions were present below all four subsystems (Table 8), and as a result, microbial transport and survival were limited. A > 99.9% removal, with respect to the initial loading rate of both tracers, was observed over the 816 hr observation period throughout the 152 cm depth by all four loading rates. The higher levels of the bacterial tracer, compared to the viral

tracer, may have resulted from the three-fold higher application rate for the bacterial tracer as compared to the viral tracer.

During the winter months, moist and unsaturated conditions were present beneath all four subsystems (Table 9). In contrast to the summer study, all four subsystems showed a higher level of bacterial and viral tracer penetration to the 152 cm depth below the trench bottom, as well as a prolonged survival over the 816 hr observation period. A possible explanation would be that temperature had a marked effect on the survival of both tracers, thereby increasing the potential for transport to the 152 cm depth. Many laboratory studies have indicated that moist soils and low temperatures favor bacterial and viral survival in soils (68). Gerba, *et al.* (33) reported that enteric bacteria survival is greatly enhanced at low temperatures. Subsequently, longer organism survival has been observed in the winter than in the summer. Duboise, *et al.* (27) reported that poliovirus survival was greatly prolonged at 4°C as compared to 20°C. They also reported that during the survival period, there was no apparent change in the ability of the virus to migrate.

In spite of the higher levels of both tracers recovered in the winter season as compared to the summer season, all four loading rates were effective in enhancing the removal of both the bacterial and viral tracers. A > 99% removal, with respect to the initial loading rate of both tracers, was observed over the 816 hr observation period throughout the 152 cm depth by all four loading rates in the winter.

2. Penn-Bucks Soil

For subsystem 1, the bacterial tracer was observed more often at levels > 100 cfu/50 ml than the viral tracer below the trench bottom in the summer season (Table 20). In the winter, both the bacterial and viral tracers were observed at levels > 100 cfu/pfu per 50 ml, respectively, below the trench bottom, although the viral tracer was observed more often in higher numbers (Table 21). Both tracers were transported to the 41-102 cm depths in both seasons, but greater numbers of each tracer was observed in the winter as compared to the summer season (Tables 20, 21). Over the 72 hr observation period, the viral tracer was reduced to low levels of 0-50 pfu/50 ml at all depths in the summer, while in the winter, the viral tracer remained at levels > 100 pfu/50 ml only at the 0-15 and 31 cm depths below the trench bottom (Tables 20, 21). The bacterial tracer remained at levels > 100 cfu/50 ml at all depths for both seasons (Tables 20, 21).

Subsystem 2 was located downslope from Subsystem 1. The bacterial and viral tracers were recovered from water samples collected from Subsystem 2; they indicated that subsurface horizontal transport of both the bacterial and viral tracers from Subsystem 1 had occurred.

Horizontal transport of both the bacterial and viral tracers was observed in low levels (0-50 cfu/pfu per 50 ml, respectively) at all depths in the summer, 1989 (Table 22). Low levels (0-50 pfu/50 ml) of the viral tracer were observed in the winter, 1990, but generally higher levels (> 50 cfu/50 ml) of the bacterial tracer were recorded (Table-23).

In Subsystem 3, both the bacterial and viral tracers were observed at low levels of 0 cfu/pfu per 50 ml, respectively, below the trench bottom during the summer season (Table 24). In the winter, both the bacterial and viral tracers were observed

Table 20. Bacterial and viral tracers enumerated for Subsystem 1 with a design loading rate of 14.3 lpd/m² in the Penn-Bucks soil during the summer, 1989[#].

Time (hr)	Depth Below Trench (cm)	Bacteria #				Viruses ###							
		1	2	3	4	1	2	3	4	5	6		
24	0-15.2	3*	0	0	1	4	0	0	0	0	0	0	0
	30.5	1	0	0	2	2	1	0	0	0	0	0	0
	40.6-101.6	2	1	0	1	4	0	0	0	0	0	0	0
48	0-15.2	3	0	0	1	4	0	0	0	0	0	0	0
	30.5	2	0	0	1	3	0	0	0	0	0	0	0
	40.6-101.6	1	2	0	1	4	0	0	0	0	0	0	0
72	0-15.2	3	0	0	1	3	1	0	0	0	0	0	0
	30.5	2	0	0	1	2	1	0	0	0	0	0	0
	40.6-101.6	2	0	0	2	4	0	0	0	0	0	0	0

* Determined using the 96-well microtiter technique.
Bacterial and viral tracers applied at 2.4 x 10⁸ cfu/m² and 3.0 x 10⁵ pfu/m², respectively.
Bacteria: 1. 0 2. 1-50 3. 51-100 4. >100.
Viruses: 1. 0 2. 1-50 3. 51-100 4. 101-1000 5. 1001-10000 6. >10000

Table 21. Bacterial and viral tracers enumerated for Subsystem 1 with a design loading rate of 14.3 lpd/m² in the Penn-Bucks soil during the winter, 1990#.

Time (hr)	Depth Below Trench (cm)	Bacteria##				Viruses###						
		1	2	3	4	1	2	3	4	5	6	
24	0-15.2	3	0	0	1	3	0	0	0	0	1	0
	30.5	2	1	0	0	2	0	0	0	0	1	0
	40.6-101.6	1	1	1	1	1	1	0	0	0	0	2
48	0-15.2	3	1	0	0	3	0	0	0	0	1	0
	30.5	2	0	0	1	2	0	0	0	0	0	1
	40.6-101.6	2	0	1	1	1	1	0	0	0	1	1
72	0-15.2	3	0	0	1	3	0	0	0	0	1	0
	30.5	2	0	0	1	2	0	0	0	1	0	0
	40.6-101.6	2	0	1	1	4	0	0	0	0	0	0

Bacterial and viral tracers applied at 6.0 x 10⁸ cfu/m² and 3.0 x 10⁸ pfu/m² respectively.

Bacteria: 1. 0 2. 1-50 3. 51-100 4. >100.

Viruses: 1. 0 2. 1-50 3. 51-100 4. 101-1000 5. 1001-10000 6. >10000.

Table 22. Bacterial and viral tracers enumerated for Subsystem 2 with a design loading rate of 30.6 Lpd/m² in the Penn-Bucks soil during the summer, 1989.

Time (hr)	Depth Below Trench (cm)	Bacteria #				Viruses #							
		1	2	3	4	1	2	3	4	5	6		
24	15.2	3	0	0	0	3	0	0	0	0	0	0	0
	30.5	3	0	0	0	3	0	0	0	0	0	0	0
	35.6-106.7	2	1	0	0	3	0	0	0	0	0	0	0
48	15.2	2	0	0	1	2	0	0	0	0	0	0	1
	30.5	3	0	0	0	3	0	0	0	0	0	0	0
	35.6-106.7	2	1	0	0	3	0	0	0	0	0	0	0
72	15.2	3	0	0	0	3	0	0	0	0	0	0	0
	30.5	3	0	0	0	3	0	0	0	0	0	0	0
	35.6-106.7	2	0	0	1	2	1	0	0	0	0	0	0

Bacteria: 1. 0 2. 1-50 3. 51-100 4. >100.

Viruses: 1. 0 2. 1-50 3. 51-100 4. 101-1000 5. 1001-10000 6. >10000.

Table 23. Bacterial and viral tracers enumerated for Subsystem 2 with a design loading rate of 30.6 Lpd/m² in the Penn-Bucks soil during the winter, 1990.

Time (hr)	Depth Below Trench (cm)	Bacteria #				Viruses #						
		1	2	3	4	1	2	3	4	5	6	
24	15.2	3	0	0	0	3	0	0	0	0	0	0
	30.5	2	0	0	1	3	0	0	0	0	0	0
	35.6-106.7	0	1	2	0	0	2	0	1	0	0	0
48	15.2	3	0	0	0	3	0	0	0	0	0	0
	30.5	2	0	0	1	2	0	0	0	0	1	0
	35.6-106.7	1	0	1	1	0	3	0	0	0	0	0
72	15.2	3	0	0	0	3	0	0	0	0	0	0
	30.5	2	0	0	1	2	1	0	0	0	0	0
	35.6-106.7	0	2	0	1	3	0	0	0	0	0	0

Bacteria: 1. 0 2. 1-50 3. 51-100 4. >100.

Viruses: 1. 0 2. 1-50 3. 51-100 4. 101-1000 5. 1001-10000 6. >10000.

Table 24. Bacterial and viral tracers enumerated for Subsystem 3 with a design loading rate of 7.3 Lpd/m² in the Penn-Bucks soil during the summer, 1989#.

Time (hr)	Depth Below Trench (cm)	Bacteria #				Viruses ##							
		1	2	3	4	1	2	3	4	5	6		
24	15.2	3	0	0	0	3	0	0	0	0	0	0	0
	30.5	3	0	0	0	3	0	0	0	0	0	0	0
	33.0-114.3	3	1	0	0	4	0	0	0	0	0	0	0
48	15.2	3	0	0	0	3	0	0	0	0	0	0	0
	30.5	3	0	0	0	3	0	0	0	0	0	0	0
	33.0-114.3	3	1	0	0	4	0	0	0	0	0	0	0
72	15.2	3	0	0	0	3	0	0	0	0	0	0	0
	30.5	3	0	0	0	3	0	0	0	0	0	0	0
	33.0-114.3	3	0	0	1	4	0	0	0	0	0	0	0

Bacterial and viral tracers applied at 1.2 x 10⁸ cfu/m² and 1.5 x 10⁵ pfu/m², respectively.

Bacteria: 1. 0 2. 1-50 3. 51-100 4. >100.

Viruses: 1. 0 2. 1-50 3. 51-100 4. 101-1000 5. 1001-10000 6. >10000.

Table 25. Bacterial and viral tracers enumerated for Subsystem 3 with a design loading rate of 7.3 Lpd/m^2 in the Penn-Bucks soil during the winter, 1990#.

Time (hr)	Depth Below Trench (cm)	Bacteria##				Viruses##							
		1	2	3	4	1	2	3	4	5	6		
24	15.2	3	0	0	0	3	0	0	0	0	0	0	0
	30.5	3	0	0	0	3	0	0	0	0	0	0	0
	33.0-114.3	3	0	0	1	3	0	0	0	0	0	0	1
48	15.2	3	0	0	0	3	0	0	0	0	0	0	0
	30.5	3	0	0	0	3	0	0	0	0	0	0	0
	33.0-114.3	3	0	0	1	3	0	0	0	0	0	1	0
72	15.2	3	0	0	0	3	0	0	0	0	0	0	0
	30.5	3	0	0	0	3	0	0	0	0	0	0	0
	33.0-114.3	3	1	0	0	4	0	0	0	0	0	0	0

Bacterial and viral tracers applied at $3.1 \times 10^8 \text{ cfu/m}^2$ and $1.5 \times 10^8 \text{ pfu/m}^2$, respectively.

Bacteria: 1. 0 2. 1-50 3. 51-100 4. >100.

Viruses: 1. 0 2. 1-50 3. 51-100 4. 101-1000 5. 1001-10000 6. >10000.

at levels > 100 cfu/pfu per 50 ml, respectively, below the trench (Table 25). Both tracers were transported to the 33-114 cm depth in both the summer and winter seasons, but higher numbers of both tracers were observed in the winter as compared to the summer (Tables 24, 25). Over the 72 hr observation period, the viral tracer decreased to levels of 0 pfu/50 ml at all depths for both seasons (Tables 24, 25). The bacterial tracer remained at levels > 100 cfu/50 ml only at the 33-114 cm depth in the summer, while in the winter, levels of less than 50 cfu/50 ml were recorded at all depths (Tables 24, 25).

Both loading rates encouraged a high level of biological treatment below the trenches, but the efficiency of removal was greater for the lower Virginia loading rate during the summer, 1989. Unsaturated flow conditions were present below each subsystem, with even drier, more unsaturated flow conditions below Subsystem 3 (Table 10). Although the bacterial tracer was observed in greater numbers than the viral tracer below both subsystems over the 72 hr observation period, with respect to the initial loading rate of each tracer, Subsystem 3 reduced both tracers >99.9% throughout the 114 cm depth, while Subsystem 1 reduced both tracers >99% throughout the 102 cm depth.

The low numbers of both tracers detected in the subsurface flow, 2.0 m from Subsystem 1 in the summer, demonstrated the high treatment efficiency from Subsystem 1 in removing both biological contaminants below the trench bottom (Table 22).

Both loading rates encouraged a high level of biological treatment below the trenches, but the lower Virginia loading rate was the most effective at removing both the bacterial and viral tracers in the winter, 1990. Higher levels of both the bacterial and viral tracers were detected at the lower depths over the 72 hr observation period in the winter in Subsystem 3 (Table 25) because of the combination of

cooler, wetter conditions below the subsystem, compared to the summer. This combination of cooler, wetter conditions enhanced the survival of both tracers, thereby increasing the likelihood of their transport to the lower depths. In Subsystem 1, the higher levels of both tracers observed in the winter below the trenches as well as in the subsurface flow below Subsystem 2 (Table 23) was not due to the moisture status present below the subsystem, since the ψ_m values remained similar for both seasons (Tables 10, 11). Instead, the transport patterns were probably the result of cooler temperatures in the winter that increased the survival of both tracers, thereby increasing the likelihood of their transport to the lower depths.

In spite of higher levels of both tracers detected in the winter, the treatment efficiency of Subsystem 3, with respect to the initial loading rate of each tracer, remained at > 99.9% throughout the 114 cm depth, while for Subsystem 1 the treatment efficiency remained at > 99% throughout the 102 cm depth.

C. Denitrification Studies

1. Edom Soil

In the summer, 1989, the N_2O-N emissions ranged from 0.74 to 0.19 $\mu g N_2O-N/g$ of dry soil in the 0-15.2 cm depth, and from 0.52 to 0 μg of N_2O-N/g of dry soil in the 15.2-30.5 cm depth (Table 26). Although Subsystem 3 was the only subsystem showing differences between the 0-15.2 and 15.2-30.5 cm depths, there was a trend demonstrated by all subsystems towards higher emission levels of N_2O-N at the upper depths. This was probably the result of a larger and more active population of denitrifying organisms in the upper soil horizon.

Table 26. N₂O-N emissions from soil samples collected during the summer of 1989 and the winter of 1990 from Edom soil.

Subsystem	Loading rate (Lpd/m ²)	Depth (cm)	Summer 1989 (ug N ₂ O-N/g dry soil)	Winter 1990 #
1	17.5	0-15.2	0.62BC	1.27A
		15.2-30.5	0.52BCD	0.55BC
2	9.0	0-15.2	0.19C	1.24A
		15.2-30.5	0.22CD	0.37CD
3	4.5	0-15.2	0.74BC	1.02AB
		15.2-30.5	0 D	0.25CD
4	5.7	0-15.2	0.73BC	1.06AB
		15.2-30.5	0.30CD	0.60BC

Means with the same letter are not significantly different using Duncan's multiple range test (p<0.05).

In the winter of 1990, the $\text{N}_2\text{O-N}$ emissions ranged from 1.27 to 1.02 $\mu\text{g N}_2\text{O-N/g}$ of dry soil in the 0-15.2 cm depth, and 0.60 to 0.25 $\mu\text{g N}_2\text{O-N/g}$ of dry soil in the 15.2-30.5 cm depth (Table 26). All four subsystems showed a greater level of $\text{N}_2\text{O-N}$ emissions in the 0-15.2 cm depth, as compared to the 15.2-30.5 cm depths, except for Subsystem 4, although a trend toward increased denitrification at the shallower depth was also evident in Subsystem 4. This higher level of $\text{N}_2\text{O-N}$ emissions in the upper depths was probably a result of a higher and more active population of denitrifying organisms in the upper soil horizon as well as of a greater supply of available C in the upper depths.

Although differences were only detected at the 0-15.2 cm depths from Subsystem 1 and Subsystem 2 in the summer of 1989 as compared to the winter of 1990, there was, however, a trend toward higher emissions in both depths in the winter as compared to the summer. Cooler temperatures during the winter months probably resulted in larger quantities of substrate being present in the soil. When the soil was incubated at 20°C , the elevated levels of substrate enhanced the level of $\text{N}_2\text{O-N}$ emitted.

All four loading rates enhanced the denitrification process in a similar manner since no differences were detected among the levels of $\text{N}_2\text{O-N}$ emitted in either the 0-15.2 or 15.2-30.5 cm depths of all four subsystems in the summer of 1989 or in the winter of 1990 (Table 26). Dosing is important to the amount of denitrification in an on-site system due to the changes it induces in the soil water status below the trenches (69). In LPD systems, dosing provides a more uniform effluent distribution and will increase the denitrification potential. Thus, all four loading rates were equally effective at promoting denitrification. In terms of overall loss of N through denitrification in the Edom soil, based on the $\text{Cl}^- - \text{NO}_3^- - \text{N}$ ratio, a maximal loss of 38% could be achieved (Table 27).

Table 27. Mean NO_3^- -N, NH_4^+ -N, TKN, and Cl^- values determined from pump chamber and groundwater samples at the Edom and Penn-Bucks soil sites.

Soil	Pump Chamber			Field Data #		
	NO_3^- -N	NH_4^+ -N mg/L	TKN Cl^-	NO_3^- -N	NH_4^+ -N mg/L	Cl^-
Edom	1.8	47.2	85.0	30.3	7.1	49.8
Penn-Bucks	3.7	24.5	30.7	8.6	5.6	54.5

Edom soil: wells located 30.5 and 45.7 cm below trench bottom.
 Penn-Bucks soil: wells located 15.2 and 30.5 cm below trench bottom.

In the summer of 1989, an energy source (glucose) was the rate-limiting factor in $\text{N}_2\text{O-N}$ emissions at the 0-15.2 cm depths in all four subsystems. Readily degradable C was the rate-limiting factor in $\text{N}_2\text{O-N}$ emissions in the 15.2-30.5 cm depth for all subsystems except Subsystem 4 (Tables 28-31). In the winter of 1990, C was the rate-limiting factor in $\text{N}_2\text{O-N}$ emissions in all four subsystems in the 0-15.2 cm depth. Carbon was rate-limiting in the 15.2-30.5 cm depth only for Subsystem 3 (Tables 28-31).

A readily available C source was the rate-limiting factor 75% of the time in both the 0-15.2 and the 15.2-30.5 cm depths in both the summer of 1989 and the winter of 1990 (Tables 28-31). Although a NO_3^- -N limitation was not tested for in this study, groundwater samples collected from wells located below each subsystem indicated that NO_3^- -N was present in abundance below each subsystem (Table 32). Thus, it was highly unlikely that NO_3^- -N would have been a rate-limiting factor in denitrification in any of the subsystems. The finding that an available C source was the rate-limiting factor below all four subsystems has been identified by other investigators. Lance, *et al.* (49) reported that achieving nitrification and denitrification in the same system is difficult because most of the organic C is consumed in the oxidative environment required for nitrification, leaving an inadequate energy supply for the denitrifying microorganisms. Bremner and Shaw (10) observed little or no gaseous loss of N from soils containing < 1% C.

2. Penn-Bucks Soil

In the summer of 1989, the $\text{N}_2\text{O-N}$ emissions ranged from 0.88 to 0.33 μg of $\text{N}_2\text{O-N/g}$ of dry soil in the 0-15.2 cm depth and 0.57 to 0.10 μg of $\text{N}_2\text{O-N/g}$ of dry soil in the 15.2-30.5 cm depth (Table 33). Although no differences were detected in

Table 28. N₂O-N emissions from samples collected during the summer of 1989 and the winter of 1990 from Egom soil that received a design loading rate of 17.5 Lpd/m².

Depth (cm)	Treatment	Mean N ₂ O-N# (ug N ₂ O-N/g dry soil)	
		Summer	Winter
0-15.2	glucose	1.3A	2.2A
	no ammendment	0.6B	1.3B

15.2-30.5	glucose	1.0A	0.3A
	no ammendment	0.5B	0.6A

Means in the same column within the same depth followed by the same letter are not significantly different using Duncan's multiple range test (p<0.05).

Table 29. N₂O-N emissions from samples collected during the summer of 1989 and the winter of 1990 from Edom soil that received a design loading rate of 9.0 Lpd.m².

Depth (cm)	Treatment	Mean N ₂ O-N [#] (ug N ₂ O-N/g dry soil)	
		Summer	Winter
0-15.2	glucose	1.6A	1.7A
	no ammendment	0.2B	1.2B

15.2-30.5	glucose	0.8A	0.8A
	no ammendment	0.2B	0.4A

Means in the same column within each depth followed by the same letter are not significantly different using Duncan's multiple range test (p<0.05).

Table 30. N₂O-N emissions from samples collected during the summer of 1989 and the winter of 1990 from Edom soil that received a design loading rate of 4.5 Lpd/m².

Depth (cm)	Treatment	Mean N ₂ O-N [#] (ug N ₂ O-N/g dry soil)	
		Summer	Winter
0-15.2	glucose	1.6A	2.2A
	no ammendment	0.7B	1.0B

15.2-30.5	glucose	0.8A	0.5A
	no ammendment	0.0B	0.3B

Means in the same column within each depth followed by the same letter are not significantly different using Duncan's multiple range test (p<0.05).

Table 31. N₂O-N emissions from samples collected during the summer of 1989 and the winter of 1990 from Edom soil that received a design loading rate of 5.7 Lpd/m².

Depth (cm)	Treatment	Mean N ₂ O-N# (ug N ₂ O-N/g dry soil)	
		Summer	Winter
0-15.2	glucose	1.5A	1.6A
	no ammendment	0.7B	1.1B
15.2-30.5	glucose	0.9A	0.8A
	no ammendment	0.3A	0.6A

Means in the same column within each depth followed by the same letter are not significantly different using Duncan's multiple range test (p<0.05).

Table 32. Mean NO_3^- -N levels determined from groundwater samples collected from 30.5 and 45.7 cm deep wells below the trench bottom in the Edom soil.

Design Loading Rate (Lpd/m ²)	Mean NO_3^- -N (mg/L)	
	30.5 cm	45.7 cm
17.5	22.0	23.0
9.0	39.0	32.0
4.5	27.0	40.0
5.7	34.0	25.0

the N₂O-N emissions between the 0-15.2 and 15.2-30.5 cm depths within each subsystem in the summer, 1989 there was a trend toward higher N₂O-N emissions in the upper depth in both subsystems. This was probably a result of a higher and more active population of denitrifying organisms in the shallower depth as compared to the lower depth.

Higher levels of N₂O-N were emitted from both depths of Subsystem 1 as compared to the same depths of Subsystem 3 in the summer of 1989 (Table 33). The combination of a higher loading rate, thereby producing a longer saturated period after dosing, as well as the higher levels of substrate supplied to the denitrifying organisms below Subsystem 1, resulted in the greater level of N₂O-N emitted from the soil of Subsystem 1.

In the winter of 1990, the N₂O-N emissions ranged from 1.43 to 1.30 μg of N₂O-N/g of dry soil in the 0-15.2 cm depth, and 1.49 to 0.83 μg of N₂O-N/g of dry soil in the 15.2-30.5 cm depth (Table 33). For Subsystem 1, roughly equal amounts of N₂O-N were emitted at the 0-15.2 and 15.2-30.5 cm depths (Table 33). Equal levels of N₂O-N emitted from both depths could have been a result of an abundance of substrate in both depths due to cooler temperatures over the winter months. For Subsystem 3, differences were detected between the 0-15.2 and 15.2-30.5 cm depths, indicating that the greater level of N₂O-N emitted from the upper depth was probably a result of a greater and more active population of denitrifying organisms in the upper depth as compared to the lower depth (Table 33).

In the winter of 1990, a difference in the level of N₂O-N emitted was only detected at the 15.2-30.5 cm depth between the two subsystems (Table 33). Although no difference was detected between the two subsystems at the 0-15.2 cm depth, a trend was demonstrated towards higher emission levels of N₂O-N from Subsystem 1 at both depths compared to the same depths of Subsystem 3 (Table 33). The higher

Table 33. N₂O-N emissions from soil samples collected during the summer of 1989 and the winter of 1990 from Penn-Bucks soil.

Subsystem	Loading rate (Lpd/m ²)	Depth (cm)	Summer 1989 (ug N ₂ O-N/g dry soil)	Winter 1990 [#]
1	14.3	0-15.2	0.88B	1.43A
		15.2-30.5	0.57BC	1.49A
3	7.3	0-15.2	0.33CD	1.30A
		15.2-30.5	0.10D	0.83B

[#] Means with the same letter are not significantly different using Duncan's multiple range test (p<0.05).

level of $\text{N}_2\text{O-N}$ emitted from Subsystem 1 was a result of the combination of a higher loading rate producing a longer saturation period after dosing, as well as of a higher quantity of substrate for the denitrifying organisms below Subsystem 1 as compared to Subsystem 3.

Higher levels of $\text{N}_2\text{O-N}$ were detected in the 0-15.2 and 15.2-30.5 cm depths in both subsystems in the winter of 1990 compared to the summer of 1989 (Table 33). The cooler climate during the winter months probably increased the level of substrate present in the soil. When the soil samples were incubated at 20°C , the elevated levels of substrate enhanced the level of $\text{N}_2\text{O-N}$ emitted.

In the summer of 1989, a readily available C source was the rate-limiting factor in $\text{N}_2\text{O-N}$ production in the 0-15.2 cm depth of both subsystems. In the 15.2-30.5 cm depth, C was the rate-limiting factor in $\text{N}_2\text{O-N}$ emissions only in Subsystem 3 (Tables 34, 35). In the winter of 1990, C was the rate-limiting factor in $\text{N}_2\text{O-N}$ emissions in the 0-15.2 cm depth only for Subsystem 3. Available C was not limiting $\text{N}_2\text{O-N}$ emissions in the 15.2-30.5 cm depth in either subsystems (Table 34, 35).

Carbon was rate-limiting at both depths 75% of the time in the lower Virginia loading rate during both seasons (Table 35). In contrast, C was rate-limiting in $\text{N}_2\text{O-N}$ emissions only 25% of the time for the full Virginia loading rate (Table 33). The greater limitation for Subsystem 3 (lower Virginia loading rate) was due to the inability of the lower loading rate at supplying the denitrifying organisms with an adequate supply of C. Although $\text{NO}_3^- \text{-N}$ was not investigated for its limitation in $\text{N}_2\text{O-N}$ emissions, groundwater samples collected from wells located below the trenches indicated that $\text{NO}_3^- \text{-N}$ was present below the subsystems (Table 36). Thus, it would have been highly unlikely that a $\text{NO}_3^- \text{-N}$ limitation would have been determined.

Table 34. N₂O -N emissions from samples collected during the summer of 1989 and the winter of 1990 from Penn-Bucks soil that received a design loading rate of 14.3 Lpd/m².

Depth (cm)	Treatment	Mean N ₂ O-N [#] (ug N ₂ O-N/g dry soil)	
		Summer	Winter
0-15.2	glucose	1.5A	1.7A
	no ammendment	0.9B	1.4A

15.2-30.5	glucose	0.8A	1.6A
	no ammendment	0.6A	1.5A

Means in the same column within each depth followed by the same letter are not significantly different using Duncan's multiple range test (p<0.05).

Table 35. N₂O-N emissions from samples collected during the summer of 1989 and the winter of 1990 from Penn-Bucks soil that received a design loading rate of 7.3 Lpd/m².

Depth (cm)	Treatment	Mean N ₂ O-N# (ug N ₂ O-N/g dry soil)	
		Summer	Winter
0-15.2	glucose	1.3A	1.9A
	no ammendment	0.3B	1.3B

15.2-30.5	glucose	0.4A	1.2A
	no ammendment	0.1B	0.8A

Means in the same column within each depth followed by the same letter are not significantly different using Duncan's multiple range test (p<0.05).

Table 36. Mean NO_3^- -N levels determined from groundwater samples collected from 15.2 and 30.5 cm deep wells below the trench bottom in Penn-Bucks soil.

Design Loading Rate (Lpd/m ²)	Mean NO_3^- -N (mg/L)	
	15.2 cm	30.5 cm
14.3	7.5	7.1
7.3	9.5	10.4

In terms of overall loss of N through denitrification in the Penn-Bucks soil, based on the Cl^- - NO_3^- -N ratio, a maximal loss of 67% could be achieved (Table 27).

Chapter V

CONCLUSIONS

The two shallow-placed LPD systems were designed to overcome soil conditions too restrictive for the successful use of a conventional OSWDS. The shallow placement, which introduces the effluent into the most biologically active and most aerated soil horizon, along with pressurized distribution that places the effluent uniformly over the entire length of the trench bottom, were used to overcome the soil restrictions present at the Edom soil site (low hydraulic conductivity), and at the Penn-Bucks soil site (low hydraulic conductivity and shallow depth of soil to bedrock).

In the Edom soil, all four loading rates performed equally well in terms of hydraulic performance, bacterial and viral tracer retention, and in enhancement of denitrification in both the summer of 1989 and the winter of 1990. Their lack of failure was attributed to uniform septic tank effluent distribution, shallow placement of the OSWDS in the most biologically active aerobic soil horizon, and the maximization of unsaturated flow as a result of reduced loading rates.

In the Penn-Bucks soil, the failure of the narrow trench design (19) was attributed to a loading rate that was too high to overcome the soil limitations present at that site. Half the Virginia loading rate appeared to function better in terms of hydraulic performance than the standard Virginia loading rate (21) because the reduced loading rate was conducive to the development of drier conditions below the trench bottom in both sampling seasons. In terms of microbial removal, half the Virginia loading rate was the most successful at retaining both the bacterial

and viral tracers and is probably a function of the drier system. In terms of enhancement of denitrification, the standard Virginia loading rate was the most effective during both the summer of 1989 and the winter of 1990, probably the result of the higher loading rate, producing a longer period of saturation after dosing, as well as of a higher level of substrate for the denitrifying microorganisms below the trench bottom.

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APPENDIX A

Design for Shallow-Placed, Low Pressure Distribution Systems

Design for Shallow-Placed Low Pressure Distribution
System at Kline Property

January 15, 1988

1. Site Location

4 miles north of Harrisonburg on Rt. 42.

Mailing address: Route 1, Box 44, Linville, Va. 22834

2. Site Constraints

- a. Percolation rate equals 120 min/in (est.)
- b. Slope = 2%
- c. Flow = 300gpd

3. Drainfield subsystem Designs

Three experimental, shallow-placed low pressure distribution systems will be installed on-site. Each system will be installed on contour and at a depth of one foot. Subsystem 1 is designed according to North Carolina State regulations with an effective trench bottom loading rate of 0.37 gpd/ft². These trenches will be installed using a ditch witch and have a trench width of 8 inches with a center to center spacing of 5 ft. This subsystem will receive 115 gpd. Subsystem 2 (VA1) is designed according to the Virginia regulations with a trench bottom loading rate of 0.22 gpd/ft². These trenches will be installed using a backhoe and have a trench width of two feet with a center to center spacing of 6 ft. This subsystem will also receive 115 gpd. The third subsystem (VA2) will also have 2 ft trenches and a center to center spacing of 6 ft, but the trench bottom loading is 0.11 gpd/ft². See Figures 1 and 2.

A. Subsystem 1: North Carolina Regulations

Loading rate = 0.05 gpd/ft² total drainfield area

115 gpd/0.05 gpd/ft² = 2300 ft²

2300 ft²/5 ft separation = 460 linear ft.

460 ft x .67 ft = 308.2 ft² trench bottom area

115 gpd/308.2 ft² = 0.37 gpd/ft² trench bottom loading rate

Design on (9) 50 ft lines, 8 in wide with 5 ft separation distance between laterals.

He + Hp	Q,man	Manifold size,in	Vel,fps	Hf,pipe	Hf,contr.	Head,adj.
1.2	45	3	1.99	---	---	1.2
1.3	40	3	1.77	.024	---	1.28
1.4	35	2	3.41	.15	.01	1.24
1.5	30	2	2.93	.25	.01	1.24
1.6	25	2	2.44	.32	.01	1.27
1.7	20	2	1.95	.37	.01	1.32
1.8	15	2	1.46	.40	.01	1.39
1.9	10	1.25	2.21	.49	.02	1.39
2.0	5	1	1.93	.58	.03	1.39

Lat	Head	Hole,in	Q,gpm	no.Holes	Spacing,in	Discharge Rate,gpm
1	1.2	3/16	0.469	11	54	5.16
2	1.28	3/16	0.484	10	60	4.84
3	1.24	3/16	0.477	10	60	4.77
4	1.24	3/16	0.477	10	60	4.77
5	1.27	3/16	0.483	10	60	4.83
6	1.32	3/16	0.492	10	60	4.92
7	1.39	3/16	0.505	10	60	5.05
8	1.39	3/16	0.505	10	60	5.05
9	1.39	3/16	0.505	10	60	5.05
Total Discharge,gpm						44.44

B. Subsystem 2: Virginia regulations (VA1)

$456 \text{ ft}^2/100 \text{ gal} \times 115 \text{ gal} = 524 \text{ ft}^2$

$115 \text{ gpd}/524 \text{ ft}^2 = .22 \text{ gpd}/\text{ft}^2$ trench bottom loading rate

$524 \text{ ft}^2/2 \text{ ft wide} = 262 \text{ linear ft}$

Design on (8) 32.5 ft lines, 2 ft wide with 6 ft separation distance between laterals.

He + Hp	Q _{man}	Manifold size, in	Vel, fps	Hf, pipe	Hf, contr.	Head, adj.
2.0	53.6	3	2.37	---	---	2.0
2.0	53.6	3	2.37	---	---	2.0
2.12	40.2	2	3.9	.165	.03	1.93
2.12	40.2	2	3.9	.165	.03	1.93
2.24	26.8	2	2.62	.245	.03	1.97
2.24	26.8	2	2.62	.245	.03	1.97
2.36	13.4	1 1/4	2.96	.405	.06	1.9
2.36	13.4	1 1/4	2.96	.405	.06	1.9

Lat	Head	Hole, in	Q, gpm	no. Holes	Spacing, in	Discharge Rate, gpm
1L	2.0	13/64	.7106	8	48	5.68
1R	2.0	13/64	.7106	8	48	5.68
2L	1.93	7/32	.8097	7	55	5.67
2R	1.93	7/32	.8097	7	55	5.67
3L	1.97	13/64	.7053	8	48	5.64
3R	1.97	13/64	.7053	8	48	5.64
4L	1.9	7/32	.8033	7	55	5.62
4R	1.9	7/32	.8033	7	55	5.62
Total Discharge, gpm						45.22

C. Subsystem 3: Modified Virginia Regulations (VA2)

$45 \text{ gal}/0.11 \text{ gpd}/\text{ft}^2 = 409 \text{ ft}^2$

$409 \text{ ft}^2/2 \text{ ft wide} = 204.5 \text{ linear ft.}$

Design on (6) 32.5 lines, 2ft wide with 6ft separation distance between laterals.

He + Hp	Q,man	Manifold size,in	Vel,fps	Hf,pipe	Hf,contr.	Head,adj.
1.1	18	1 1/4	3.98	---	---	1.1
1.1	18	1 1/4	3.98	---	---	1.1
1.22	12	1 1/4	2.65	.13	---	1.09
1.22	12	1 1/4	2.65	.13	---	1.09
1.34	6	1 1/4	1.33	.17	---	1.17
1.34	6	1 1/4	1.33	.17	---	1.17

Lat	Head	Hole,in	Q,gpm	no.Holes	Spacing,in	Discharge Rate,gpm
1L	1.1	3/16	.4491	7	55	3.14
1R	1.1	3/16	.4491	7	55	3.14
2L	1.09	3/16	.4471	7	55	3.13
2R	1.09	3/16	.4471	7	55	3.13
3L	1.17	3/16	.4632	7	55	3.24
3R	1.17	3/16	.4632	7	55	3.24
Total Discharge,gpm						19.02

4. Dosing Volume

4 in. Manifold
246 ft
 $246 \text{ ft} \times 66.12 \text{ gal}/100 \text{ ft} = 163 \text{ gal}$

3 in. Manifold
34 ft
 $34 \text{ ft} \times 36.7 \text{ gal}/100 \text{ ft} = 12.5 \text{ gal}$

2 in. Manifold
22 ft
 $22 \text{ ft} \times 16.2 \text{ gal}/100 \text{ ft} = 3.6 \text{ gal}$

1 1/4 in. Manifold
29 ft
 $29 \text{ ft} \times 6.4 \text{ gal}/100 \text{ ft} = 1.9 \text{ gal}$

1 in. Manifold
5 ft
 $5 \text{ ft} \times 4.1 \text{ gal}/100 \text{ ft} = .2 \text{ gal}$

Laterals
 $(4 \times 65) + (3 \times 65) + (9 \times 50) = 905 \text{ ft}$
 $905 \text{ ft} \times 6.4 \text{ gal}/100 \text{ ft} = 58 \text{ gal}$

Dosing Volume
 $181.2 \text{ gal} + 7(58 \text{ gal}) = 587.2 \text{ gal}$
 $181.2 \text{ gal} + 10(58 \text{ gal}) = 763 \text{ gal}$
choose 600 gal/dose

5. Depth of Effluent in Trenches

a. Subsystem 1:

$171 \text{ gal} \times \text{ft}^3/7.48 \text{ gal} = 22.9 \text{ ft}^3 \text{ applied}$
 $22.9 \text{ ft}^3 \div (9 \times 50 \text{ ft} \times .67 \text{ ft}) = .076 \text{ ft}$
.076 ft = .91 in

b. Subsystem 2:

$171 \text{ gal} \times \text{ft}^3/7.48 \text{ gal} = 22.9 \text{ ft}^3 \text{ applied}$
 $22.9 \text{ ft}^3 \div (8 \times 32.5 \text{ ft} \times 2 \text{ ft}) = .04 \text{ ft}$
.04 ft = .48 in

c. Subsystem 3:

$65 \text{ gal} \times \text{ft}^3/7.48 \text{ gal} = 8.7 \text{ ft}^3$
 $8.7 \text{ ft}^3 \div (6 \times 32.5 \text{ ft} \times 2 \text{ ft}) = .02 \text{ ft}$
.02 ft = .24 in

6. Pump Specification

a. Head Losses

1) Frictional

4 in. manifold $Q = 110 \text{ gpm}$
.7 ft/100 ft $\times 209 \text{ ft} = 1.5 \text{ ft}$

4 in. manifold Q = 46 gpm
 $.136 \text{ ft}/100 \text{ ft} \times 37.5 \text{ ft} = .05 \text{ ft}$

3 in. manifold Q = 45 gpm
 $.5 \text{ ft}/100 \text{ ft} \times 34 \text{ ft} = .17 \text{ ft}$

2 in. manifold Q = 40 gpm (max)
 $2.75 \text{ ft}/100 \text{ ft} \times 22 \text{ ft} = 0.605 \text{ ft}$

1 1/4 in. manifold Q = 18 gpm (max)
 $4.67 \text{ ft}/100 \text{ ft} \times 29 \text{ ft} = 1.35 \text{ ft}$

1 in. manifold Q = 5 gpm
 $1.72 \text{ ft}/100 \text{ ft} \times 5 \text{ ft} = .09 \text{ ft}$

Total

$1.2(1.5 + .05 + .17 + .61 + 1.35 + .09) = 4.52 \text{ ft}$

2) Elevation Head

- a) 5 ft from pump to manifold
- b) 12 ft from pump chamber to field
- c) 1 ft to top of field
- d) Total - 18 ft of elevation head

3) Pressure Head

3.0 ft pressure head (extra 1 ft head for future adjustments to field)

4) Total Head Loss

$4.52 \text{ ft} + 18 \text{ ft} + 3.0 \text{ ft} = 25.5 \text{ ft}$
 Safety factor = 30 ft

b. Pumping Capacity

1/4" drainhole to be placed above check valve but within tank to allow manifold to drain thus avoiding any potential freezing in the line.

$$\frac{\pi(.25)^2}{576} \times 2233 \times \sqrt{18 \text{ ft}} = 3.23 \text{ gpm}$$

$3.23 + 44.44 + 45.22 + 19.02 = 112 \text{ gpm}$

c. Pump must be able to deliver 112 gpm against 30ft of head.

7. Gravel Calculations

$455 \text{ ft} \times 2 \text{ ft} \times .67 \text{ ft} = 610 \text{ ft}^3$

$450 \text{ ft} \times .67 \text{ ft} \times .67 \text{ ft} = 202 \text{ ft}^3$

$610 + 202 = 812 \text{ ft}^3 \times 1.1 = 895 \text{ ft}^3$

$895 \text{ ft}^3 \times 1 \text{ yd}^3/27 \text{ ft}^3 = 33.15 = 34 \text{ yd}$

$34 \text{ yds} \times 1.35 \text{ ton/yd} = 46 \text{ tons}$

8. Top Soil Calculations

The entire drainfield area is to be covered with approximately 1 ft of soil to protect the system from freezing.

$$120 \text{ ft} \times 44 \text{ ft} \times .5 \text{ ft} = 2640 \text{ ft}^3$$

use 3:1 sides

$$1/2 (2.8 \text{ ft})(.5 \text{ ft}) \times (44 + 44 + 120 + 120) = 230 \text{ ft}^3$$

$$2640 \text{ ft}^3 + 230 \text{ ft}^3 = 2870 \text{ ft}^3$$

$$2870 \text{ ft}^3 \times 1 \text{ yd}^3/27 \text{ ft}^3 = 107 \text{ yd}^3$$

NEED 107 yd³ of top soil

General notes on installation of subsystems

1. All trenches are to be installed on the contour at a depth of 12 in.
2. Subsystems 2 and 3 (VA1 and VA2) have 2ft wide trenches and subsystem 1 (N.C.) has 8in wide trenches. The trenches in 2 and 3 will be dug with a conventional backhoe. The trenches for system 1 will be installed with a trenching machine (ditch witch).
3. All laterals will be underlain with 6in of gravel with 2in of gravel covering the laterals. Mirafi cloth will be placed over the gravel and the system backfilled with at least 4in of soil.
4. The ends of the laterals will be equipped with 12in. turnups with removable threaded caps. 3 1/2ft riser pipes with threaded couplings adaptable to turnup will be supplied for each lateral. See figure 6.
5. Discharge holes in laterals should be evenly spaced along the length of the lateral, but no hole should be placed within 24in of manifold. See Figures 3-5 for layout.
6. Note that all laterals are 1 ft longer than design length to allow for connection to manifold.
7. A step (or block) of soil is to be left at the end of each lateral trench where it connects to the manifold trench.
8. The entire drainfield area will be covered with approximately .5 ft of soil to protect the system from freezing.
9. Details of manifold connections and pump chamber can be found in figures 7 and 8.
NOTE 1/4 in drainhole in tank but above check valve.

Listing Sheet (1)

Septic Tank

- (3) 4in sch 40 couplings
- (40ft) 4in sch 40 PVC pipe
- (3) 4in sch 40 ells (90 deg)
- (1) 4in bullrun valve
- (2) 4in sch 40 ells (45 deg)

Pump Chamber

- (1) 2000 gallon (minimum) 1 piece, with gasket, pumping chamber, set in place
- (1) concrete riser with lid to cover access to pump chamber(well curb with lid) or equivalent.(See Figure 8)
- (1) sewage pump with 110 or 220v, installed on site to pump a minimum of 131 gpm against 17 feet of head set to pump 335 gallons per dose, placed on 6 or 8in concrete block in pump chamber.
- (1) control panel plus on/off and high water floats for pump. Panel must have visual and audible high water alarm and be equipped with a counter that advances each time the pump turns on. Floats must be able to be adjusted at the end of the experimental phase to deliver 425g.
- (1) check valve (size dependent on diameter of pump outlet)
- (1) gate valve in tank (size dependent on diameter of pump outlet)
- (1) quick release coupling (size dependent on diameter of pump outlet) must be able to stand pumping pressures
- (1) all connections, piping to bring pump discharge to 4 in. sch 40 line outside of pump chamber
- (2) meter boxes with 1 ft extension for each with lids

Miscellaneous

- 4 pints PVC cleaner
- 4 pints PVC glue
- 1 in-house water meter with necessary fittings

NOTE: all fittings to be sch 40, pressure fittings.

All materials are to be delivered to the job site in accordance with schedule developed by VPI & SU personnel.

NOTE: VPI & SU will supply piping, fittings, and valves to transport effluent from immediately outside pump chamber through manifold and to drainfield.

Listing Sheet (2)

A. Vendor will be responsible for

1. installing in-house water meter
2. installing pump chamber
3. setting the pump
4. installing pump alarm panel in home and all necessary electrical connections between pump, alarm panel, and household current. Connections must conform with attached specifications (p.11)
5. installing manifold and drainfield to the specifications of VPI & SU personnel.

B. The following material will be supplied to the Dennis Kline home:

1. Total of 46 tons of crushed limestone gravel (1/2 to 3/4 in diameter) to be delivered on-site before day of construction.
2. 107 yd³ of good quality top soil to be delivered on-site during construction.

C. Vendor will specify hourly charge for:

1. backhoe with loader for installation of site. One foot and 2ft buckets required on backhoe.
2. A Ditch Witch (trenching machine) capable of installing 8in wide trenches (no substitutes allowable)
3. hourly rate for laborers as needed.

Work will begin as soon as possible. Contact should be made with VPI directly after the contract is awarded to coordinate an initial meeting and actual installation. VPI & SU will supply piping, fittings and valves to transport effluent from immediately outside pump chamber through manifold and to drainfield.

Specifications for pump wiring

Enclosures: The electric motor control center, master disconnect switch, and alarm controls shall be installed in a NEMA 4 (National Electric Manufacturers Association) enclosure.

Electrical Junctions: All electrical junctions shall be of a permanent or semi-permanent nature (hard wired). The use of a temporary plug to connect the motor control device, master disconnect switch, or alarm is prohibited.

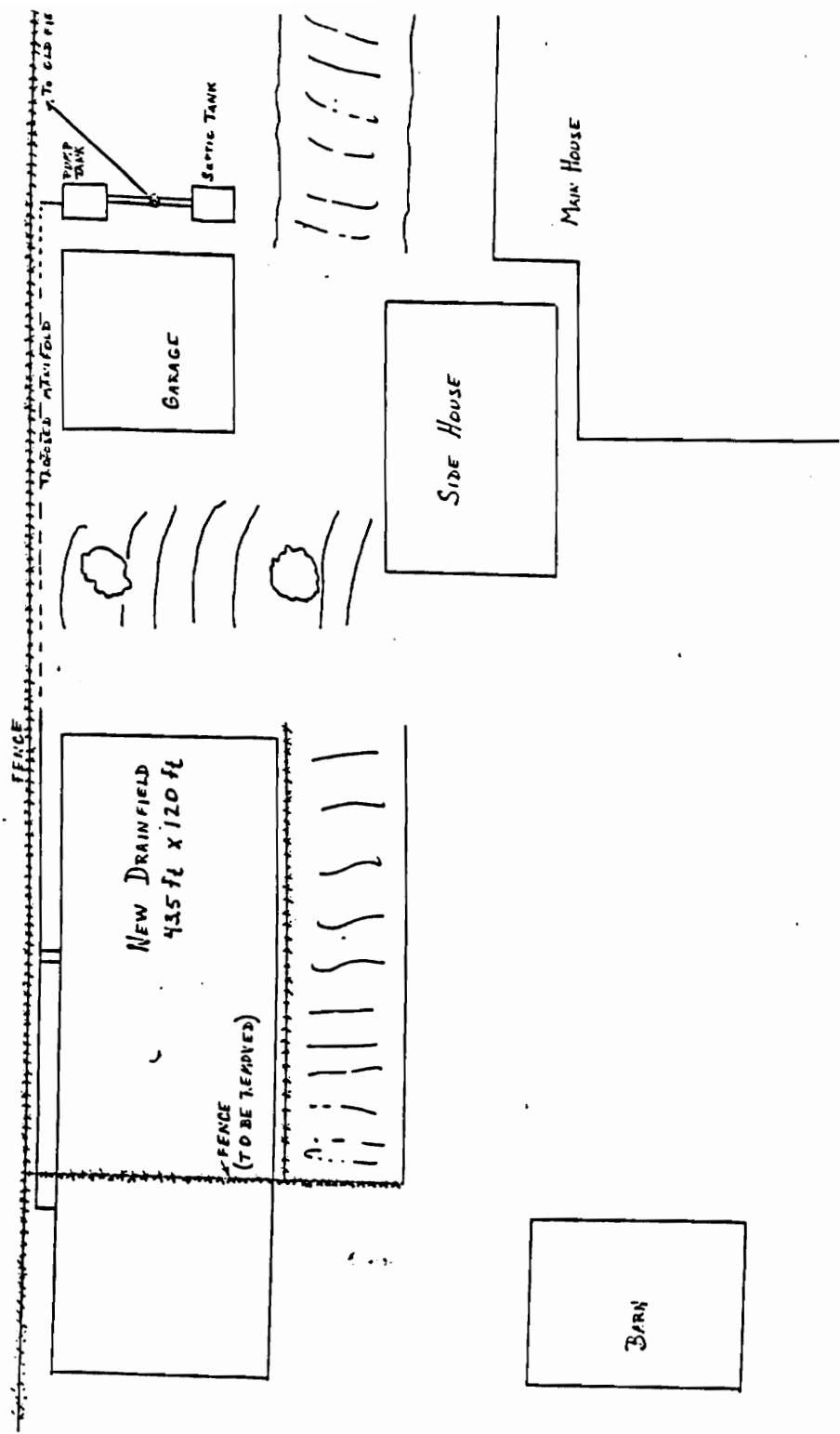


Figure 1. General location of system.

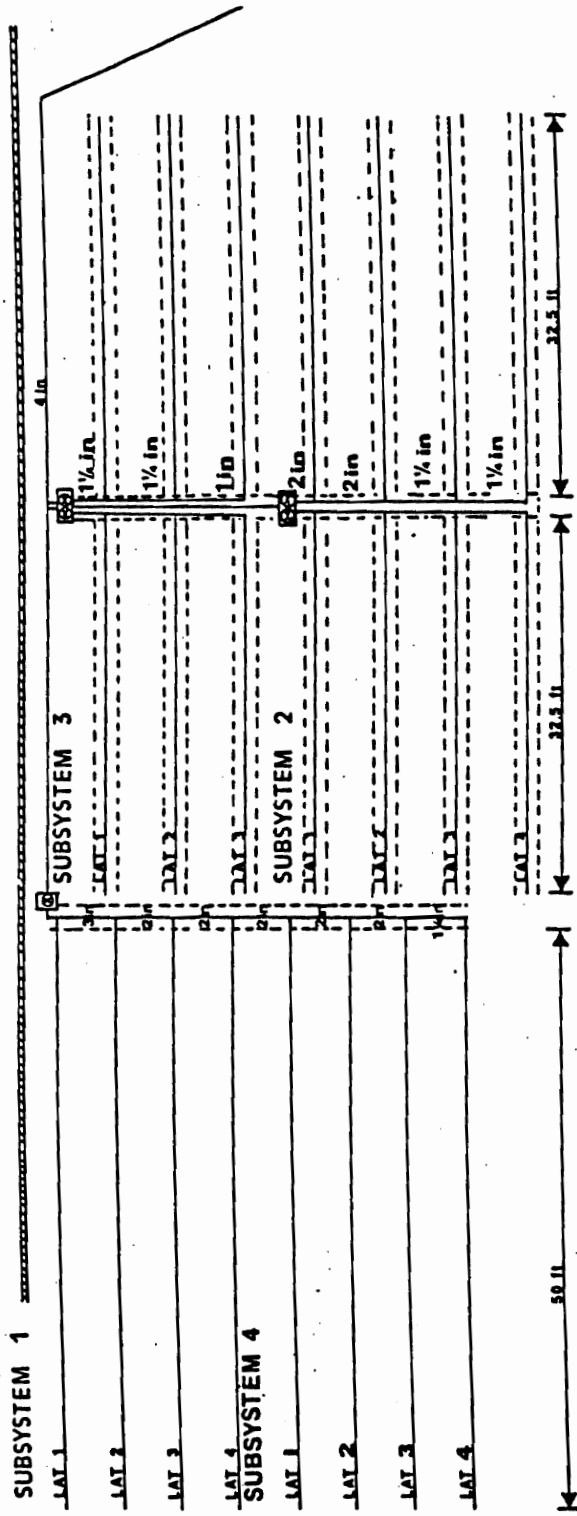


Figure 2. Layout of Kline system. All laterals are 1 1/2" in diameter. Manifold diameter are as indicated.

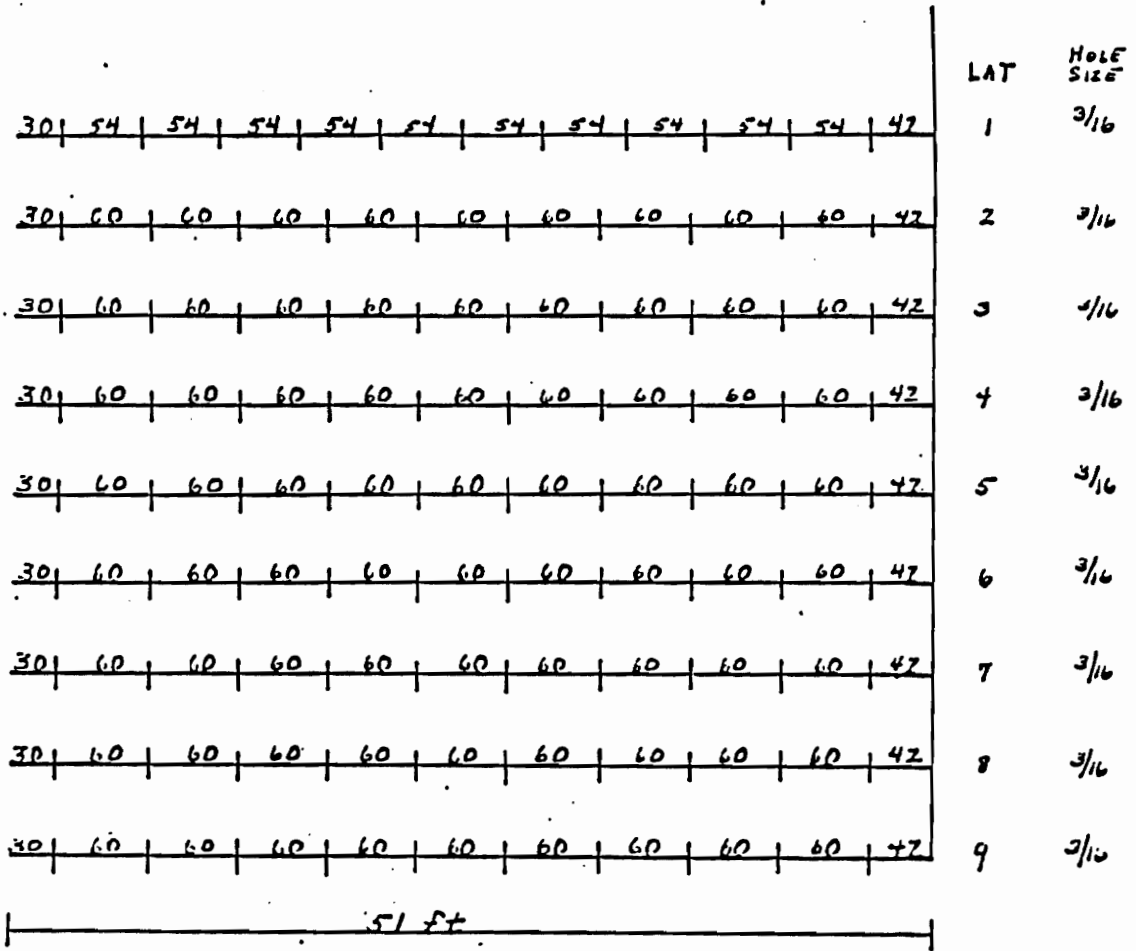
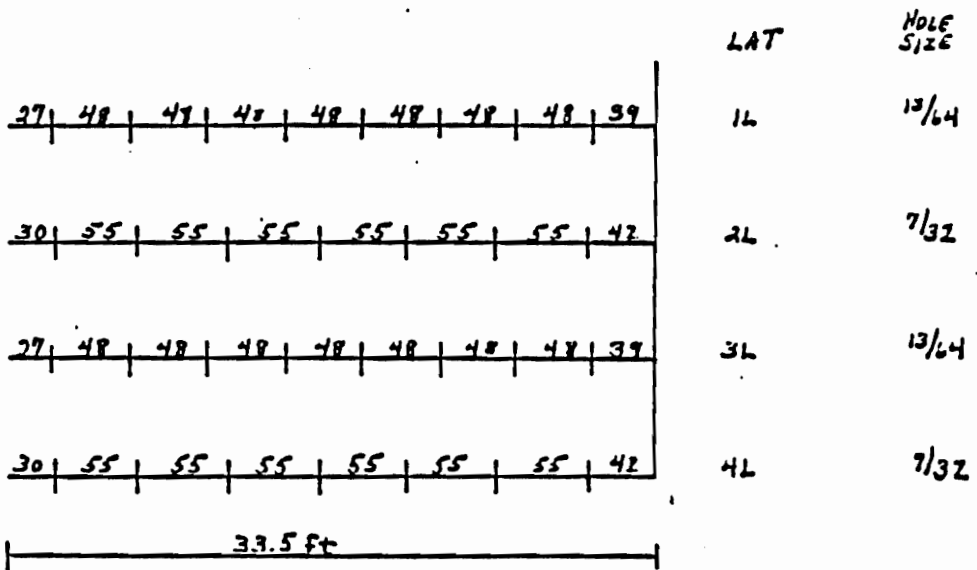
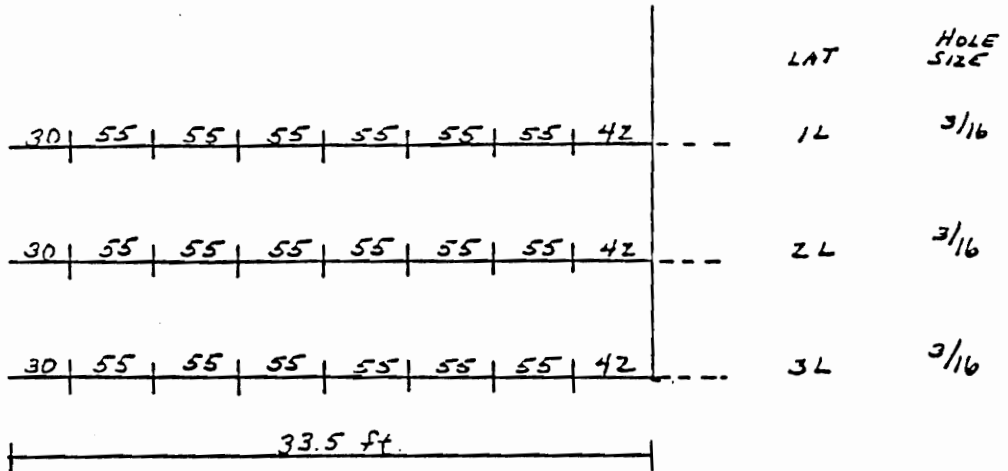


Figure 3. Subsystem I - Hole size and spacing in inches.



NOTE: REPEAT HOLES FOR OTHER HALF OF LATERALS (1R, 2R, 3R, 4R)

Figure 4. Subsystem 2 - Hole size and spacing in inches.



NOTE: REPEAT HOLES FOR OTHER HALF OF LATERALS (1R, 2R, 3R).

Figure 5. Subsystem 3 - Hole size and spacing in inches.

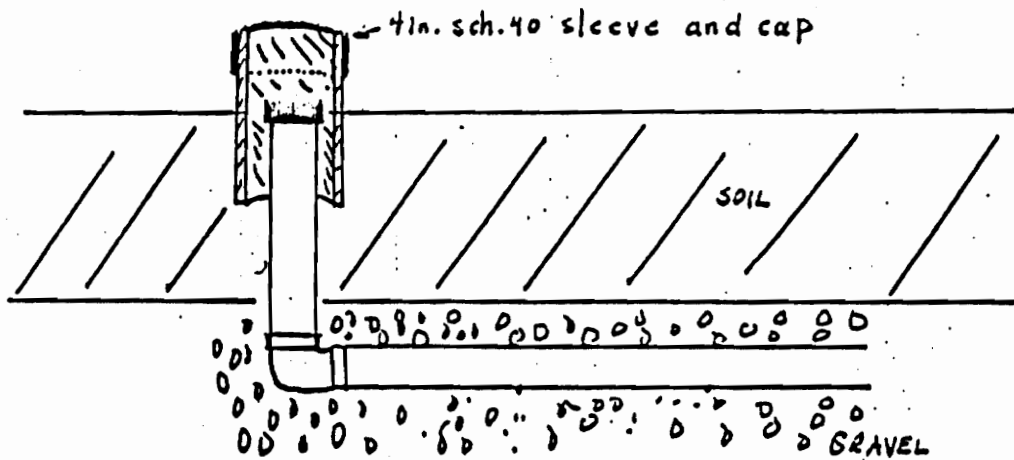
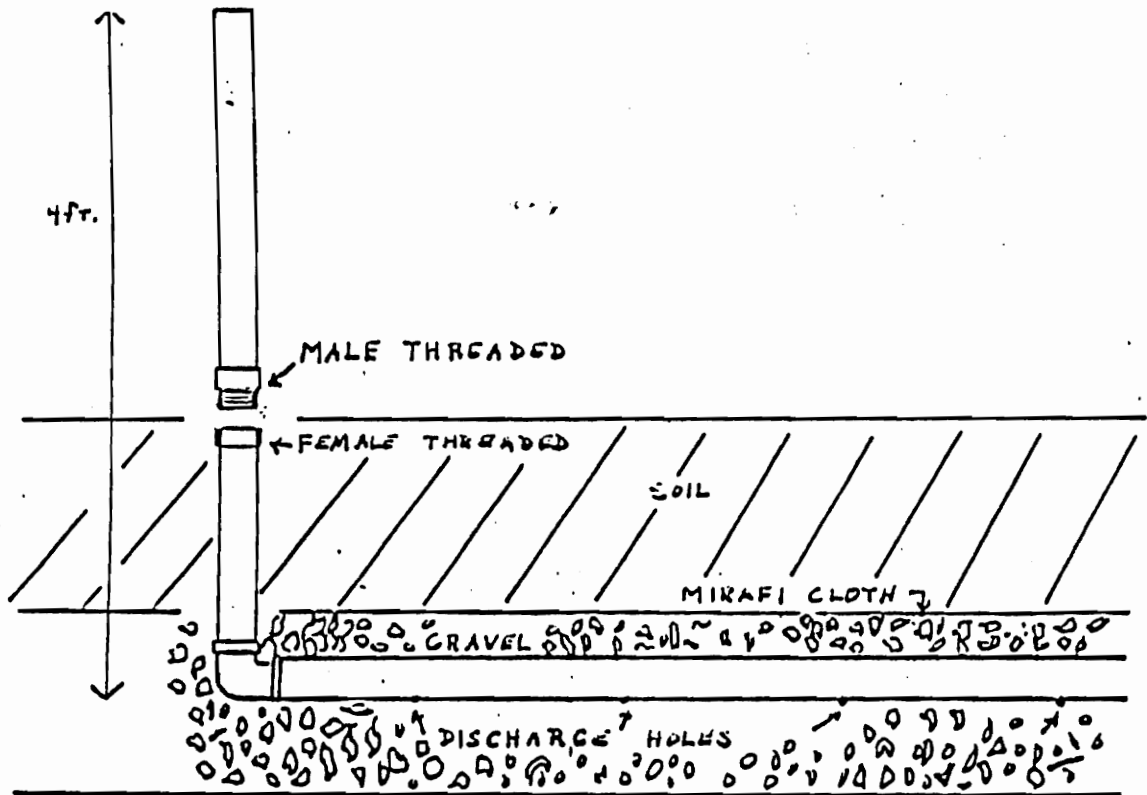
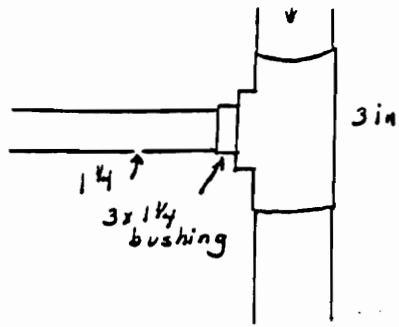
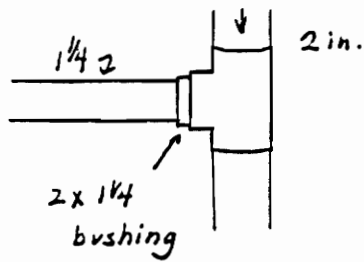


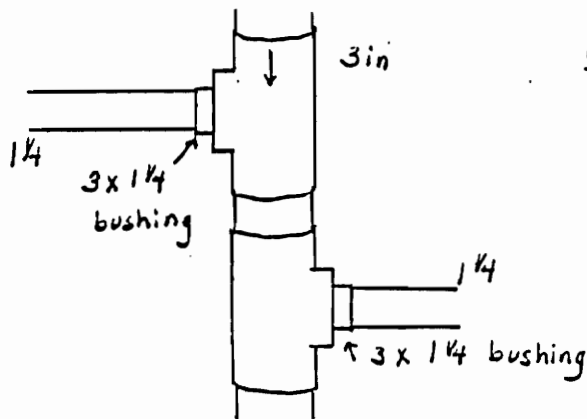
Figure 6. Riser pipe details.



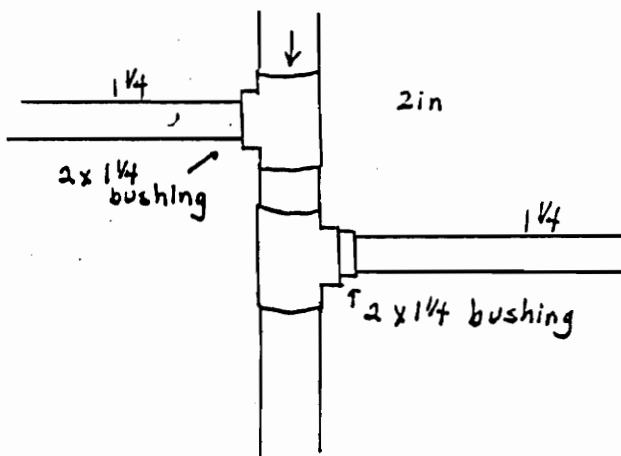
Subsystem 1
Laterals 1, 2



Subsystem 1
Laterals 3, 4, 5, 6, 7



Subsystem 2
Lateral 1



Subsystem 2
Laterals 2, 3

Figure 7. Detail of manifold connections.

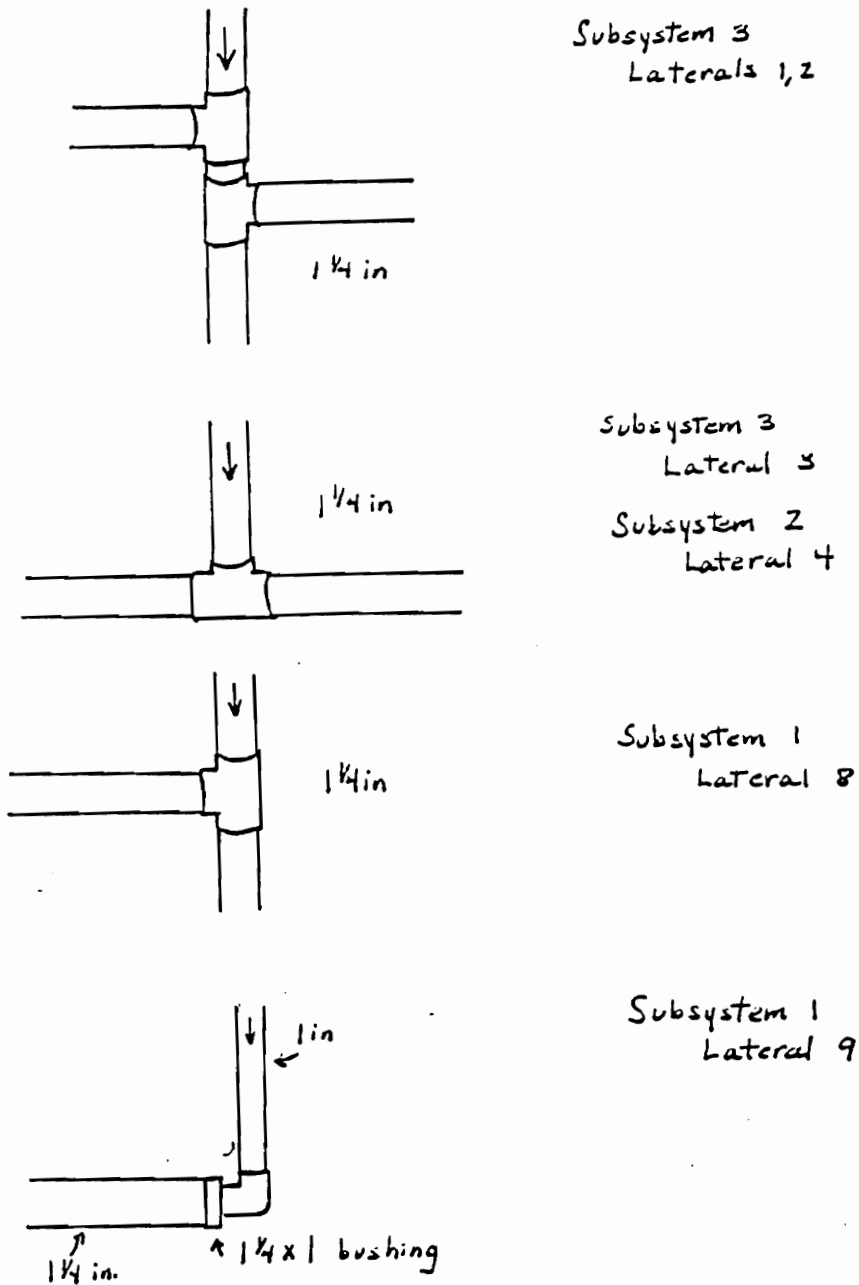


Figure 7. Detail of manifold connections. (continued)

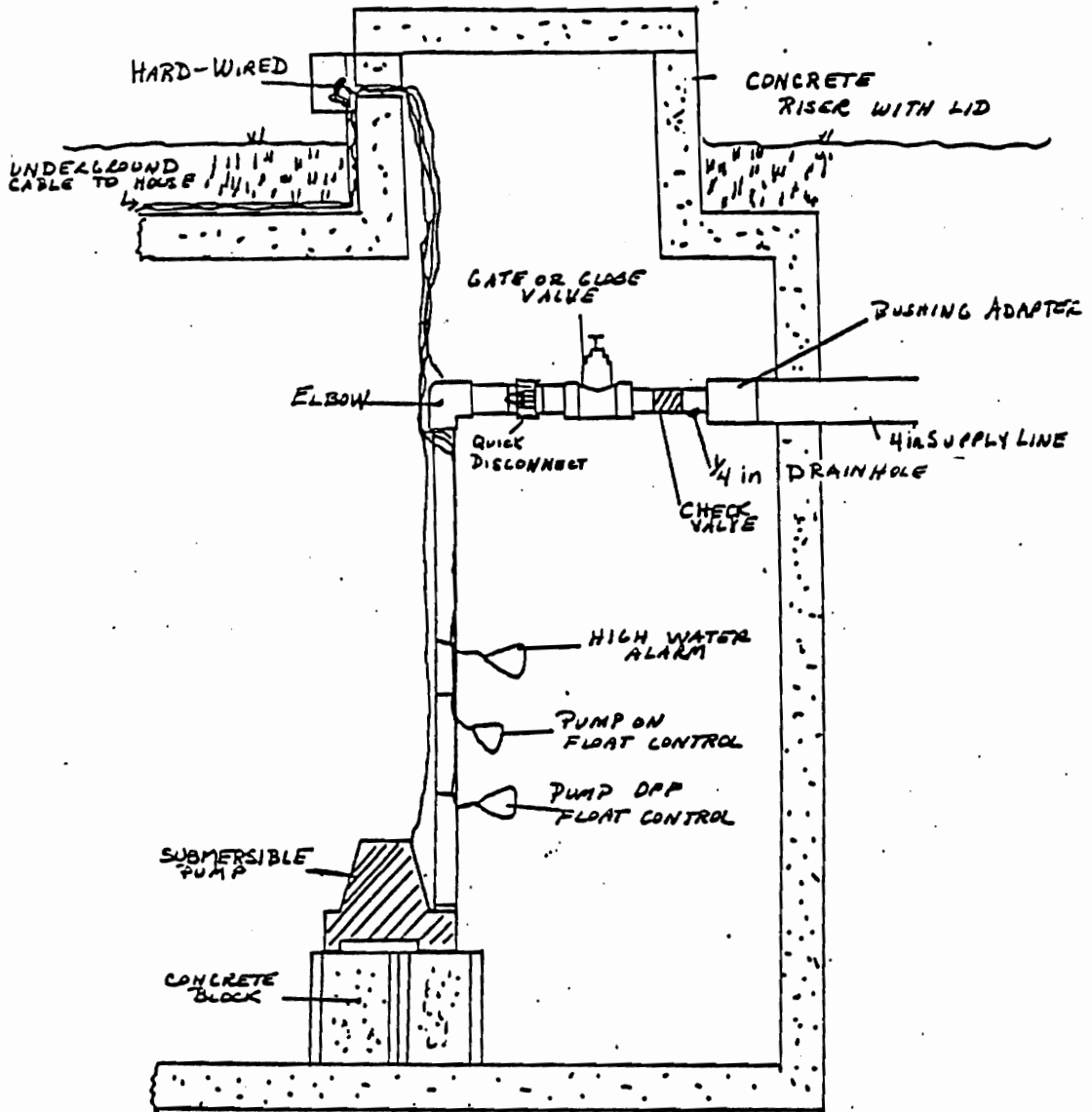


Figure 8. Pump chamber details.

Design for Shallow-Placed Low Pressure Distribution
System at Thomas Property

March 9, 1988

1. Site Location

Rt. 285 to Knokesville

Left onto Fitzwater Dr.

Take Rt. on Aden Dr.

Pass a highschool

Left onto Parkgate Dr.

House on left - white bungalow. 11504 Parkgate Dr.

2. Site Constraints

- a. Percolation rate equals 90 min/in (est.)
- b. Slope - variable: 2-4%
- c. 3 bedrooms

3. Flow calculations

$$150 \text{ gpd/bedroom} \times 3 \text{ bedrooms} = 450 \text{ gpm}$$

4. System Description

Low pressure distribution lines will be placed at 12 inches below the soil surface. Subsystem 1 will be installed according to Virginia regulations with 2 foot wide trenches, 6ft separation distance between laterals, and a 0.35 gpd/ft² trench bottom loading rate. Subsystem 2 is based on North Carolina's criteria and will have 8 inch wide trenches, 5ft separation distance between laterals, and a .75 gpd/ft² trench bottom loading rate. Subsystem 3 will have 2 ft wide trenches, and a 6ft separation distance between laterals as in subsystem 1, but will have a loading rate of .175 gpd/ft². The experimental system has been sized to treat approximately 300 gallons. With only two people presently residing in the house, a large system would not have been dosed with any regularity and the resulting data would not have been representative. In order to accomodate design flows for a three bedroom house, the system will be adjusted at the end of the experimental phase to accomodate 455 gpd. A reserve system has been added to treat 175 gallons and is designed according to Virginia regulations with 2 foot wide trenches and a loading rate of .35 gpd/ft². In addition the head on Subsystem 3 will be increased to double the discharge rate to .35 gpd/ft². Subsystem 2, (North Carolina) will be abandoned at the end of the experiment. Table 1 demonstrates the change in flow distribution during and after the experimental phase.

Table 1. Flow distribution during and after the experimental phase.

	During (gal)	After (gal)
Subsystem 1 (VA1)	175	175
Subsystem 2 (NC)	75	-
Subsystem 3 (VA2)	52.5	105
Reserve	-	175
Total	302.5	455

Subsystem 1: VAI

Lat	He+Hp	Q _{man}	Manifold in.	Vel fps	H _L Pipe	H _L Contr.	H _L Cum	Adj Head
1	2.0	50	3	2.21	-	-	-	2.0
2	2.12	40	3	1.77	.02	-	.02	2.10
3	2.24	30	2 1/2	2.05	.04	-	.06	2.18
4	2.36	20	2	1.95	.05	-	.11	2.25
5	2.48	10	1 1/4	2.21	.09	.02	.22	2.26

Lat	Head	Hole,in	Q,gpm	No. Holes	Spacing,in	Discharge Rate,gpm
1	2.0	13/64	.7106	14	42.86	9.95
2	2.1	3/16	.6205	16	37.5	9.93
3	2.18	3/16	.6322	16	37.5	10.12
4	2.25	15/64	1.004	10	60	10.04
5	2.26	15/64	1.004	10	60	10.04
Total Discharge,gpm						50.08

B. Subsystem 2 (NC)

Lat	He+Hp	Q,man	Manifold in.	Vel fps	H _L Pipe	H _L Contr.	H _L Cum	Adj Head
1	2.0	21	2	2.05	-	-	-	2.0
2	2.1	14	1 1/2	2.26	.07	.01	.08	2.02
3	2.2	7	1 1/4	1.55	.04	.01	.13	2.07

Lat	Head	Hole,in	Q,gpm	no.Holes	Spacing,in	Discharge Rate,gpm
1	2.0	13/64	.7106	10	60	7.11
2	2.02	13/64	.7142	10	60	7.14
3	2.07	13/64	.7229	10	60	7.23
Total Discharge,gpm						21.48

C. Subsystem 3: (VA2)

a) Experimental

Lat	He + Hp	Q,man	Manifold in.	Vel fps	H _L Pipe	H _L Contr.	H _L Cum	Adj Head
1	1.0	15	1 1/2	2.42	-	-	-	1.0
2	1.24	10	1 1/2	1.62	.04	-	.04	1.20
3	1.48	5	1 1/4	1.11	.02	.01	.07	1.41

Lat	Head	Hole,in	Q,gpm	no.Holes	Spacing,in	Discharge Rate,gpm
1	1.0	13/64	.5025	10	60	5.03
2	1.20	3/16	.4691	11	54.5	5.16
3	1.41	3/16	.5085	10	60	5.08
Total Discharge,gpm						15.27

b) Permanent

Lat	He + Hp	Q,man	Manifold in.	Vel fps	H _L Pipe	H _L Contr.	H _L Cum	Adj Head
1	4.0	30	1 1/2	4.85	-	-	-	4.0
2	4.24	20	1 1/2	3.23	.16	-	.16	4.08
3	4.48	10	1 1/4	2.21	.09	.02	.27	4.21

Lat	Head	Hole,in	Q,gpm	no.Holes	Spacing,in	Discharge Rate,gpm
1	4.0	13/64	1.005	10	60	10.05
2	4.08	3/16	.8649	11	54.5	9.51
3	4.21	3/16	.8786	10	60	8.79
Total Discharge,gpm						28.35

Reserve Subsystem

Lat	He+Hp	Q,man	Manifold in.	Vel fps	H _L Pipe	H _L Contr.	H _L Cum	Adj Head
1	2.0	50	3	2.21	-	-	-	2.0
2	2.24	40	3	1.77	.02	-	.02	2.22
3	2.48	30	2 1/2	2.05	.04	-	.06	2.42
4	2.72	20	2	1.95	.05	-	.11	2.61
5	2.86	10	1 1/4	2.21	.09	.02	.22	2.64

Lat	Head	Hole,in	Q,gpm	no.Holes	Spacing,in	Discharge Rate,gpm
1	2.0	13/64	.7106	14	42.9	9.95
2	2.22	3/16	.638	16	37.5	10.21
3	2.42	3/16	.666	15	40	9.99
4	2.61	13/64	.812	12	50	9.74
5	2.64	13/64	.816	12	50	9.79
Total Discharge,gpm						49.68

Dosing Volume

A. Experimental System

a. Manifold

- 1) 4 in.
 $50\text{ft} \times 66.12 \text{ gal}/100\text{ft} = 33.06 \text{ gal}$
- 2) 3 in.
 $15 + 40 + 6 + 6 = 67\text{ft}$
 $67\text{ft} \times 36.7\text{gal}/100\text{ft} = 24.6 \text{ gal}$
- 3) 2 1/2 in.
 $100 + 6 = 106\text{ft}$
 $106\text{ft} \times 24.91 \text{ gal}/100\text{ft} = 26.4\text{gal}$
- 4) 2 in.
 $12\text{ft} \times 16.2 \text{ gal}/100\text{ft} = 1.94 \text{ gal}$
- 5) 1 1/2 in.
 $(6 + 6 + 6) \times 9.2 \text{ gal}/100\text{ft} = 1.66 \text{ gal}$
- 6) 1 1/4 in.
 $(6 + 6 + 6) \times 6.4 \text{ gal}/100\text{ft} = 1.15 \text{ gal}$
- 7) Manifold Total
88.8 gal

b. Laterals

$$11 \times 50 \times 6.4 \text{ gal}/100\text{ft} = 35.2 \text{ gal}$$

c. Dosing Volume

$$88.8 + 7(35.2) = 335.2 \text{ gal}$$
$$88.8 + 10(35.2) = 440.8 \text{ gal}$$

Set Dosing volume for 335 gallons

B) Permanent System

a. Manifold

- 1) 4 in.
 $50 \text{ ft} \times 66.12 \text{ gal}/100\text{ft} = 33.06 \text{ gal}$
- 2) 3 in. manifold
 $(15 + 40 + 120 + 6 + 6 + 6) \times 36.7 \text{ gal}/100\text{ft} = 70.83 \text{ gal}$
- 3) 2 1/2 in manifold
 $(100 + 6 + 6) \times 24.91 \text{ gal}/100 \text{ ft} = 27.9 \text{ gal}$
- 4) 2 in manifold
 $(6 + 6) \times 16.2 \text{ gal}/100\text{ft} = 1.94 \text{ gal}$
- 5) 1 1/2 in manifold
 $(6 + 6) \times 9.2 \text{ gal}/100 \text{ ft} = 1.1 \text{ gal}$
- 6) 1 1/4 in manifold

$$(6 + 6 + 6) \times 6.4 \text{ gal}/100 \text{ ft} = 1.15 \text{ gal}$$

7) Manifold Total
136 gallons

b. Laterals

$$13 \times 50 \times 6.4 \text{ gal}/100 \text{ ft} = 41.6 \text{ gallons}$$

c. Dosing Volume

$$136 + 7(41.6) = 427 \text{ gallons}$$

$$136 + 10(41.6) = 552 \text{ gallons}$$

Set dosing volume for 425 gallons.

d. Depth of Effluent in Trenches

1) Experimental

a) Subsystem 1

$$194.3 \text{ g} \times \text{ft}^3/7.48 \text{ g} = 26 \text{ ft}^3 \text{ applied}$$

$$26 \text{ ft}^3 \div (5 \times 50 \text{ ft} \times 2 \text{ ft}) = .052 \text{ ft}$$

$$.052 \text{ ft} = .624 \text{ in}$$

b) Subsystem 2

$$80.4 \text{ g} \times \text{ft}^3/7.48 \text{ g} = 10.75 \text{ ft}^3 \text{ applied}$$

$$10.75 \text{ ft}^3 \div (3 \times 50 \text{ ft} \times .67 \text{ ft}) = .106 \text{ ft}$$

$$.106 \text{ ft} = 1.28 \text{ in}$$

c) Subsystem 3

$$57 \text{ g} \times \text{ft}^3/7.48 \text{ g} = 7.62 \text{ ft}^3 \text{ applied}$$

$$7.62 \text{ ft}^3 \div (3 \times 50 \text{ ft} \times 2 \text{ ft}) = .025$$

$$.025 \text{ ft} = .305 \text{ in}$$

2) Permanent

a) Subsystem 1

$$165.75 \text{ g} \times \text{ft}^3/7.48 \text{ g} = 22.16 \text{ ft}^3 \text{ applied}$$

$$22.16 \text{ ft}^3 \div (5 \times 50 \text{ ft} \times 2 \text{ ft}) = .044 \text{ ft}$$

$$.044 \text{ ft} = .53 \text{ in}$$

b) Subsystem 2

Not Used

c) Subsystem 3

$$93.5 \text{ g} \times \text{ft}^3/7.48 \text{ g} = 12.5 \text{ ft}^3 \text{ applied}$$

$$12.5 \text{ ft}^3 \div (3 \times 50 \text{ ft} \times 2 \text{ ft}) = .042 \text{ ft}$$

$$.042 \text{ ft} = .504 \text{ in}$$

d) Reserve System

$$165.75 \text{ g} \times \text{ft}^3/7.48 \text{ g} = 22.16 \text{ ft}^3 \text{ applied}$$

$$22.16 \text{ ft}^3 \div (5 \times 50 \text{ ft} \times 2 \text{ ft}) = .044 \text{ ft}$$

$$.044 \text{ ft} = .53 \text{ in}$$

e. Pump Specifications

1) Head Losses

a) Frictional

i. Experimental

Size, in	Q	H _L , ft/100ft	L,ft	H _L ,ft
4	86.8	.44	50	.22
3	71.5	1.18	15	.18
3	50	.6	40	.24
3	40	.4	6	.02
2 1/2	15	.19	100	.19
2 1/2	30	.68	6	.04
2	20	.76	6	.05
2	21	.84	6	.05
1 1/2	14	1.37	5	.07
1 1/2	15	1.53	5	.08
1 1/2	10	.72	6	.04
1 1/4	10	1.55	6	.09
1 1/4	7	.81	5	.04
1 1/4	5	.44	6	.03
Total Head Loss				1.34

ii. Permanent

Size, in	Q	H _L , ft/100ft	L,ft	H _L ,ft
4	128	.914	50	.46
3	50	.6	15+40+100+20	1.05
3	40	.4	6+6	.05
2 1/2	30	.68	100+6+6	.76
2	20	.76	6+6	.09
1 1/2	30	5.53	5	.28
1 1/2	20	2.61	6	.16
1 1/4	10	1.55	6+6+6	.28
Total Head Loss				3.13 ft

b) Elevation Head

i. 5 ft from pump to manifold

ii. 2 ft to top of field

iii. total = 7ft

c) Pressure Head

4.0 ft pressure head

d) Total Head Loss

i. Experimental = 1.34ft + 7ft + 4.0ft = 12.34ft

ii. Permanent = 3.13ft + 7ft + 4.0ft = 14.13ft

iii. Specify pump on 14.13ft x 1.2 = 17ft

2) Pumping Capacity

a) Experimental

$$50.08 + 15.25 + 21.48 = 86.8 \text{ GPM}$$

b) Permanent

$$50.08 + 28.35 + 49.68 = 128.1 \text{ GPM}$$

c) 1/4" drainhole to be placed above check valve but within tank to allow manifold to drain. See Figure 8.

$$\frac{\pi(.25)^2}{576} = 2233 \times \sqrt{14.13\text{ft}} = 2.86\text{gpm}$$

3) Pump Specifications

Pump must be able to deliver 131 GPM against 17ft of head.

f. Gravel Calculations

1) 2ft trenches

$$13 \times 50\text{ft} \times 2\text{ft} \times .67\text{ft} = 871\text{ft}^3$$

2) 8 in. trenches

$$3 \times 50\text{ft} \times .67\text{ft} \times .67\text{ft} = 67.3\text{ft}^3$$

3) Total

$$871\text{ft}^3 + 67.3\text{ft}^3 = 938\text{ft}^3$$

$$938\text{ft}^3 \times 1\text{yd}^3/27\text{ft}^3 = 34.8\text{yd}^3$$

$$34.8\text{yd}^3 \times 1.35 \text{ ton/yd} = 47 \text{ tons}$$

$$47 \text{ tons} \times 1.1 = 52 \text{ tons}$$

g. Top Soil Calculations

1) $50 \times 42 \times .5 = 1050\text{ft}^3$

2) $50 \times 46 \times .5 = 1150\text{ft}^3$

3) $4(50 \times .375) + 2(45 \times .375) + 2(49 \times .375) = 145.5\text{ft}^3$

4) $1050 + 1150 + 145.5 = 2347\text{ft}^3$

5) $2347\text{ft}^3 \times 1\text{yd}^3/27\text{ft}^3 = 86.9\text{yd}^3$

6) $86.9\text{yd}^3 \times 1.1 = 96\text{yd}^3$

7) $96\text{yd}^3 - .5(34.8) = 78.6\text{yd}^3$

(subtracting a portion of fill available from gravel displacement)

General notes on installation of subsystems

- 1) All trenches are to be installed on the contour at a depth of 12 in.
- 2) Subsystems 1, 3, the reserve have 2ft wide trenches and subsystem 2 (N.C.) has 8in wide trenches. The trenches in 1, 3 and reserve will be dug with a conventional backhoe. The trenches for system 2 will be installed with a trenching machine (ditch witch), capable of digging an 8in trench.
- 3) All laterals will be underlain with 6in of gravel with 2in of gravel covering the laterals. Mirafi cloth will be placed over the gravel and the system backfilled with at least 4in of soil.
- 4) The ends of the laterals will be equipped with 12in. turnups with removable threaded caps. 3ft riser pipes with threaded couplings adaptable to turnup will be supplied for each lateral. See figure 7.
- 5) Discharge holes in laterals should be evenly spaced along the length of the lateral, but no hole should be placed within 24in of manifold. See Figures 3-6 for layout.
- 6) Note that all laterals are 1 ft longer than design length to allow for connection to manifold. See Figures 1 and 2.
- 7) A step (or block) of soil is to be left at the end of each lateral trench where it connects to the manifold trench. See Figure 9.
- 8) The entire drainfield area will be covered with approximately .5 ft of soil to protect the system from freezing.
- 9) Details of manifold connections and pump chamber can be found in figure 8. Note that a 1/4 drainhole is placed inside of pump tank, but in front of check valve

Listing Sheet (1)

Septic Tank

- (3) 4in sch 40 couplings
- (40ft) 4in sch 40 PVC pipe
- (3) 4in sch 40 ells (90 deg)
- (1) 4in bullrun valve
- (2) 4in sch 40 ells (45 deg)

Pump Chamber

- (1) 2000 gallon (minimum) 1 piece, with gasket, pumping chamber, set in place
- (1) concrete riser with lid to cover access to pump chamber(well curb with lid) or equivalent
- (1) sewage pump with 110 or 220v, installed on site to pump a minimum of 112 gpm against 30 feet of head set to pump 600 gallons per dose, placed on 6 or 8in concrete block in pump chamber.
- (1) control panel with event counter and floats for pump
- (1) check valve (size dependent on diameter of pump outlet)
- (1) gate or globe valve in tank (size dependent on diameter of pump outlet)
- (1) quick release coupling (size dependent on diameter of pump outlet) must be able to stand pumping pressures
- (1) all connections, piping to bring pump discharge to 4 in. sch 40 line outside of pump chamber
- (2) meter boxes with 1 ft extension for each

Miscellaneous

- (950ft) untreated building paper
- 4 pints PVC cleaner
- 4 pints PVC glue
- 1 in-house water meter with necessary fittings

NOTE: all fittings to be sch 40, pressure fittings.

All materials are to be delivered to the job site in accordance with schedule developed by VPI & SU personnel.

NOTE: VPI & SU will supply piping, fittings, and valves to transport effluent from immediately outside pump chamber through manifold and to drainfield.

Listing Sheet (2)

A. Vendor will be responsible for

- 1) installing in-house water meter
- 2) installing pump chamber
- 3) setting the pump
- 4) installing pump alarm panel in home and all necessary electrical connections between pump, alarm panel, and household current. Connections must conform with attached specifications.(See following page)
- 5) installing manifold and drainfield to the specifications of VPI & SU personnel.
- 6) final grading and seeding of site.

B. The following material will be supplied to the Douglas Thomas home:

- 1) Total of 52 tons of crushed limestone gravel (1/2 to 3/4 in diameter) to be delivered on-site before day of construction.
- 2) 77yd³ of good quality top soil to be delivered on-site during construction.

C. Vendor will specify hourly charge for:

- 1) backhoe with loader for installation of site. One foot and 2ft buckets required on backhoe.
- 2) A Ditch Witch (trenching machine) capable of installing 8in wide trenches (no substitutes allowed)
- 3) hourly rate for laborers as needed.

Work will begin as soon as possible. Contact should be made with VPI directly after the contract is awarded to coordinate an initial meeting and actual installation. VPI & SU will supply piping, fittings and valves to transport effluent from immediately outside pump chamber through manifold and to drainfield.

Specifications for pump wiring

Enclosures: The electric motor control center, master disconnect switch, and alarm controls shall be installed in a NEMA 4 (National Electric Manufacturers Association) enclosure outside of the pumping chamber.

Electrical Junctions: All electrical junctions shall be of a permanent or semi-permanent nature (hard wired). The use of a temporary plug to connect the motor control device, master disconnect switch, or alarm is prohibited.

VPI Listing Sheet

Piping

80 ft	4 in. sch 40 PVC
220 ft	3 in. sch 40 PVC
120 ft	2 1/2 in. sch 40 PVC
40 ft	2 in. sch 40 PVC
20 ft	1 1/2 in. sch 40 PVC
920 ft	1 1/4 in. sch 40 PVC

Fittings (all sch 40 PVC pressure fittings)

(2)	4 in. couplings
(2)	4 in. ells 45°
(16)	4 in. caps
(1)	4 in. x 3 in. reducing bushing
(10)	3 in. coupling
(5)	3 in. tees
(2)	3 in. ells 45°
(3)	3 in. ells 90°
(1)	3 in. x 2 in. reducing bushing
(2)	3 in. x 2 1/2 in. reducing bushing
(2)	3 in. x 1 1/4 in. reducing bushing
(7)	2 1/2 in. coupling
(2)	2 1/2 in. tee
(2)	2 1/2 in. ells 45°
(2)	2 1/2 in. x 2 in. reducing bushing
(2)	2 1/2 in. x 1 1/4 in. reducing bushing
(1)	2 1/2 in. x 1 1/2 in. reducing bushing
(2)	2 in. tee
(1)	2 in. ell 90°
(1)	2 in. x 1 1/2 in. reducing bushing
(4)	2 in. x 1 1/4 in. reducing bushing
(2)	1 1/2 in. tee
(4)	1 1/2 in. x 1 1/4 in. reducing bushing
(1)	1 1/2 in. ell 90°
(4)	1 1/4 in. tee
(20)	1 1/4 in. ell 90°
(50)	1 1/4 in. coupling
(16)	1 1/4 in. male threaded plugs
(16 sets)	1 1/4 in. male/female threaded adapters
(2)	3 in. gate valves (PVC or brass) plus fitting to attach to PVC
(1)	2 in. gate valve (PVC or brass) plus fitting to connect to PVC
(1)	2 1/2 in. gate valve (PVC or brass) plus fitting to connect to PVC
(2)	teflon tape
650 ft	2 ft. wide mirafi cloth
150 ft	8 in. wide mirafi cloth

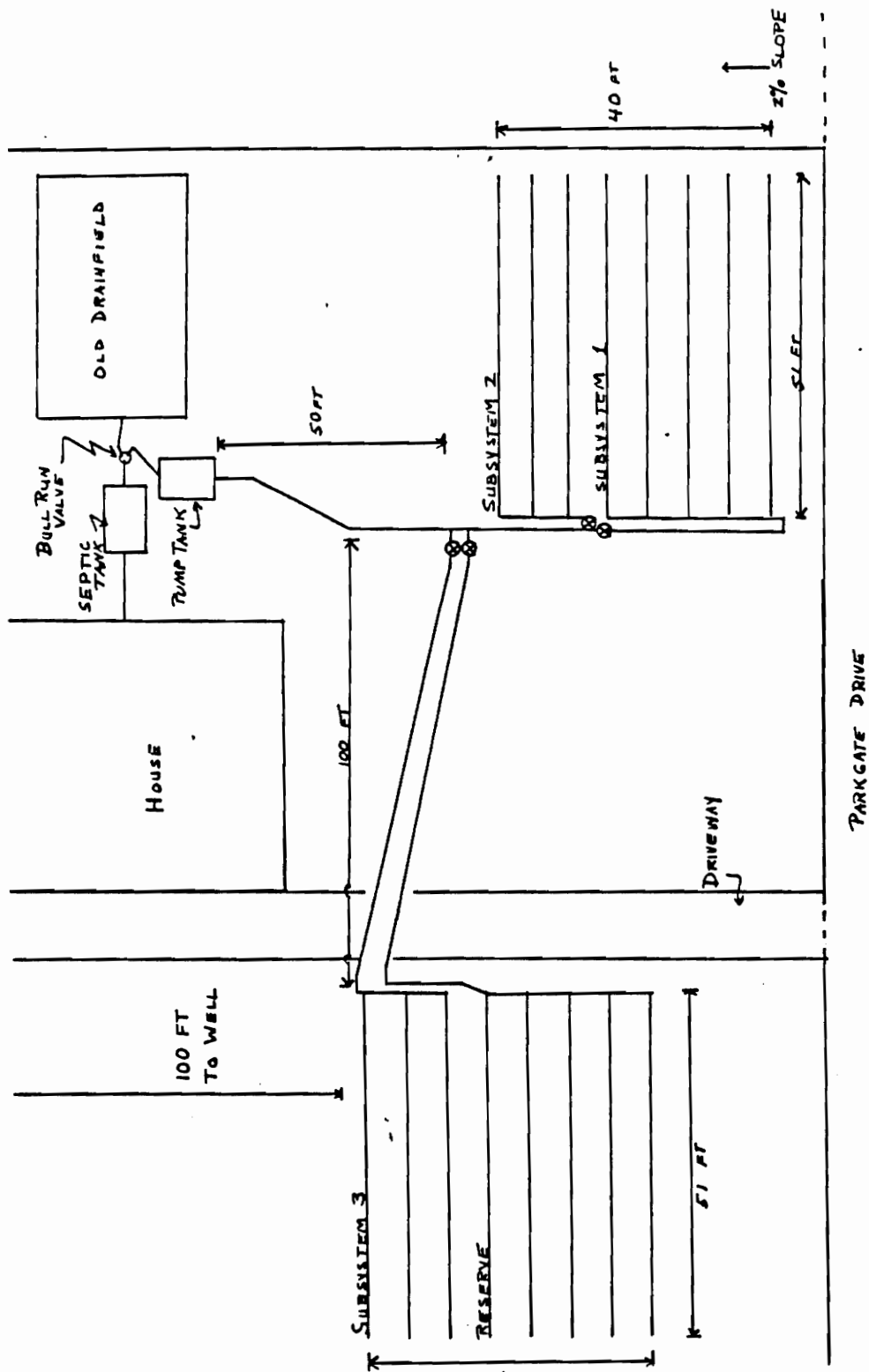


Figure 1. General layout of Thomas system.

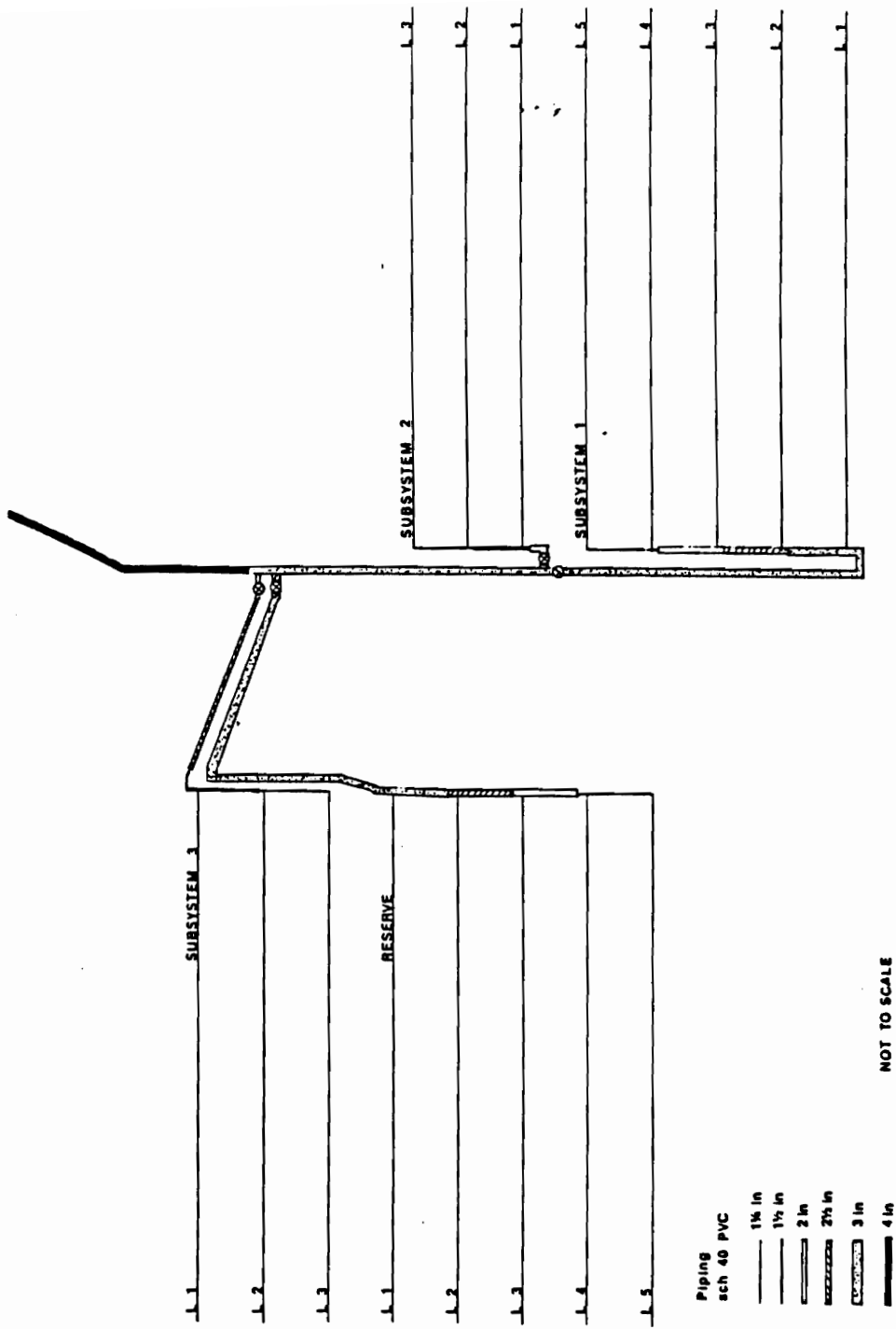


Figure 2. Piping layout.

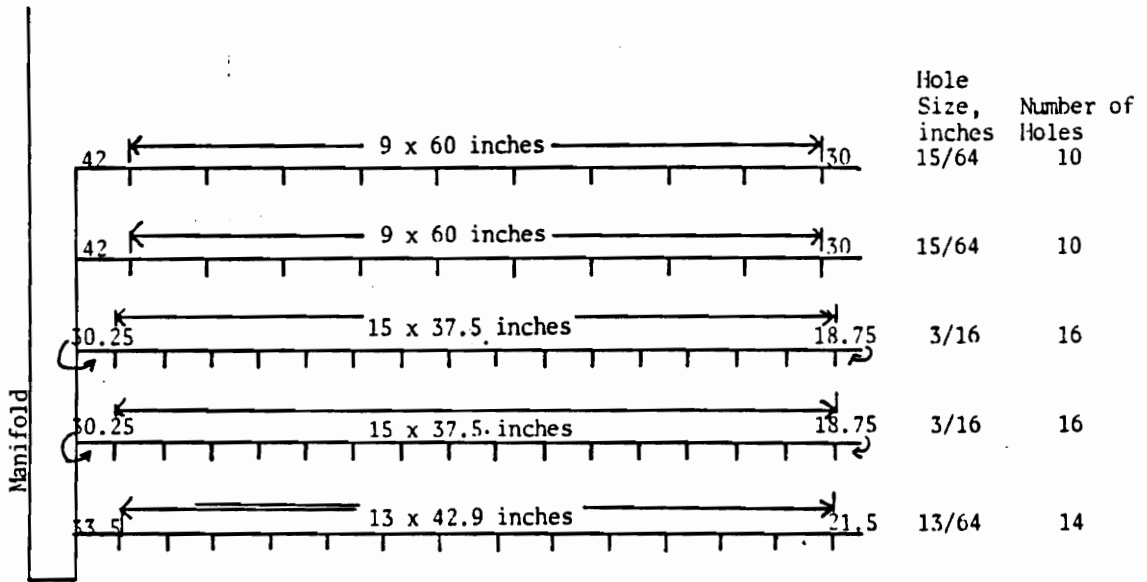


Figure 3. Subsystem 1 - Hole size and spacing in inches.

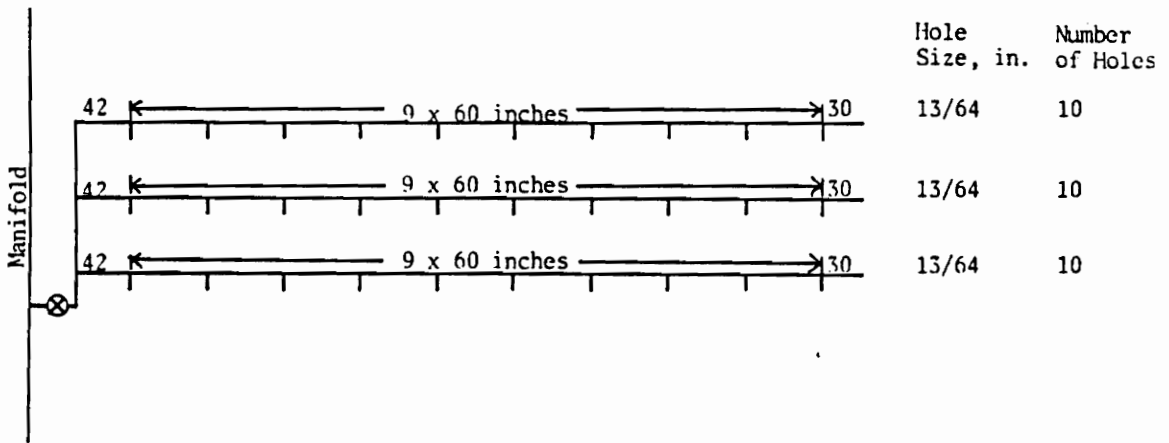


Figure 4. Subsystem 2 - Hole size and spacing in inches.

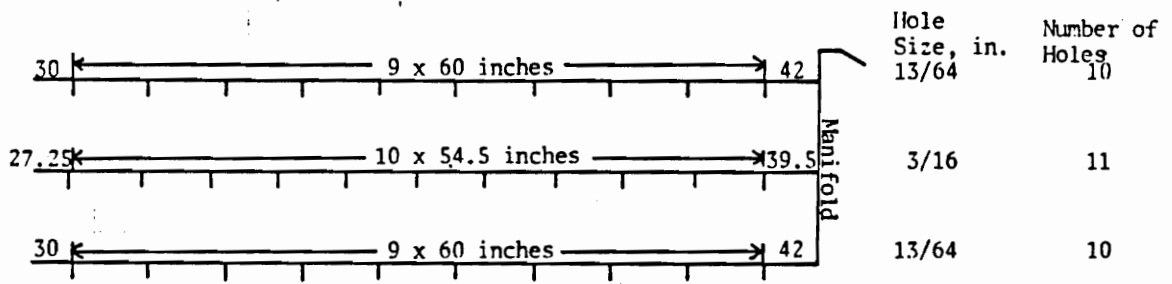


Figure 5. Subsystem 3 - Hole size and spacing in inches.

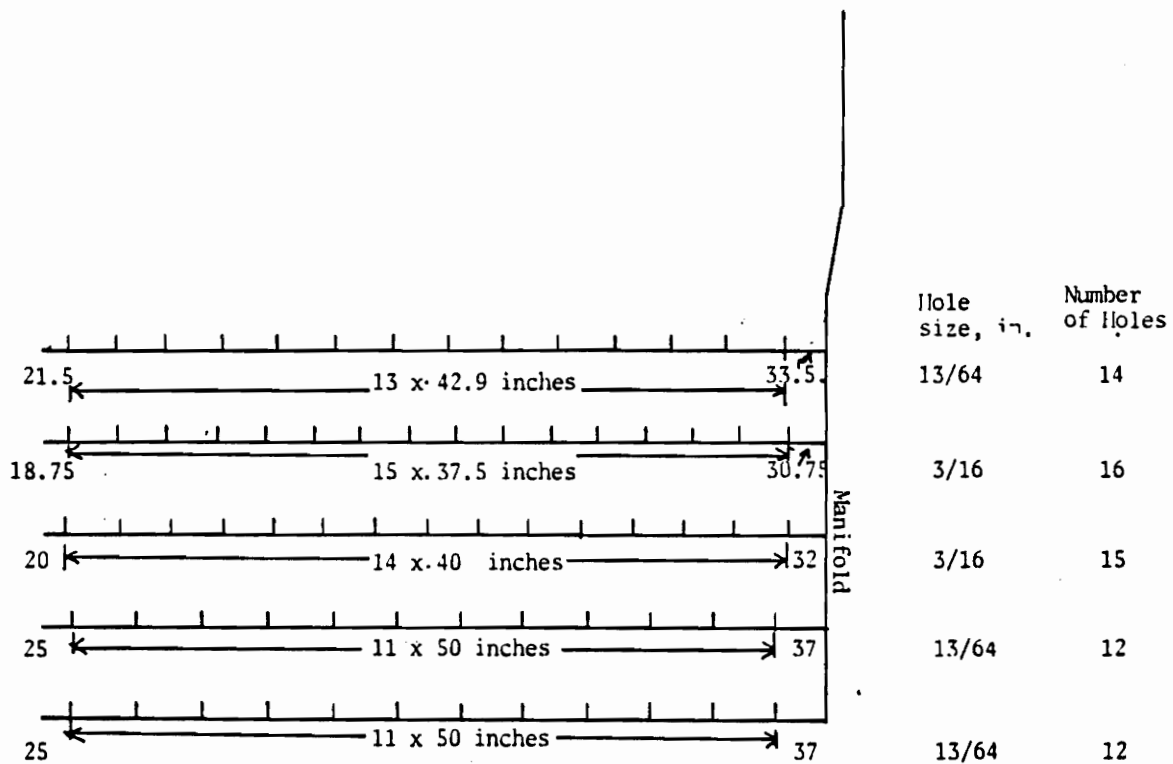


Figure 6. Reserve Subsystem - Hole size and spacing.

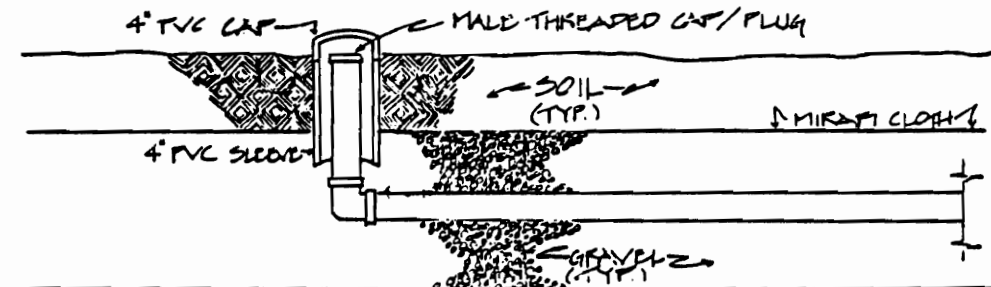
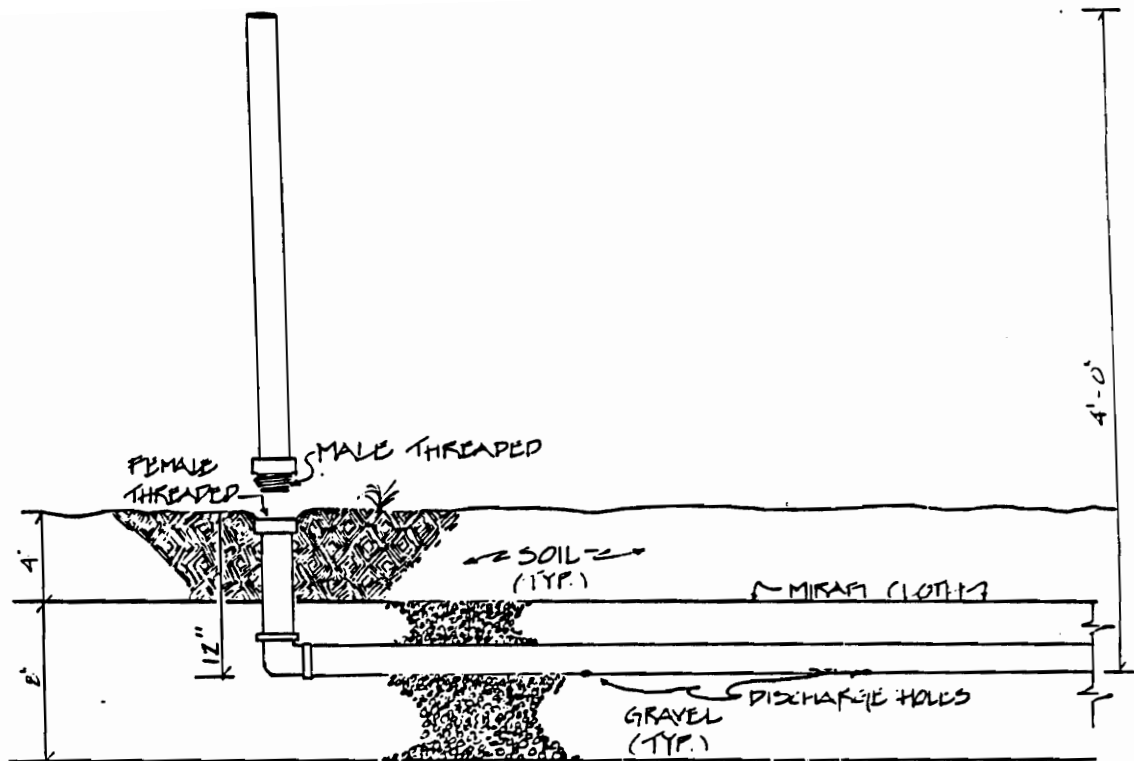


Figure 7. Riser details.

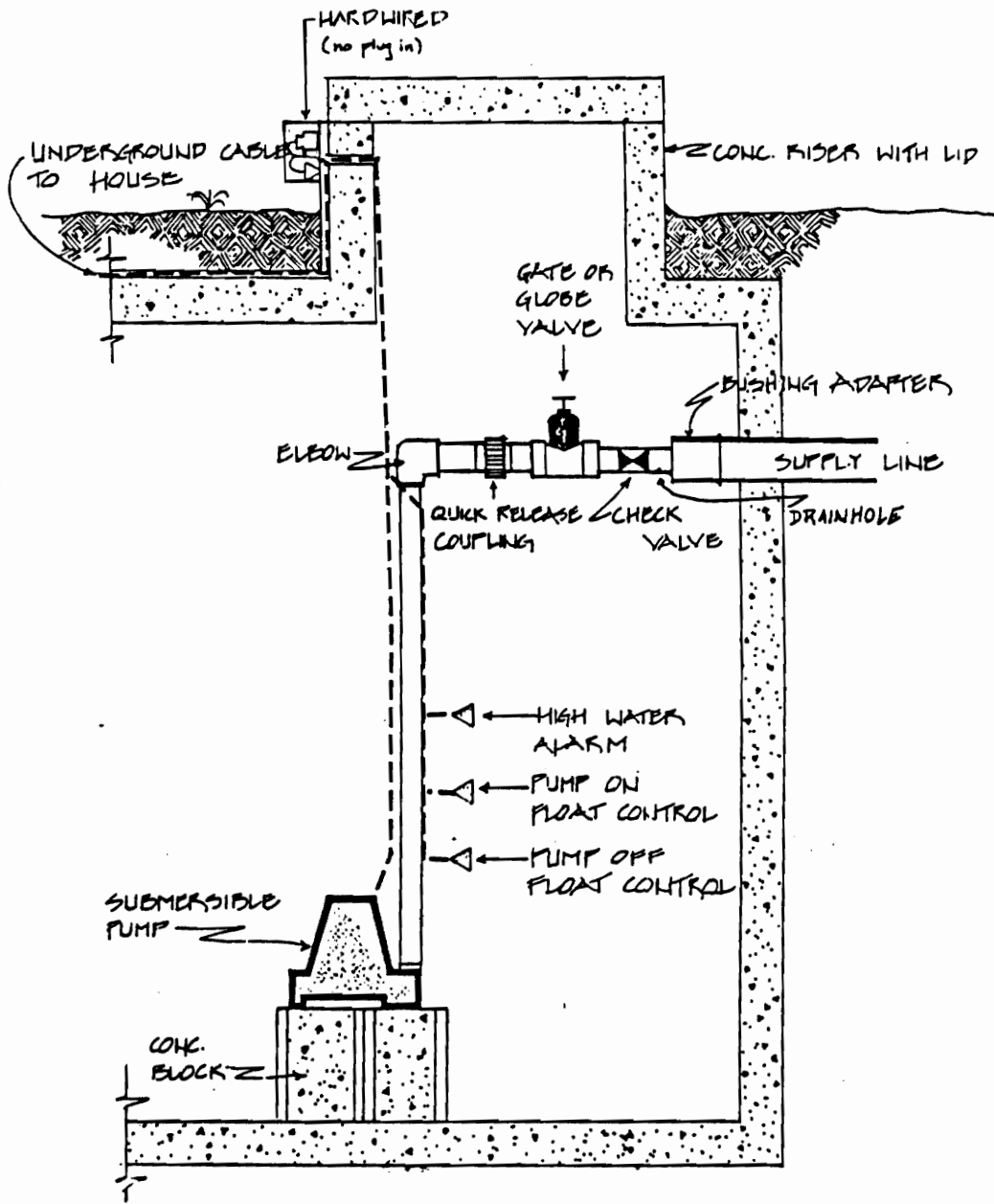


Figure 8. Pump chamber details.

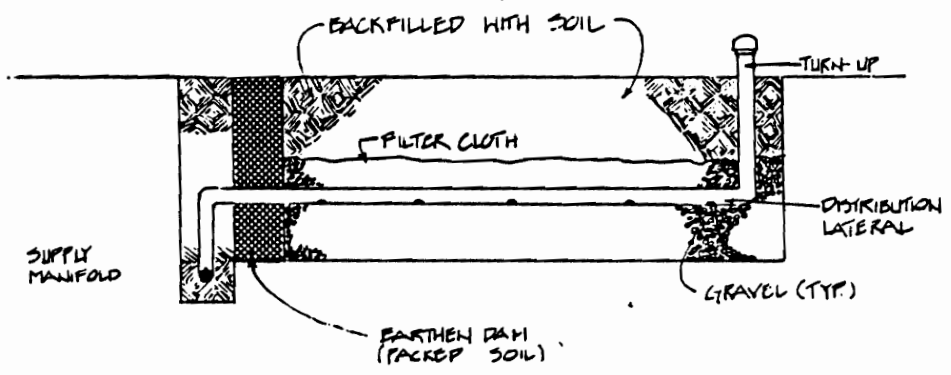


Figure 9. Trench detail with soil dam.

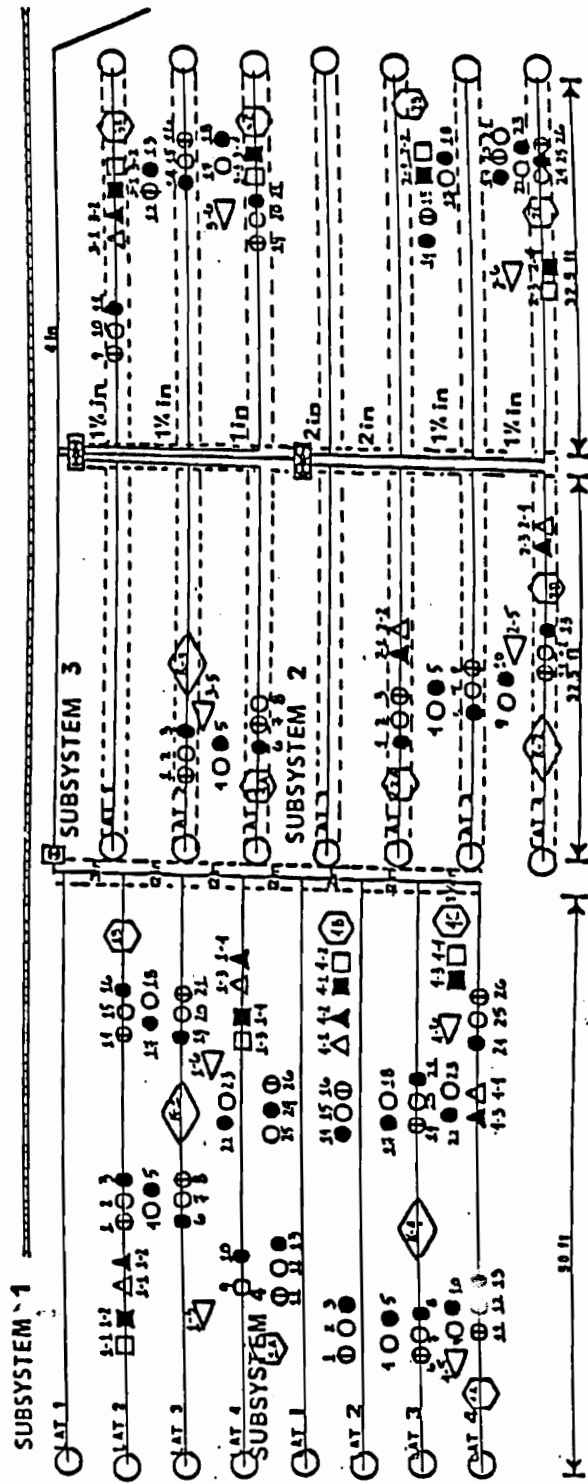
APPENDIX B

Design for Monitoring of Shallow-Placed, Low Pressure Distribution Systems

MONITORING LAYOUT FOR HARRISONBURG, VIRGINIA SITE

KEY

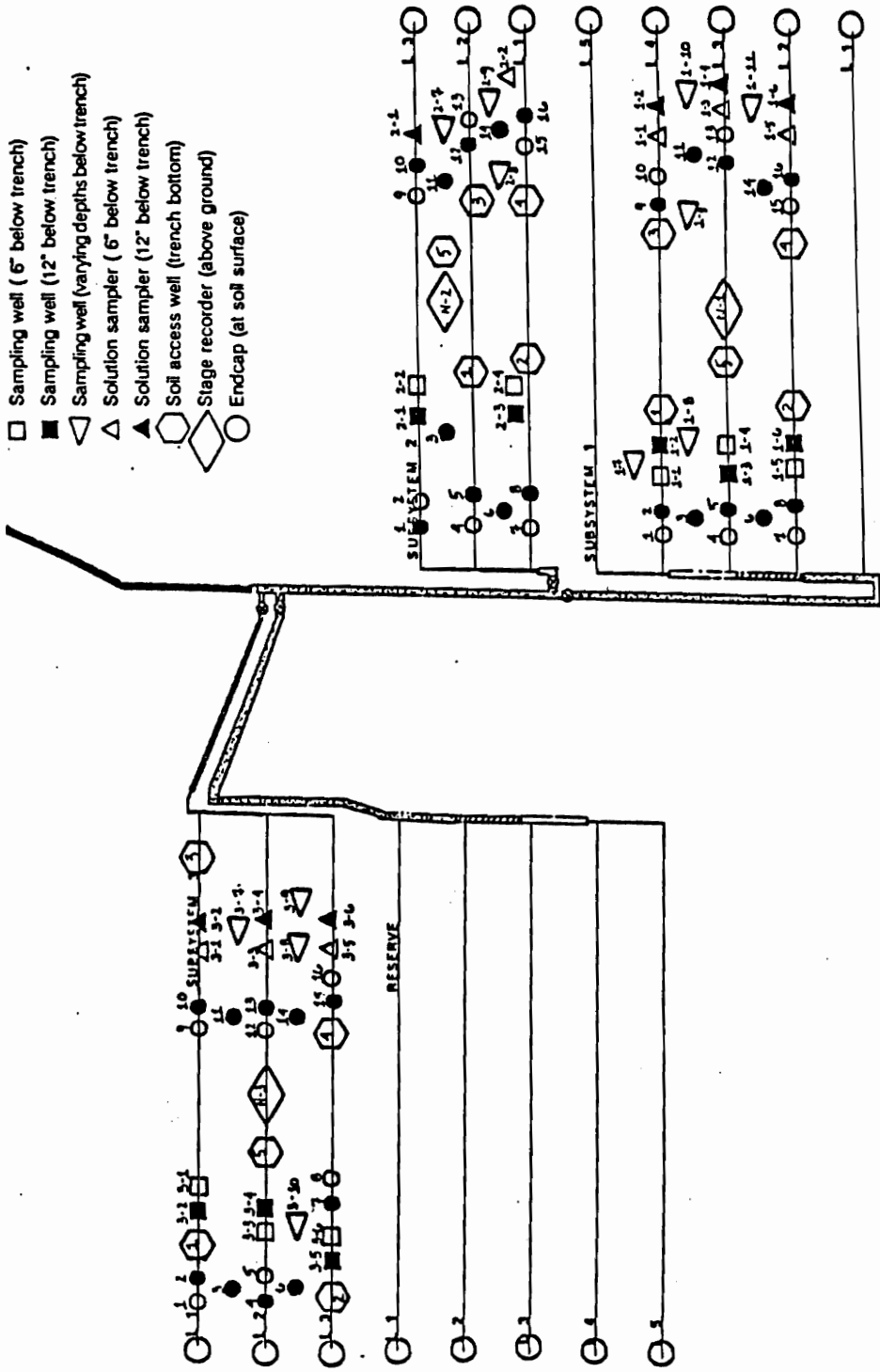
- ⊙ Tensiometer (6" below trench)
- Tensiometer (12" below trench)
- Tensiometer (18" below trench)
- Sampling well (12" below trench)
- Sampling well (18" below trench)
- ▽ Sampling well (60" below trench)
- △ Solution sampler (12" below trench)
- ▲ Solution sampler (18" below trench)
- ◇ Soil access well (trench bottom)
- ◇ Stage recorder (above soil surface)
- Endcap (at soil surface)



MONITORING LAYOUT FOR NOKESVILLE, VIRGINIA SITE

KEY

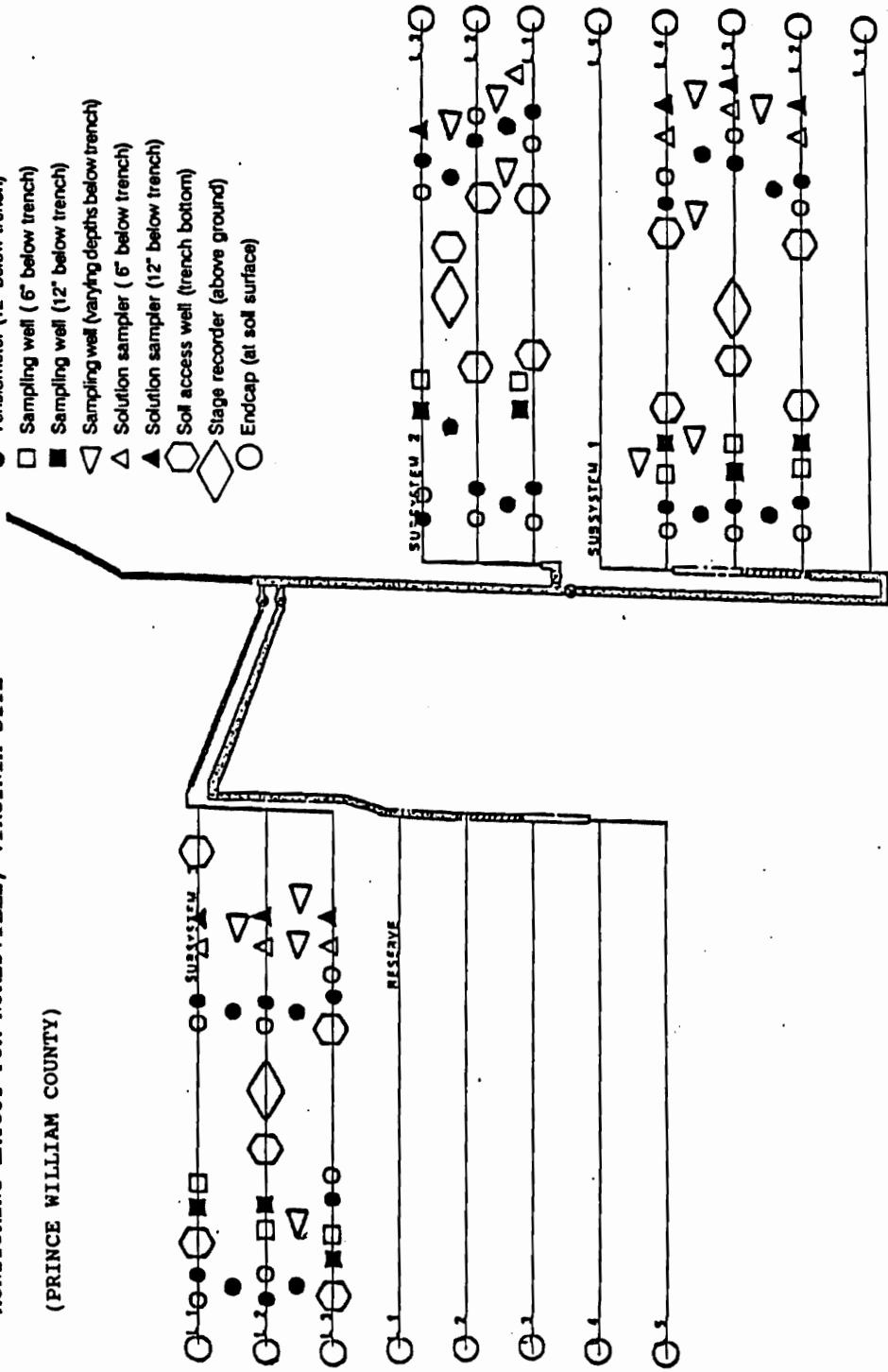
- Tensiometer (6" below trench)
- Tensiometer (12" below trench)
- Sampling well (6" below trench)
- Sampling well (12" below trench)
- ▽ Sampling well (varying depths below trench)
- △ Solution sampler (6" below trench)
- ▲ Solution sampler (12" below trench)
- ◇ Soil access well (trench bottom)
- ◇ Stage recorder (above ground)
- Endcap (at soil surface)



MONITORING LAYOUT FOR NOKESVILLE, VIRGINIA SITE
(PRINCE WILLIAM COUNTY)

KEY

- Tensiometer (6" below trench)
- Tensiometer (12" below trench)
- Sampling well (6" below trench)
- Sampling well (12" below trench)
- ▽ Sampling well (varying depths below trench)
- △ Solution sampler (6" below trench)
- ▲ Solution sampler (12" below trench)
- ◊ Soil access well (trench bottom)
- Stage recorder (above ground)
- Endcap (at soil surface)



VITA

The author was born June 21, 1964 in London, Ontario, Canada. She spent her childhood in Mississauga, Ontario, Canada, and graduated from Toronto District Christian Highschool in June, 1982 and Erindale Secondary School in June, 1983.

She attended Calvin College, Grand Rapids, MI for three years where she completed her Bachelor of Science degree in Biology in May, 1986.

After graduation, the author was employed for two years as a research technician in the Agriculture Microbiology Division of Allelix Crop Technologies, Inc.

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