WASHINGTON STATE DEPARTMENT OF HEALTH

Vertical Separation

A REVIEW OF AVAILABLE SCIENTIFIC LITERATURE AND A LISTING FROM FIFTEEN OTHER STATES

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Introduction/Summary

On-site sewage treatment and disposal serves approximately 25% of the homes in the U.S. and continues to be utilized where community facilities are not available. Properly sited, designed, installed and maintained on-site sewage systems provide a level of treatment and disposal that meets or exceeds the treatment provided at most municipal treatment plants. Moreover, the treated effluent is returned to the environment over a much broader area and therefore has a much smaller impact on the receiving environment.

For effective treatment, it is essential that on-site sewage systems include, among other things, provisions for an adequate vertical separation. Vertical separation primarily affects degradation of organic nutrients (i.e. BOD_5) and removal of bacteria and viruses. It also plays a role in converting nitrogen to soluble nitrate (NO_3^-) ions which can then readily migrate into the groundwater unless denitrifying conditions are present.

This review and the conclusions are based on all the research and review findings related to vertical separation that this office could locate. There is an obvious need for further research under field conditions. This research is necessary to refine our understanding of the fate of contaminants entering onsite sewage systems in various soil types.

Definitions

1. Vertical Separation

Vertical separation is the depth of permeable, unsaturated soil (soil types 2-6, as per WAC 248-96-094) that exists between the bottom of a subsurface soil absorption system and some restrictive or limiting layer or feature such as a water table, bedrock, hardpan, unacceptable fine textured soils, or excessively permeable material.

2. Saturated Flow

Saturated flow in soil occurs when the water content of the soil is great enough to fill even the largest continuous pores and then moves downward strictly by gravity. This movement is relatively rapid in soils with coarse texture and/or good structure. Since the pores are filled with water, air is prevented from entering, thereby promoting anaerobic conditions.

3. Unsaturated Flow

Unsaturated flow occurs when water moves through the micro pores and along surfaces of the soil particles by capillary forces (matric potential). Water moves from the wetter to drier areas and moves much slower than in saturated flow conditions. In addition, the larger pores are filled with air, thus promoting aerobic conditions in the soil. It should be noted that there is a continuum from unsaturated to saturated flow, and the definitions here are the extremes of the continuum.

4. Treatment of Sewage

Treatment is the process of purification by which the disease microorganisms, the organic nutrients and the inorganic materials are removed from the wastewater before being returned to the hydrologic cycle. Removal of pathogens is accomplished during slowed passage by their bonding to soil particles and by natural die-off due to an unfavorable environment of aerobic soils and predatory soil organisms.

The organic nutrients are metabolized by the soil organisms, a process that is nearly complete under aerobic, unsaturated flow conditions. Removal efficiencies of the various inorganic compounds vary with the compound and the soil conditions.

Nitrogen enters the system largely as ammonia, which is oxidized in the aerobic treatment process to nitrate, a highly soluble ion. It then passes through most soils unaltered into the groundwater. Most onsite sewage systems rely on dilution to lower the nitrate concentration to drinking water standards.

Phosphate, the other common contaminant of domestic wastewater, is readily absorbed in the soil. Most published field research shows that little or no phosphate moves from the onsite system to groundwater even under saturated conditions. They further indicate that phosphate contamination is limited to shallow groundwaters adjacent to onsite disposal systems where the soil is coarse-textured and low in hydrous oxides, or where there is poor effluent distribution and rapid movement of effluent away from the onsite sewage system.

Significance

Vertical separation has been shown to be essential for removal of pathogenic and biochemical sewage contaminants to an acceptable level. In order to achieve vertical separation as defined, the hydraulic loading must be low enough so that movement of the wastewater occurs under unsaturated conditions. During unsaturated flow, water moves through the soil by matric forces, which hold the wastewater in close proximity to the soil surfaces and the soil microorganisms, where treatment readily occurs. Unsaturated flow also occurs much slower than saturated flow and therefore increases the contact time of the wastewater with the unsaturated soil. In addition, it permits aerobic conditions, which promote faster and more complete treatment of the wastewater. There is a certain necessary distance that wastewater must travel under unsaturated conditions in order to provide adequate treatment. The actual distance required is discussed in other sections. Years of experience and research have produced tables of maximum application rates for the various types of soil which will maintain unsaturated flows.

The above conditions emphasize treatment without considering disposal. Disposal (i.e. moving the effluent away from the site) is also important and goes hand in hand with treatment. When proper disposal does not occur, vertical separation is reduced or even disappears due to saturation of the receiving soil under the drainfield (also called groundwater mounding). As the vertical separation disappears, treatment of the effluent is adversely affected. Therefore, disposal is essential but should occur only after acceptable treatment is accomplished. Most effluent from an on-site sewage system eventually enters the groundwater. It is therefore imperative for treatment to be accomplished to a known and acceptable degree before discharge to the groundwater or surface water (where shellfish and water recreation could be compromised without adequate treatment).

Horizontal movement is a common route of disposal for onsite sewage systems, therefore horizontal separation distances are often used to provide public health protection of wells, springs and surface waters. Research has shown (see next section) that vertical separation is much more effective in removing contaminants and therefore protecting public health than horizontal separation, because horizontal flow usually requires saturated conditions. By first providing treatment with adequate vertical separation before horizontal flow, when it occurs, disposes of the effluent, degradation of water recreation and shellfish growing areas by on-site sewage systems is also prevented.

Review of Research Findings

1. Saturated Flow

Hansel and Machmeier (1980) state that if the groundwater table or other barrier layer is too close to the bottom of the trench, saturated flow will result.[6] Under those conditions saturated flow results due to groundwater mounding under the drainfield. An exception to this general pattern would be where good disposal capability prevents the groundwater mounding, such as when a coarse sandy soil overlies a shallow restrictive layer on a steep slope. Under saturated soil conditions, water flows through the macropores, and can result in short circuiting of the soil purification process. This is of particular concern in soils overlying creviced bedrock or high water tables.[9] It is also important on shoreline properties adjacent to shellfish and water recreation areas. Stiles and Crohurst (1927) compared the movement of coliform organisms with that of the chemical uranin, from polluted trenches intersecting the groundwater (saturated conditions). They found bacteria 232 feet and uranin 450 feet from the trench. They also concluded that the ultimate distance to which the pollution will be carried is dependent upon a number of complex and interlocking factors, namely wet and dry weather, with resulting rise and fall of the ground water; the length of each of these periods; the rate of the groundwater flow (depending upon the "head," which in turn is dependent on the rainfall); and also the factor of the viability of the organisms under conditions of moisture, pH, food supply, etc.[3,11] Yates and Yates (1989) cite reports of viral migration of 1600 meters (5249 feet) in karst terrain (porous limestone with deep fissures) and 400 meters (1312 feet) in sandy soil (Gerba, 1984; Keswick and Gerba, 1980).[14]

Macropore flow through saturated strongly structured soils or soils of the sandy textural family may result in pathogen travel over relatively long distances with minimal treatment.[10] Romero (1970) cites a number of pit privy studies where the pits intersected, or were within close proximity to, the water table. Elevated bacterial levels were temporarily detected up to 24.4 meters (80 feet) horizontally from the source.[11] Reneau et al. (1985) cite studies where vertical movement of the bacteria through a fragipan was limited. Horizontal movement of effluent above the fragipan resulted in significant removals of the bacteria but only after effluent had travelled horizontally a minimal distance of 6.1 to 12 meters (20 to 39 feet). The fecal coliform counts in water samples collected at 12 meters were only slightly lower than in samples collected at 6.1 meters.[10] Hagadorn et al (1978) found that flushes of bacteria (reaching a horizontal distance of 15 meters (49 feet) coincided with rainfall events and a water table rise to within 15 centimeters (6 inches) of the surface, and that macropores aided in the rapid transport of the bacteria under saturated flow conditions.[5]

In summary, the following types of soil conditions would prevent safe soil treatment and disposal. They each result in saturated flow conditions before adequate treatment can occur: (1) shallow soils over creviced bedrock (or excessively permeable soils), (2) shallow soil over high groundwater tables, and (3) impermeable soils.[7]

2. Unsaturated Flow

Unsaturated flow with effluent movement through small pores increases the efficiency of both bacterial and viral removal due to slower average pore water velocities and increased surface contact per net distance traveled.[9] One of the keys to proper functioning of a septic system is ensuring that the vertical separation between the bottom of the drainfield and the water table is large enough so that unsaturated conditions will be maintained even during wet seasons. Maintenance of this unsaturated zone helps to ensure that good aeration and slow travel of effluent will be achieved. Good aeration is necessary to achieve decomposition of organic particles and compounds, biodegradation of detergents, and die-off of bacteria and viruses. Slow travel gives opportunity for good contact between soil particles and effluent, adsorption of effluent constituents to soil particles, extended opportunity for natural die-off of bacteria and inactivation of viruses, and biodegradation of degradable materials.[2] The efficiency of unsaturated flow conditions at removing biological contaminants has been demonstrated. Unsaturated conditions in sand columns were more effective for virus inactivation than saturated conditions (Lance et al 1976; Lance and Gerba, 1980).[9]

Reneau et al (1989) summarizes and restates the conditions that several researchers (Bouma et al, 1972; Caldwell 1937, 1938a & 1938b; Caldwell & Parr, 1937) concluded were important for unsaturated flow: uniform effluent distribution, development of a surface clogging mat (in coarse-textured soils), well drained soils, and moisture deficits.[9] It should be noted that the clogging mat is most needed (and least likely to develop) in the coarse-textured soils and therefore some other means of uniform distribution needs to be used. Stewart and Reneau (1988) reported that the migration of fecal coliforms is restricted even during high water periods if the STE (septic tank effluent) is uniformly distributed, the OSWDS (onsite wastewater disposal system) is placed in the more biologically active and aerobic soil horizons, and the unsaturated flow is maximized.[12]

Another key factor regulating bacterial removal from wastewater during percolation is the liquid flow regime in the soil. Unsaturated (as compared to saturated) flow involves liquid movement through only the smaller soil pores, increased contact of wastewater with soil particles as well as increased liquid detention time in the soil. Unsaturated flow can be attained by two general methods: (1) dosing uniformly over the field surface (particularly at low doses); and (2) development of soil surface clogging (as created by organic material buildup or smearing of the infiltrative surface) which decreases the infiltration rate into the soil, promoting unsaturated flow.[7]

3. Amount of Vertical Separation Required for Microbial

What is an adequate separation between the bottom of the drainfield and the wet season water table? The separation distance required by agencies varies widely from state to state around the U.S., and the evidence is not yet completely assembled to say exactly what separation is adequate in the range of soil conditions, effluent qualities, and effluent loading rates that may be found around the country. Meanwhile the USEPA Design Manual recommends a minimum water-unsaturated soil thickness of 24 to 48 inches.[2] In column studies, viral deactivation occurs within 40 centimeters (16 inches) with unsaturated flow (Lance et al, 1976; Lance and Gerba,1984).[9] Under unsaturated flow conditions, bacteria can be adequately removed within .9 to 1.2 meters (3 to 4 feet) of effluent travel through soils (USEPA, 1980; Hansel and Machmeier, 1980). Hagedorn et al (1981) reviewed a report by Bouma et al (1972) that examined 19 subsurface soil disposal systems. Fecal coliforms were reduced to background levels within 61 centimeters (2 feet) of the trench bottom. Even in a sandy soil, Ziebell et al (1974) reported a 3000-fold reduction in bacteria levels 38 centimeters (15 inches) below the trench bottom and 30 centimeters (1 foot) laterally.[10]

Low pressure distribution can be used to provide equal distribution over the entire drainfield surface where site conditions yield minimal vertical separation. Stewart and Reneau (1984) installed a shallow-placed LPD (low pressure distribution) system to increase the unsaturated zone in a Typic Ochraquult (high water table) soil. After 2 years, fecal coliforms were detected in only 5% of the 150 samples collected from shallow wells (150 centimeters deep). Samples that contained fecal coliforms were restricted to periods of high water tables and were confined to the effluent distribution area.[10] Stewart and Reneau (1988) installed and tested a low pressure distribution system in soils with a fluctuating high water table. Few fecal coliforms were present at the 1.5 meters (5 feet) depth within the OSWDS even during the period of highest water tables, January through March of 1982, when macropore flow would be at a maximum.[12]

Brown et al (1979) noted that most fecal coliform bacteria and coliphage virus were removed within the first 30 centimeters (1 foot) of unsaturated soil beneath absorption trenches in east Texas. Occasionally a few coliforms were observed 120 centimeters (4 feet) below the trenches. Cogger et al (1988) and Moe et al (1984) found substantial although not total removal of bacteria and viruses in a sandy soil on the North Carolina coast where the water table fluctuated from 30 to 90 centimeters (1 to 3 feet) beneath the absorption trenches. Microbial removal was 1 - 2.5 orders of magnitude less beneath an adjacent system where the ground water table was 30 centimeters higher (i.e. at or near the bottom of the absorption trenches). In laboratory studies, Magdoff et al (1974) noted complete removal of fecal coliforms and fecal streptococci in a 90 centimeters (3 foot) column containing sand underlain by silt loam, while Willman et al (1981) obtained substantial but incomplete coliform removal in a series of 60-centimeter (2 foot) columns containing a variety of sand and clay mixtures. These (field and column) studies, along with others not reported here, indicate that substantial bacterial and viral removal occur within the first foot of unsaturated soil, and removal is nearly complete within 60 to 120 centimeters (2 to 4 feet) beneath the trenches.[4]

Tyler et al (1977) stated that at a distance of 1 foot into the soil surrounding the trench there was a 3-log reduction in bacterial numbers and within the second foot counts were to the acceptable range for a fully treated wastewater. Some bacteria and viruses in the wastewater are pathogens. Their movement during unsaturated flow is expected to be limited to within a meter (40 inches).[13] Studies have shown that where it is sufficiently unsaturated, 60 to 90 centimeters (2 to 3 feet) of soil is adequate to remove nearly all fecal indicator bacteria and viruses.[8] Lysimeter tests of the impact of septic field leachate on groundwater indicates that coliphage viruses and fecal coliform bacteria were removed by passage through approximately 100 centimeters (40 inches) of any of the soils tested.[1]

4. Chemical Treatment Related to Vertical Separation

Brown et al (1977) reported that heavy metals accumulated immediately adjacent to the point of application in the soil. Phosphates moved only slowly in the soil and their movement was greatest in sandy soils. Under reduced (anaerobic) conditions, ammonia accumulated in the soils and moved only about as far and as fast as phosphates. When the soil was allowed to become oxidized large amounts of nitrogen were converted to nitrate which rapidly leached to the groundwater. Therefore, nitrate leachate was the greatest environmental hazard identified in this study.[1] Reneau et al (1985) summarized the research on processes and transport through the soil of nitrogen and phosphorus. They concur with findings of Brown et al (1977).[10]

Vertical Separation Requirements in Various States

The amount of vertical separation required in various states is highly variable. Where the separation is allowed to be less than two feet, there is no statement of the technical justification for doing so. The following data were extracted from the regulations from the listed states.

Alabama	1.5 feet	Minimum
Colorado	4 feet	May be reduced if designed by a registered engineer and approved by the local board of health (where local regulations permit such variances for exclusively domestic wastes).
Florida	3.5 feet 2 feet	To impervious layer. To highest level of the water table.
Idaho	3-6 feet 4 feet	To water table or fractured bedrock, depending on soil type. To an impervious layer
Louisiana	2 feet 4 feet	To the maximum level of water table. To impervious layer.
Maine	1-2 feet	Depending on soil and subsoil
New Jersey	4 feet	

North Carolina	1 foot	
Oregon	4 feet .5 foot 0 feet	To permanent water table To impervious layer when bottom of trenches are in rapidly or very rapidly permeable soils. To temporary water table (dries up for period of time each year) or permanent water table where it is determined by groundwater study that degradation of the groundwater and public health hazard will not occur and where water table is 2 feet below the ground surface.
Pennsylvania	4 feet	
South Dakota	4 feet	
Utah	2 feet	
West Virginia	3 feet	
Wisconsin	3 feet	
Wyoming	4 feet	

Summary and Conclusions

The amount of vertical separation necessary is still being debated, as there is disagreement over the degree of treatment needed. Research so far shows that .61 to 1.2 meters (2 to 4 feet) of vertical separation will adequately remove bacteria (<200 fecal coliforms per 100 milliliters) depending on soil type and conditions. In order to assure an unsaturated zone of 2 feet, it usually is necessary to construct a system with even greater separation in order to account for groundwater mounding. Therefore, the scientific literature is strongly indicating a final (as constructed) vertical separation that is greater than 2 feet. It should also be noted that there is often loss of soil depth during lot development, making it reasonable to require additional vertical separation in the preliminary design to allow for such damage.

Annotated Bibliography

1. Brown, K.W., J.F. Slowey & H.W. Wolf, 1977. "The Movement of Salts, Nutrients, Fecal Coliform and Virus Below Septic Leach Fields in Three Soils", *Home Sewage Treatment*,

American Society of Agricultural Engineers Publication 5-77, St. Joseph, MI.

Lysimeter tests of the impact of septic field leachate on groundwater indicate that coliphage and fecal coliform were removed by passage through approximately 100 cm of any of the soils tested. Heavy metals accumulated immediately adjacent to the point of application in the soil. Phosphates moved only slowly in the soil and their movement was greatest in sandy soils. Under reduced conditions, ammonia accumulated in the soils and moved about as far and as fast as phosphates. When the soil was allowed to become oxidized large amounts of nitrogen were converted to nitrate which rapidly leached to the groundwater. Nitrate leachate is the greatest environmental hazard identified in this study.

2. Brown, R.B., 1988. "Introduction to Soils and the Functioning of Onsite Sewage Systems", *Proceedings of the 3rd Midyear Conference on Onsite Wastewater Management and Groundwater Protection*, National Environmental Health Association, Denver, CO.

One of the keys to proper functioning of a septic system is ensuring that the vertical separation between the bottom of the drainfield and the water table is large enough so that unsaturated conditions will be maintained even during wet seasons. Maintenance of this unsaturated zone helps to ensure that good aeration and slow travel of effluent will be achieved. <u>Good aeration</u> is necessary to achieve decomposition of organic particles and compounds, biodegradation of detergents, and die-off of bacteria and viruses. <u>Slow travel</u> gives opportunity for good contact between soil particles and effluent, adsorption of effluent constituents to soil particles, extended opportunity for natural die-off of bacteria and viruses, and biodegradation of degradable materials.

Water travels more slowly through an unsaturated soil (i.e., a soil whose pores are not entirely filled with water) than it would travel through the same soil were it saturated. The slower the velocity of flow, the longer is the residence time of the effluent in the unsaturated zone and the greater the opportunity for cleanup of the effluent as it travels through the soil.

To design a septic system such that an unsaturated zone will exist beneath the drainfield even during the wet season, one must know the depth to the wet season water table at the site.

What is an adequate separation between the bottom of the drainfield and the wet season water table? The separation distance required by agencies varies widely from state to state around the U.S., and the evidence is not yet completely assembled to say exactly what separation is adequate in the range of soil conditions, effluent qualities, and effluent loading rates that may be found around the country. Meanwhile the EPA <u>Design Manual</u> recommends a minimum water-unsaturated soil thickness of 24 to 48 inches.

3. Butler, R.G., G.T. Orlob, and P.H. McGauhey, 1954. Underground Movement of Bacterial and Chemical Pollutants", *J. American Water Works Assoc.*, 46(2):97-111.

Stiles and Crohurst compared the movement of coliform organisms with that of the chemical uranin, from polluted trenches intersecting the ground water. They found bacteria 232 feet and uranin 450 feet from the trench. In both studies they reported movement in the direction of ground water flow only and more extensive travel in wet weather than dry.

4. Cogger, C.G., 1988. "On-site Septic Systems: The Risk of Groundwater Contamination", *J. Environmental Health*, 51:12-16.

Cites numerous examples showing the potential for microbial persistence and transport when there is no unsaturated zone beneath the absorption trenches.

Brown et al (1979) noted that most fecal coliform bacteria and coliphage virus were removed within the first 30 cm (1 foot) of unsaturated soil beneath absorption trenches in east Texas. Occasionally a few coliforms were observed 120 cm (4 feet) below the trenches. Cogger et al (1988) and Mob et al (1984) found substantial although not total removal of bacteria and viruses in a sandy soil on the North Carolina coast where the water table fluctuated from 30 to 90 cm (1 to 3 feet) beneath the absorption trenches.
Microbial removal was 1 - 2.5 orders of magnitude less beneath an adjacent system where the ground water table was 30 cm higher [i.e. at or near the depth of the absorption trenches].

In laboratory studies, Magdoff et al (1974) noted complete removal of fecal coliforms and fecal streptococci in a 90 cm (3 foot) column containing sand underlain by silt loam, while Willman et al (1981) obtained substantial but incomplete coliform removal in a series of 60 cm (2 foot) columns containing a variety of sand and clay mixtures. These [field and column] studies, along with others not reported here, indicate that substantial bacterial and viral removal occur within the first foot of unsaturated soil, and removal is nearly complete within 60 to 120 cm (2 to 4 feet) beneath the trenches.

5. Hagedorn, C., D.T. Hansen, and G.H. Simonson, 1978. "Survival and Movement of Fecal Indicator Bacteria in Soil under Conditions of Saturated Flow", *J. Environmental Qualilty*, 7(1):55-59.

These data indicate that rainfall washed large numbers of bacteria from the inoculation pits and that they moved as a front (pulse) through the soil in the direction of water flow and took a longer time to reach the more distant sampling wells.

The bacterial population peak reaching the 1500 cm wells appeared to be associated with the first rainfall period.

No indicator bacteria were found in the 300 cm wells during either of the sampling periods ad it may have taken longer than 32 days for he bacteria to arrive at the 3000 cm well.

Our results indicate that both indicator bacteria [E. coli and S. faecalis] survived in appreciable numbers throughout 32 days and, with the wet and cool soil conditions, it is highlly probable that their survival would extend considerably beyond 32 days. During this time the water table fluctuated from 15 to 45 cm from the surface.

6. Hansel M.J., and R.E. Machmeier, 1980. "Onsite Wastewater Treatment on Problem Soils", *Journal of Water Pollution Control Federation*, 52(3):548-558.

It is absolutely necessary to have .9 meters (3 feet) of unsaturated soil for the proper treatment of wastewater. (from unpublished communication with Otis.)

If unsaturated flow does not occur, the treatment efficiencies in Table I are not realized. Of particular concern are pathogenic bacteria, which have been shown to travel as far as 100 meters under saturated soil conditions (Ziebell et al, 1975). If the groundwater table or other barrier layer is too close to the bottom of the trench, saturated flow will result. If the soil is too coarse, the biomass may not form, or if it forms, may not be extensive enough to result in unsaturated flows (Bouma 1972). More than .9 meters of soil beneath the bottom of the trench in such soils will not appreciably improve treatment if unsaturated flow cannot be established.

7. McCoy,E. and W.A. Ziebell, 1975. "Effects of Effluent on Groundwater: Bacteriological Aspects", *Proceedings of the Second National Conference on Individual Onsite Wastewater Systems*, National Sanitation Foundation, Ann Arbor, MI.

Another key factor regulating bacterial removal from wastewater during percolation is the liquid flow regime in the soil. The following data will show that higher degrees of purification can be achieved under unsaturated flow regimes, particularly in non- aggregated soils (as sands, loamy sands, etc.). Unsaturated (as compared to saturated) flow involves liquid movement through only the smaller soil pores, increasing the contact of wastewater with soil particles as well as the liquid detention time in the soil.
Unsaturated flow can be attained by two general methods, the first being application rate: continuous ponding without clogging (as during periods of local overloading in an absorption field) results in flow conditions approaching saturation, while dosing uniformly over the field surface (particularly at low doses) provides unsaturated flow. Secondly, soil surface clogging (as created by organic material buildup or smearing of the infiltrative surface) decreases the infiltration rate into the soil, promoting unsaturated flow.

Columns loaded at 2.4 gpd removed approx. 92% of the fecal coliforms, while columns loaded at 1.2 gpd removed approximately 99.9%.

It is impossible to state with certainty the precise number of feet of soil which will retain contaminants. Three types of soil conditions which would prevent safe soil disposal are:

(1) shallow soils over creviced bedrock, (2) shallow soil over high groundwater tables, and
(3) impermeable soils.

8. Otis, R.J., J.C. Converse, B.L. Carlile and J.E. Witty, 1977. "Effluent Distribution", *Home Sewage Treatment*, American Society of Agricultural Engineers, Publication 5-77, St. Joseph, MI.

Studies have shown that where sufficiently unsaturated, 60 to 90 cm (2 to 3 feet) of soil is adequate to remove nearly all fecal indicator bacteria and viruses. If the soil is saturated or nearly saturated, removals become unacceptable.

9. Reneau, R.B., C. Hagadorn and M.J. Degen, 1989. "Fate and Transport of Biological Contaminants from On-site Disposal of Domestic Wastewater", *J. Environ. Qual.* 18(2):135- 144.

Flow through macropores can result in short-circuiting of the soil purification process. This is of particular concern in soils overlying creviced bedrock or high water tables.

Unsaturated flow with effluent movement through small pores increases the efficiency of both bacterial and viral removal due to slower average pore water velocities and increased surface contact per net distance traveled.

Conditions that contribute to unsaturated flow include uniform effluent distribution, development of a surface clogging mat (in coarse-textured soils), well drained soils, and moisture deficits (Bouma 1972; Caldwell 1937, 1938a & 1938b; Caldwell & Parr, 1937).

The efficiency of unsaturated flow conditions at removing biological contaminants has been demonstrated. Unsaturated conditions in sand columns were more effective for virus inactivation than saturated conditions (Lance et al 1976; Lance and Gerba, 1980).

In column studies, viral deactivation occurs within 40 cm with unsaturated flow (Lance et al, 1976; Lance and Gerba,1984).

10. Reneau, R.B., J.J. Simon, and M.J. Degen, 1985. "Treatment by Onsite Systems", *Proceedings of a Workshop on Utilization, Treatment and Disposal of Waste on Land*. Soil Science Society of America, Madison, WI. Dec. 6-7.

Macropore flow through saturated strongly structured soils or soils of the sandy textural family may result in pathogen travel over relatively long distances with minimal treatment. Romero (1970) cites a number of pit privy studies where the pits intersected or were within close proximity to the water table. Elevated bacterial levels were temporarily detected up to 24.4 m horizontally from the source.

Vertical movement of the bacteria through a fragipan was limited. Horizontal movement of effluent above the fragipan resulted in significant removals of the bacteria but only after effluent had travelled horizontally a minimal distance of 6.1 to 12 m. The fecal coliform counts in water samples collected at 12 m were only slightly lower than in samples collected at 6.1 m.

Hagadorn et al (1978) found that flushes of bacteria coincided with rainfall events and a water table rise to within 15 cm of the surface, [and macropores] aided in the rapid transport of the bacteria under saturated flow conditions.

Under unsaturated flow conditions, bacteria can be adequately removed within 0.9 to 1.2 m of

effluent flow through soils (U.S.E.P.A. 1980; Hansel & Machmeier, 1980).
Hagadorn et al (1981) reviewed a report by Bouma et al (1972) which examined 19 subsurface soil disposal systems. Fecal coliforms were reduced to background levels within 61 cm of the trench bottom. Even in a sandy soil Ziebell et al (1974) reported a 3000 fold reduction in bacteria levels 38 cm below the trench bottom and 30 cm laterally. Stewart and Reneau (1984) installed a shallow-placed, LPD system to increase the unsaturated zone in a Typic Ochraquult. After 2 years, fecal coliforms had been detected in only 5% of the 150 samples collected from shallow wells (150 cm deep). Samples that contained fecal coliforms were restricted to periods of high water tables and were confined to the effluent distribution area.

11. Romero, J.C., 1970. "The Movement of Viruses Through Porous Media", *Groundwater*, 8(4):37-48.

Stiles and Crohurst (1923) summarize a number of studies of groundwater pollution by privy wastes and the following is one of their findings: The ultimate distance to which the pollution will be carried is dependent upon a number of complex and interlocking factors, namely wet and dry weather, with resulting rise and fall of the groundwater flow (depending on the "head" which in turn is dependent upon the rainfall); and obviously also the factor of the viability of the organisms under conditions of moisture, pH, food supply, etc.

Cites a number of pit privy studies where the pits intersected or were within close proximity to the water table. Elevated bacterial levels were temporarily detected up to
24.4 m horizontally from the source.

12. Stewart, L. W. and R.B. Reneau, Jr., 1988. "Shallowly Placed, Low Pressure Distribution System to Treat Domestic Wastewater in Soils with Fluctuating High Water Tables.", *J. Environ. Qual*. 17(3):499-504.

Installed and tested a low pressure distribution system in soils with a fluctuating high water table. Few fecal coliforms were present at the 1.5 m depth within the OSWDS even during the period of highest water tables, January through March of 1982, when macropore flow would be at a maximum. The restricted migration of fecal coliforms even during high water periods is attributed to uniform STE distribution, placement of the OSWDS in the more biologically active and aerobic soil horizons, and maximizing unsaturated flow.

13. Tyler, E.J., R. Laak, E. McCoy and S.S. Sandhu, 1977. "The Soil as a Treatment System." *Home Sewage Treatment*. American Society of Agricultural Engineers Publication 5-77, St. Joseph, Michigan.

At a distance of 1 foot into the soil surrounding the trench there was a 3 log reduction in bacterial numbers and within the second foot counts are to the acceptable range for a fully treated wastewater.

Some bacteria and viruses added to the wastewaters are pathogens. Their movement during unsaturated flow is expected to be limited to within a meter.

14. Yates, M.V., S.R. Yates, 1989. "Septic Tank Setback Distances: A Way to Minimize Virus Contamination of Drinking Water", *Ground Water* 27(2):202-208.

Numerous studies have shown that microorganisms can travel considerable distances in the subsurface; these have been reviewed by Yates and Yates (1988). Viruses in particular, due to their small size (20 to 200 nm) and long survival times, can migrate very large distances in soil and ground water; as much as 1600 m have been reported for certain viruses in karst [porous limestone, with cracks and fissures] terrain (Gerba, 1984) and up to 400 m in sandy soil (Keswick and Gerba, 1980).

Additional Reading

1. Bouma, J. W.A. Ziebell, W.G. Walker, P.G. Olcutt, E. McCoy and F.D. Hole, 1972. "Soil Absorption of Septic Tank Effluent", *Extension Circular No. 20, University of Wisconsin*, Madison.

2. Brown, K.W., H.W. Wolf, K.C. Donnelly and J.F. Slowey, 1979. "The Movement of Fecal Coliforms and Coliphages Below Septic Lines", *J. Environmental Quality* 8:121-125.

3. Caldwell, E.L., 1937. "Pollution from Pit Latrines When an Impervious Structure Closely Underlies the Flow", *J. Infectious Diseases* 61:269-288.

4. Caldwell, E.L., 1938a. "Pollution Flow from a Pit Latrine when Permeable Soils of Considerable Depth Exist Below the Pit", *J. Infectious Diseases* 62:225-258.

5. Caldwell, E.L., 1938b. "Studies in Subsoil Pollution in Relation to JPossible Contamination of Ground Water from Human Excreta Deposited in Experimental Latrines", *J. Infectious Diseases* 62:273-292.

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