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SMALL SCALE WASTE MANAGEMENT PROJECT

**Soil-Based Treatment of On-Site Waste Water
Treatment Mechanisms and Design Considerations**

by

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SOIL-BASED TREATMENT OF ON-SITE WASTE WATER

TREATMENT MECHANISMS AND DESIGN CONSIDERATIONS

By

James C. Converse¹

The ultimate receiver of waste water is either 1) the air through evaporation, 2) surface waters or 3) ground water via surface or subsurface discharge. This publication discusses some of the concepts of soil-based on-site treatment used for both domestic and commercial wastewater. Soil-based treatment has been practiced for many years and will continue to be a very important even with the advent of new treatment technologies. However, the primary role of soil may change depending on the degree of pretreatment prior to effluent discharge to the soil.

Role of Soil in On-site Wastewater Treatment

As a soil tester, system designer or installer, you must be knowledgeable of the role that soil has in on-site wastewater treatment, today and in the future. Soil based units such as the in-ground trench and bed, at-grade and mounds have been the primary workhorse for on-site domestic and commercial wastewater treatment and they will continue to be a very important component.

Until now society has viewed on-site wastewater treatment as a temporary fix until sewers arrive. However, that attitude is changing. As we move into the next millennium, society will be relying more and more on on-site wastewater treatment with the soil as the treatment/dispersal unit because the large municipal wastewater treatment systems will become too costly especially in the more rural low density areas. However, it will be more common for small communities, with failing onsite systems to implement, a mixture of on-lot treatment and a collection system where all or a portion of the wastewater will be collected and transported to a central wastewater treatment system and discharged to a soil treatment/dispersal unit for recharge to the ground water. **In this scenario the septic tank serves as the pretreatment unit and the soil serves as the primary treatment of the wastewater and dispersal into the environment with the ground water as the final receiver.**

Today, the on-site wastewater treatment technology is rapidly expanding. These new technologies can and will be able to "purify" the wastewater to a point that it can be recycled to the home for toilet flushing and for bathing and even consumption. However, we are not yet, psychologically, to the point where we will consume it without first discharging it to the soil where it will percolate to the ground water to be used as our drinking water. Since more of the

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treatment is done by the pretreatment unit, the soil becomes less important for treatment but still has the responsibility for dispersal. Thus, there is room for higher loadings and less separation distance. Waste water treated to this level will be referred to as "highly pretreated effluent".

In this scenario the pretreatment unit serves as the primary treatment unit and the soil "polishes" and disperses the effluent into the environment with ground water as the final receiver.

The scenario chosen by the designer will dictate the design of the soil treatment/dispersal unit such as the size of the soil unit and the separation distances to the seasonal/permanent ground water and bedrock.

Soil Loading Rates

Hydraulic Loading Rate: The amount of waste water applied to the soil in "gallons/square foot per day" or in centimeters/day or indirectly as "square feet of absorption area/bedroom" will be dependent upon the following:

Wastewater quality - septic tank effluent or highly pretreated effluent

Soil morphological characteristics- soil texture, soil structure and soil consistence.

Percolation rates have been used and are still being used in some areas. Using soil morphology for determining loading rates is superior and more accurate but the soil evaluator/designer must be well versed in the practice. Converse and Tyler (1991) give soil loading rates of 0.2 to 0.8 gpd/ft² based on morphological factors for soils receiving septic tank effluent.

Soil systems receiving highly pretreated effluent can be loaded at higher rates than soil systems receiving septic tank effluent. Tyler and Converse(1994) suggest soil loading rate 0.4 - 13 gpd/ft² for soils receiving highly pretreated effluent from units such as aerobic units or sand filters. These are suggested loading rates which have not been thoroughly tested in the field. Also, other factors, discussed later, must also be considered. At these higher loading rates, it is imperative that the pretreatment unit consistently discharges a high quality effluent and does not discharge excessive amounts of BOD and suspended solids which may result in failure of the soil unit. Soils receiving highly pretreated effluents serve as the final "polishing unit". Clogging mat development is unlikely and the soil will not adequately polish the effluent if overloaded as the effluent moves too quickly through the soil. The effluent should be spread out over a larger area for better dilution with the ground water. The only way to do that is with pressure distribution.

Linear Loading Rate: Linear loading rate is a relatively new concept related to system configuration. It is defined as: **the amount of wastewater applied daily along the landscape contour expressed in gpd/linear foot.** It relates to conveying the effluent away from the system once it has entered the soil. It is more important for sites where part or all the effluent

moves laterally away from the system due to a restrictive soil horizon or seasonal saturation that limits vertical flow. All systems should have their long dimension along the site contour.

Linear loading rate is extremely important when configuring systems. It is also an important concept when considering downsizing of the soil treatment/dispersal unit with highly pretreated effluent. Fig. 1 demonstrates linear loading rate relative to configuring the system receiving septic tank effluent and also for downsizing the soil treatment/dispersal unit receiving highly pretreated effluent. The middle and right figures have the same soil loading rate but the right figure has twice the linear loading rate. The left figure has half the soil loading rate of the middle and right. The linear loading rate for the left and middle figure are the same but the right figure has twice the linear loading rate.

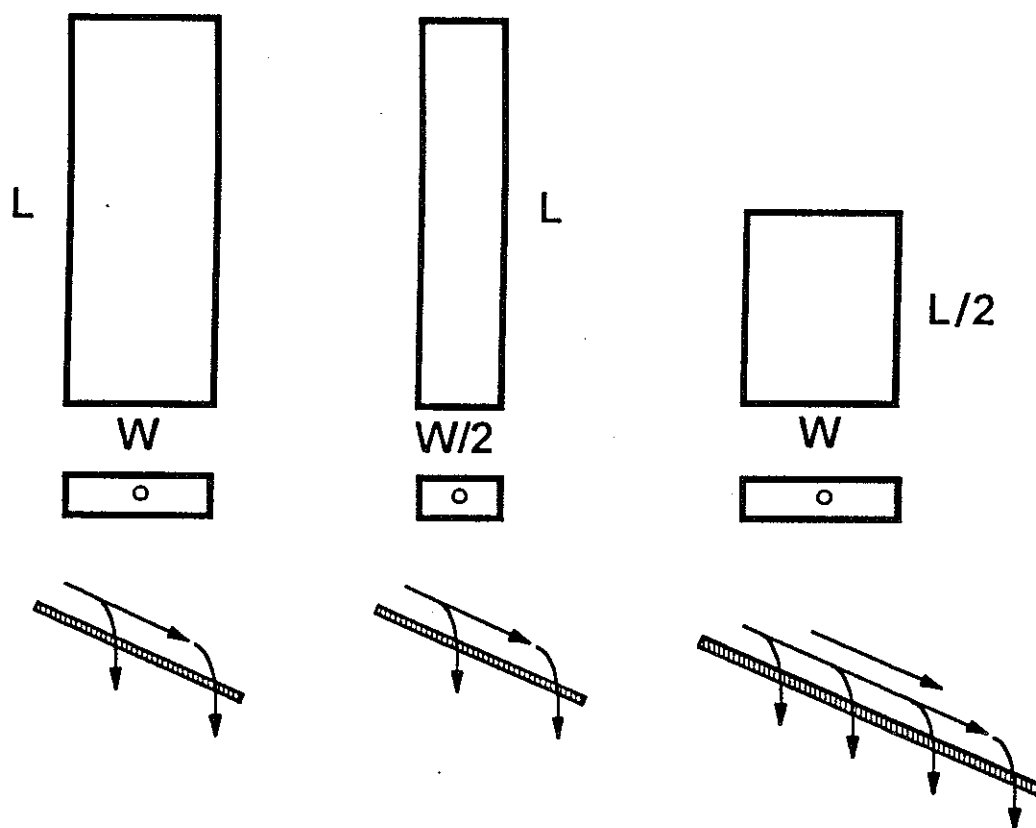


Fig. 1. These three diagrams illustrate how configuration affects linear loading rates. The flow rate (gpd) is the same to all three units. The left diagram is loaded at half the soil loading rate as the middle and left figures. The middle one has the same linear loading rate as the left one. The right figure has twice the linear loading rate of the middle and left one. If the flow is horizontal, the right one has to move twice as much effluent per foot along the contour as do the middle and left unit.

Organic Loading Rate: Organic loading relates to the amount of organic matter, measured by BOD, TOC and COD, that is introduced into the treatment system. The more organic matter introduced the greater the impact. For example, on-site systems receiving restaurant wastes will typically receive more organic matter than systems receiving domestic wastewater even though both may be receiving the same hydraulic loading rate. Siegrist et al. (1984) found that septic tank effluent BOD from restaurants was 2-3 times greater than septic tank effluent BOD from homes. Typical BOD₅ from a septic tank receiving domestic waste water is 150 - 200 mg/L with flows in range of 300 gpd. which yields an organic load of 0.44 lbs/day. A restaurant with a BOD of 1000 mg/L and the same flow rate will produce 2.5 lbs/day. If the systems were loaded at the same hydraulic loading, the one receiving the restaurant waste would have to "work" 5-6 times more than the one receiving domestic wastewater. In all likelihood the system receiving the restaurant waste will pond and fail more quickly than the one receiving domestic waste water. **When sizing systems the designer must evaluate the amount of organic loading going to the system and size the system at the same organic loading rate including fats, oils and greases as is done for domestic wastewater.**

Oxygen Demand: Bacteria and other biota operate under either aerobic conditions (molecular oxygen present) or under anaerobic conditions (no molecular oxygen present). If a soil treatment/dispersal unit operates under anaerobic conditions for extended periods of time, a clogging mat forms resulting in effluent ponding and failure. The clogging mat provides an excellent treatment medium but it can severely restrict the hydraulic flow.

Oxygen demand is estimated by BOD₅ and the amount of oxygen it takes to convert organic nitrogen and ammonia to nitrate. Using BOD₅ will underestimate the amount of oxygen required as it is the ultimate BOD value and not the 5 day BOD value. However, BOD₅ will probably be used for the estimate.

The lack of oxygen results in a predominance of anaerobic bacteria at this interface. Anaerobic bacteria are less efficient and slower in converting organic matter to carbon dioxide and water and they also produce materials that tend to clog the soil pores. This clogging mat builds up over time because of limited oxygen available. If more oxygen were available, or if the level of organic material (BOD and nitrogen) were reduced, the oxygen demand would be less and the clogging mat development would be reduced.

Oxygen enters the area by diffusion. It is a very slow process especially if the interface is deep and the soils are tight. Figure 2 shows how oxygen enters by diffusion. Muhuta and Boyle (1991) developed a model of gas transport beneath systems based on a laboratory model. They estimated gas transfer for an in-ground aggregate soil absorption unit receiving septic tank effluent with a TOC of 80 mg/L and TKN of 50 mg/L and loaded at rate of 0.29 gpd/ft² into a relatively homogeneous sandy soil. The trench/bed width should be less than 12 ft wide with spacing of 20-30 ft between trenches/beds and depth of ground water beneath the infiltrative surface should be greater than 5 ft to maintain aerobic conditions within the vadose zone. No reference was given to depth of infiltrative surface by the authors, but shallower systems would

allow for better diffusion. For heavier soils and less homogeneous soils, the trench/bed width should be narrower.

For systems receiving septic tank effluent, the system should be designed to meet the oxygen demand. Unfortunately, there is no defined procedure for doing so at this time. However, some practical considerations such as 1) reducing the organic matter in the waste stream via pretreatment, 2) making trenches/beds narrower 3) installing trenches/beds shallower and 4) reducing the hydraulic loading rate to the system will assist in meeting the oxygen demand and minimizing the clogging mat development. Systems receiving highly treated effluent have already had the oxygen demand met for the most part and a clogging mat is unlikely to develop.

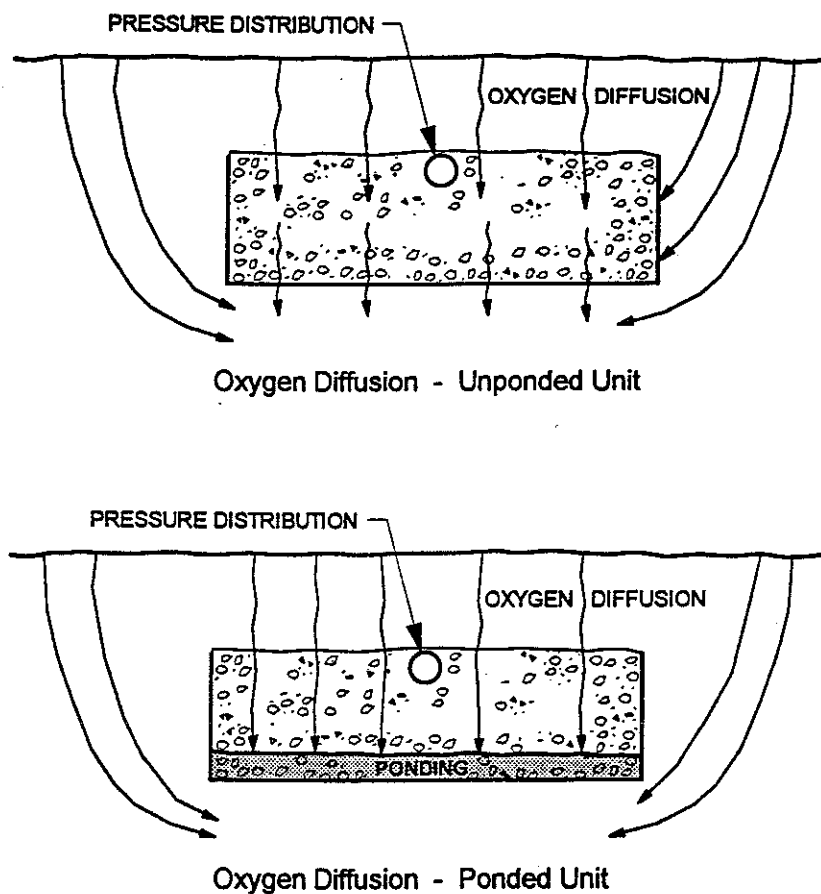


Fig. 2. Cross section of in-ground trench/bed depicting oxygen transfer into and around a the unit. The critical area for oxygen is at the soil/ aggregate interface and directly beneath the interface. The top figure illustrates transfer with no ponding and the bottom one depicts ponding where the only effective transfer is around the edges of the unit. Other units such as mounds and at-grades have oxygen transfer paths.

Treatment Mechanisms

Soil Morphology: The soil profile consists of solids and pores filled with water or air. Under saturated conditions, all the pores are filled with water. Pores range in size from small to large. Pores can be interconnected to better transport water. The solid component consists of cobbles, gravel, sand, silt and clay particles. These components can be intermixed to form various textures such as sandy loam, silt loam, loam and clay loam.

Soil particles consist of single grain (sands) or peds of different shapes. Soil structure is a method of defining the shape of the peds such as angular blocky, subangular blocky and platy. Peds can be weak (less stable), moderate or strong (more stable). There are cracks between the peds. In addition to cracks worm channels, and old root channels form conduits for water flow.

Soil Biota: The vast majority of the biological, physical and chemical interactions take place in the upper horizons of the soil profile. Oxygen levels are higher in these upper horizons. Most of the soil biota live in the upper foot or two of the soil and over half of the water is utilized in the first 1-2 ft. Since most of the activity takes place in these shallow horizons, then the waste water should be introduced into these areas. However, in the colder climates biota activity is at a minimum during cold periods and system freezing is a major concern. Thus, there is a tendency to place the soil absorption unit deeper in the soil profile. We need to rethink this philosophy and consider placing the waste waters in the upper horizons for better nutrient recycling and wastewater treatment as this is where most of the soil and water activity is located.

Fluid Flows: Wastewater treatment is best performed in an unsaturated soil environment. Oxygen moves more freely through the soil under unsaturated conditions than saturated conditions. Also, effluent moves more slowly under unsaturated conditions than saturated conditions. Treatment is a function of contact time with the bacteria. Thus, treatment is more complete when the effluent moves slowly through the profile as there is more contact time with the bacteria.

When a large quantity of water is added to the soil, it will flow rapidly downward under the influence of gravity under saturated conditions through the larger pores and worm and root channels, initially bypassing the finer pores. As it moves down the larger pores the matrix potential and capillary action will pull it into the finer pores. When very small quantities of water are applied to the soil, such as via a misting or sprinkling, it will enter the smaller pores via matrix potential and move very slowly through the soil downward as well as sideways.

BOD and Suspended Solids: As the effluent moves through the soil, the larger organic particles are filtered out. The finer solids and dissolved organic solids are consumed by the bacteria, which are attached to the soil particles. They convert this organic matter to carbon dioxide, water and energy.

Pathogens: The soil is a hostile environment for pathogens. Bacterial pathogens are filtered out in the soil and usually die off because they can not compete in this "hostile environment". Soil bacteria will normally consume pathogens. Viruses normally travel further in the soil profile than bacteria as they are smaller and not as easily filtered out as are bacteria and are more resistant to die-off. It is generally agreed that the soil does a reasonable job of attenuating viruses but further research is needed to better define the fate of viruses in soils.

Nitrogen: As organic nitrogen is converted to ammonia/ammonium ions, the positively charged ammonium ions adhere to the negatively charged soil particles. Soil bacteria in the presence of oxygen convert the ammonium ion to nitrite and then nitrate. If anoxic areas (absence of oxygen) are present in the soil and a carbon source (BOD) is available some of the nitrate is converted by bacteria to nitrogen gas (denitrification). Plant roots will absorb ammonia and nitrate for nutrients. Nitrate, beyond the reach of the plant roots, will leach to the ground water. The ammonium ion will remain attached to the soil particle until converted to nitrate. However, if oxygen is not present, the soil cation exchange sites will become full and the ammonia will migrate downward especially in sand where the number of exchange sites is limited compared to the finer textured soils such as clay. Fig. 3 illustrates the conversion of nitrogen.

Phosphorus: Phosphorus is absorbed to the calcium, iron and aluminum present in the soil. In the sandy soils where there are fewer of these elements the phosphate ion will migrate further than in the finer textured soils. Around lakes with sandy soils, the threat of phosphorus leaching into the ground water from on-site systems and eventually into the lakes is much greater than leaching into the ground water from on-site systems located in the finer textured soils.

Effluent Distribution

Gravity Distribution: The vast majority of onsite systems move water by gravity flow from the septic tank to the soil treatment/dispersal component. Effluent enters through a distribution box, drop box or manifold. As the effluent enters the 4" perforated pipe it flows out of the pipe at one or two locations, down through the aggregate to the soil surface and spreads out on the surface with the degree of spread being a function of the flow rate and the infiltration rate. Because this small area is receiving a large hydraulic and organic load, a clogging mat forms, restricting flow.

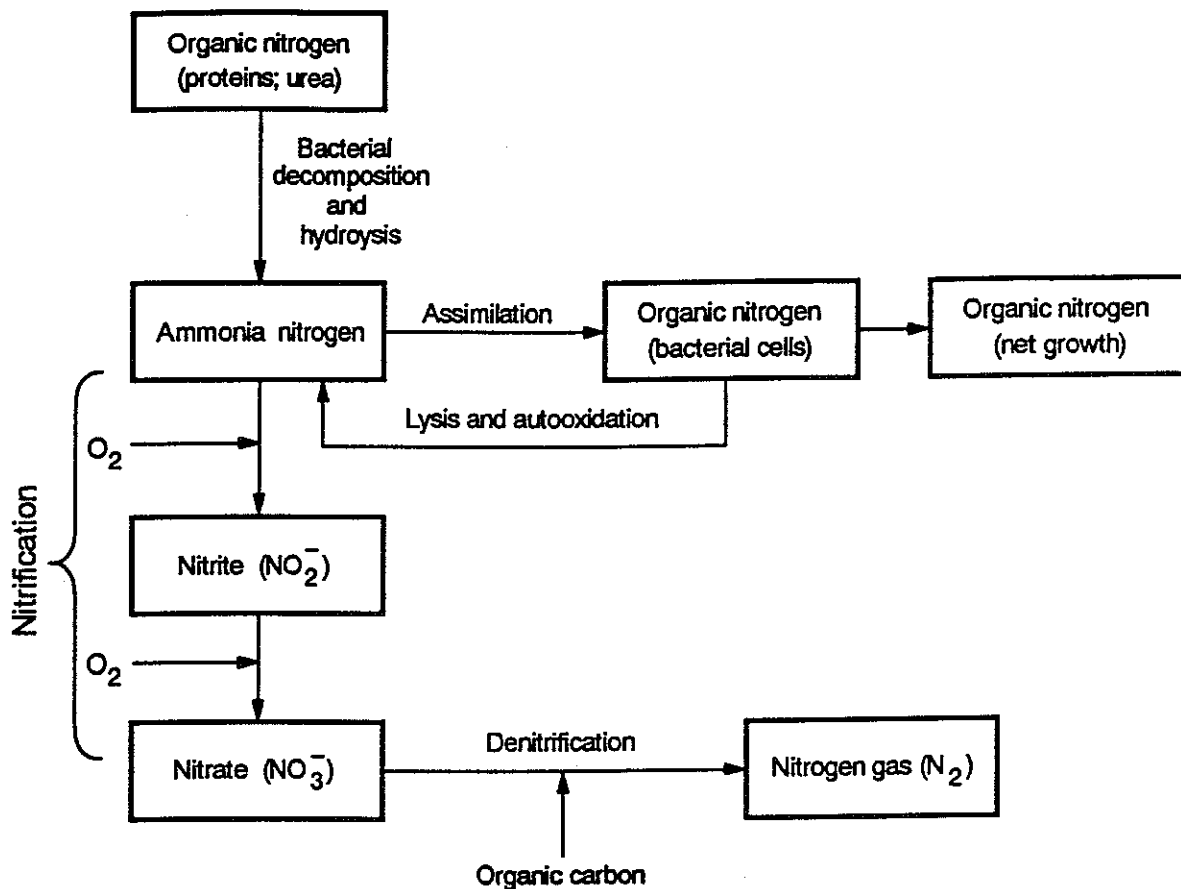


Fig. 3. Nitrification and denitrification cycle (Metcalf and Edy, 1991).

The flow moves to the outer edges of the clogging mat with the clogging mat ever enlarging. Treatment is compromised in these high flow areas because the effluent moves through the soil rapidly, reducing the contact time. Effluent quality is very good beneath the clogging mat but the hydraulic conductivity has been reduced. Eventually the infiltrative area becomes clogged resulting in ponding. Clogging can be controlled by periodically “resting” the soil absorption area. This allows the effluent to drain and exposes the infiltrative area to oxygen where aerobic bacteria break down the clogging mat. Systems incorporating drop boxes or distribution boxes allows for trenches to be selectively rested.

Demand Dosing: Systems with pump chambers, such as mounds, typically use demand dosing of effluent where a large quantity of effluent accumulates and on demand (float level activates), a large quantity of effluent is pumped to the soil treatment/dispersal unit where it rapidly infiltrates into the soil if no clogging mat has developed. Treatment, though better than gravity flow prior to clogging mat development, is compromised because of the large flow. Actual flow may be one or two times per day with flow of 150-200 g.p.d./dose.

Time dosing: Time dosing uses a timer to control the dose volume and time of dosing. A small amount (40-50 gallons/dose) is pumped to the soil treatment/dispersal unit. The effluent is spread somewhat uniformly via a pressured distribution network over the infiltrative surface and slowly infiltrates into the soil and is “held” in the upper horizons for the bacterial to “clean” the wastewater. This method will provide for a better quality effluent leaving the soil treatment area. This concept requires that surge storage be provided in the septic tank (with a pump vault) or a pump chamber following a septic tank.

Separation distances:

Soil is an excellent medium for treating wastewater. However, soils are very variable and the degree of treatment will vary depending upon a number of factors. Based on years of experience and field observations, treatment is best accomplished if sufficient unsaturated soil is available. Flow through unsaturated soil allows time for the soil biota to reduce the BOD and suspended solids, convert the nitrogen to nitrate, allow the phosphorus to precipitate, allow the pathogens to die off and allow other chemical/biological/physical reactions to take place.

Separation distances dictated by local/state codes from 1-4 ft with 3 ft as the typical value. Although not defined in the code, treatment will vary depending on such factors as wastewater strength, loading rate, type of distribution of wastewater and the amount of clogging mat development.

Pathogen removal, more so than BOD and suspended solids, is a function of separation distance. The current separation distances, such as the 3 ft distance, is based on septic tank effluent which typically produces effluents with fecal coliform counts of 10^5 col./100 mL. If a pretreatment unit, such as a sand filter, reduces the fecal coliforms more than does a septic tank, then it makes sense to allow less separation distance from the infiltrative surface to the limiting condition of seasonal saturation and bedrock. However, the caveat is that there will be no clogging mat development in dispersal units receiving highly pretreated area so it is imperative that the effluent be distributed somewhat uniformly over the surface and the system is not excessively loaded. The Wisconsin proposed code and the existing current code for replacement under certain conditions, gives a 2 ft soil separation credit for dispersal units receiving effluent with fecal coliform counts less than 1000 col./100 mL and a 1 ft credit for dispersal units receiving effluent with fecal coliform counts $>1,000$ and $<10,000$ col./100 mL on a consistent basis.

Although not part of the code, it may be possible to reduce the separation distance based on type of application. For example, distributing the effluent in frequent micro doses over a large area, such as drip distribution, allows more contact time for the soil biota to remove the pathogens in relatively short distances as the effluent is retained in the soil profile for longer time. Also, if the effluent is introduced in the upper horizons where the soil biota activity is the greatest, shorter separation distances may be possible. However, additional research which is currently underway, must be completed to verify this.

It should be noted that the less separation distance to seasonal saturation, the more difficult it is to remove the effluent hydraulically away from the system as the wetter soil in close proximity to the dispersal unit has less matric potential for pulling the water away from the dispersal unit. This could result in ponding within the trench or leakage out the toe of mound and at-grade units.

Types of Soil Treatment/Dispersal Units

The type of soil treatment unit and dispersal unit will be dictated by the quality of effluent; septic tank or highly pretreated, and the soil site conditions.

For septic tank effluent:

1. In-ground units - A series of parallel shallow narrow trenches spaced several feet apart. Beds are used but not recommended because of width. Trenches may be filled with aggregate, chambers or other acceptable material to provide pore space.
2. At-grade unit - where the soil is tilled and aggregate placed on the ground surface and covered over. (Converse and Tyler, 1990)
3. Mounds - where soil is tilled, coarse sand placed on the tilled surface, with a narrow aggregate area formed in the sand with soil over the total area (Converse and Tyler, 1990).
4. Septic drip distribution - Septic tank effluent is filtered and pumped under high pressure through a series of small diameter tubing with emitters located in the tubing at 1 ft or 2 ft intervals. Drip distribution provides the best distribution of effluent over a large area. It is recommended to be installed shallow. (American Manufacturing, 1998; Geoflow, 1998)

For highly pretreated effluent:

1. In ground units - A series of parallel shallow narrow trenches spaced several feet apart. Beds are used but not recommended because of width. Trenches may be filled with aggregates, chamber or other acceptable material to provide pore space.
2. Half-pipe unit: a series of half pipes up to 12" wide with pressure distribution. Half pipes are placed in trenches up to 10" deep. Effluent is distributed through small diameter pipe laying on the soil in the bottom of the unit. (Orengo Systems, Inc.)
3. At-grade unit - where the soil is tilled and aggregate placed on the ground surface and covered over. (Converse and Tyler, 1990)

4. Modified Mounds - where soil is tilled, 3-4" of sand placed on the surface, with a narrow band of aggregate placed in the sand with soil over the total area (Converse and Tyler, 1998).
5. Drip distribution - Highly pretreated effluent is filtered and pumped under high pressure through a series of small diameter tubing with emitters located in the tubing at 1 ft or 2 ft intervals. Drip distribution provides the best distribution of effluent over a large area. It recommended to be installed shallow (American Manufacturing Co, 1998, Geoflow, 1998)

The Ideal Treatment/Dispersal Unit for Septic Tank Effluent.

The goal of the designer is to install a system that approaches the ideal system. However, site restrictions or variations in wastewater quality may not allow this so compromises must be made.

A two compartment septic tank with a filter in the second compartment.

A pump chamber with surge storage capacity and pump controller for time dosing. A compromise would be to have a pump vault in the second compartment with a hole in the middle of the dividing wall so that both compartments would serve as surge capacity.

Effluent uniformly distributed to a shallow, narrow infiltrative surface which allows for maximum oxygen transfer, maximum biological activity and plant root uptake of nutrients. Effluent is dosed to the soil in small quantities for maximum treatment. Mounds and at-grades could substitute for an in-ground trench. Drip distribution could also be considered.

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