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SECTION X SUBSURFACE WASTEWATER ABSORPTION SYSTEM DESIGN

A. Introduction

This section provides guidance for design of subsurface wastewater absorption systems (SWAS) under various conditions that control such designs, including:

- soil characteristics,
- ground water conditions,
- wastewater flows and characteristics,
- long term acceptance rates,
- effective infiltrative surface areas,
- linear loading rates,
- vertical separating distance to the seasonal high ground water table,
- travel times from the SWAS to a point of concern,
- flow distribution,
- systems in natural soils, and,
- systems constructed in fill materials.

B. Vertical and Horizontal Separating Distances

1. Introduction

The U.S. EPA indicates that over one-half of the waterborne disease outbreaks in the United States are due to the consumption of contaminated ground water. While some of these outbreaks are caused by chemical contamination, the majority are caused by consumption of groundwater that has been contaminated due to the presence of bacteria and viruses in domestic wastewater that has been discharged onto or into the soil.

In particular, in recent times the U.S. EPA and public health agencies have become concerned with viruses. Viruses are of major concern because of their ability to survive for long periods of time in the subsurface and still remain infectious, and the very small number (as little as one virulent particle in some cases) are thought to cause disease. While there are some bacteria and parasites that can cause infection if ingested in small numbers, of greatest concern are the viruses that may find their way into the ground water.

2. Goals for removal/inactivation of Pathogens

Protozoa and helminths are occasionally found in septic tank effluent but are not usually found in groundwater beneath a SWAS. Because of their relatively large size, pathogens such as helminths (parasitic worms, such as roundworms and tapeworms) and protozoa (*Cryptosporidium parvum* and *Giardia lamblia*, and their cysts or oocysts) are generally removed in the biomat that forms at the soil interface of the SWAS and in the underlying unsaturated soils before reaching the water table, although this might not be the case for very coarse soils.

However, bacteria and viruses are much smaller and, when discharged to a SWAS, can move into ground and surface waters, initiate significant health problems, and promote outbreaks of waterborne disease (VA Division of Health-1990). While pathogenic bacteria are of public health concern, studies have shown that viruses travel further and can exist in a viable state for a much longer time than pathogenic bacteria. Therefore, viruses are of significant concern with respect to public health considerations. Where adequate removal/inactivation of viruses is obtained, it is probable that adequate removal of other pathogenic microorganisms has also occurred.

The Department had a detailed review and study of the literature conducted on the fate and transport of pathogens in the subsurface (Jacobson-2002). The results of that study indicated that it is reasonable to establish a goal of at least a 5 $\log_{10}$ (99.999%) removal/inactivation of viruses from domestic wastewater discharged to an OWRS before the commingled wastewater/ground water reaches a sensitive receptor, and that a greater removal/inactivation is preferable.

3. Vertical Separating Distance

Recent detailed studies in Florida, Colorado and Massachusetts have confirmed earlier studies that indicated a three Log_{10} (99.9%) removal/inactivation of viruses can be obtained when domestic wastewater has:

a.) been pretreated in a septic tank and discharged to a properly designed SWAS,

b.) percolated through the biomat that forms at the SWAS-soil interface and,

c.) has moved slowly down through at least three feet of suitable aerobic, unsaturated soil.

Under design flow conditions, additional vertical separating distance may be necessary to provide adequate hydraulic reserve capacity. While the examples contained in this section do not address reserve hydraulic capacity, adequate reserve capacity shall be provided in the system design. This should be discussed with Department staff.

4. Horizontal Separating Distance

While the most significant renovation of septic tank effluent occurs at the biomat that develops at the soil interface with the SWAS and in the unsaturated soil beneath the SWAS, renovation of the percolate from the SWAS continues after it reaches the saturated zone. The effectiveness of renovation in the saturated zone depends on factors such as the type and strain of virus, physical, chemical and biological characteristics of the virus, the physical and chemical characteristics of the soil through which the percolate flows, the temperature of the ground water, and the natural processes that tend to remove or degrade viruses in the subsurface. These natural processes include sorption, ion-exchange, dispersion, and microbial degradation.

Numerous studies have been conducted in an attempt to quantify the rate of virus removal in the ground water. The only factor that has consistently been shown to demonstrate a statistically significant correlation with the decay rate of viruses under saturated flow conditions has been the ground water temperature. Yates et al. (1987) determined from 172 virus experiments conducted at temperatures ranging from 4° to 32°C that the virus inactivation rate could be expressed by the following equation:

$$\text{Inactivation Rate, } Log_{10}\ day^{-1} = (0.018 \times T) - 0.0144,$$

where T = ground water temperature, °C. The mean ground water temperature in Connecticut, in the zone affected by seasonal fluctuations, can be assumed to be at least 10°C, except in the extreme northeastern and northwestern corners of the state. Inserting that value in the equation above results in an inactivation rate of 0.036 log_{10} day^{-1}. This indicates that, in Connecticut, viruses can survive for long periods of time in the ground water. If the goal for virus removal/inactivation is selected to be five (5) log_{10} for sensitive receptors, and a three (3) log_{10} removal/inactivation is anticipated before the wastewater reaches the ground water, an additional two (2) log_{10} inactivation would be required as the viruses travel with the ground water. Based on an inactivation rate of 0.036 log_{10} per day, a travel time of 56 days is indicated between a SWAS and existing and potential sensitive receptors such as:

a. the outer limit of the cone of depression of a public (community) drinking water supply well,
b. a surface water body used, or intended to be used, as a source of public (community) drinking water supply,
c. a private drinking water supply well serving an individual residence.
d. an impoundment used for aquaculture.

The minimum required travel time to all other points of concern should be not less than 21 days, and a greater travel time is preferable.

It should be noted that some investigators have found that passage of raw wastewater through a septic tank resulted in a reduction of virus concentration in the tank effluent. For example, Higgins et al. (2000) found a 74% (< 1 log_{10}) reduction. On the other hand, other investigators have found little or no such reduction. Thus, while a septic tank may effect some reduction in virus concentration, the amount of reduction is in question.

Therefore, any reduction in virus concentration effected by a septic tank is considered to be a safety factor and any such reduction should not be credited as part of the five (5) log_{10} reduction goal.

C. Long Term Acceptance Rate (LTAR)

1. General

The Department's criteria for hydraulic design of a subsurface wastewater absorption system (SWAS) are based on consideration of both the hydraulic capacity of the soil in which the system is located, and the long term acceptance rate (LTAR) of pretreated wastewater by the biocrust (biomat) that develops at the soil/SWAS interface (infiltrative surfaces). The determination of the soil hydraulic capacity has been addressed in Section VI- Hydraulic Capacity Analysis. This sub-section addresses the selection of the LTAR of the SWAS infiltrative surfaces.

As indicated in Section II, the thickness and susceptibility of the biocrust to clogging is related to the dissolved and suspended organic matter remaining in the pretreated wastewater (the "organic loading rate"). Excessive organic loading rates will result in conditions leading to a thicker biological/zoogleal layer that severely reduces the rate of flow into the unsaturated soil zone and causes anaerobic conditions to persist.

The LTAR may be defined as the infiltrative surface loading rate at which a SWAS will continuously accept effluent for a long period of time, and is dependent upon the soil characteristics, the biomat, and the wastewater characteristics (Anderson, et al.-1991). Healy and Laak (1974) determined the following relationship between the LTAR of a soil and the soil hydraulic conductivity:

$$LTAR = 5K - [1.2/(Log_{10}K)].$$

In this formula LTAR is in units of gpd/ft^2 and K, saturated hydraulic conductivity, is in units of ft/minute.

Figure LTAR-1 presents this expression in graphical format. For effluent from household septic tanks, the maximum stable LTAR value allowed by the CTDEP is 0.80 gallons per day per square foot of effective leaching area. This corresponds to a K value of ~28 ft/day (0.0197 ft/min. or 0.010 cm/sec).

Siegrist (1987) stated that the rate of discharge from a SWAS to the underlying unsaturated zone should not exceed 3% to 5% of the saturated hydraulic conductivity. He stated that such low discharge rates (hydraulic loading rates) are required in order to maintain adequate soil aeration and the low soil moisture content in the unsaturated zone that will allow intimate contact between the percolate from the SWAS and the soil particles. These conditions are required for removal/attenuation of pathogens and other contaminants in the percolate. The LTAR rates obtained from Figure LTAR-1 satisfy this requirement.

Laak (1970) hypothesized that the service life of a SWAS is related to the sum of the BOD_5 and TSS and that increasing the pretreatment of domestic wastewater prior to discharge to a SWAS would increase the service life of the SWAS. Based on the results of his studies at the University of Toronto (Laak-1966), he suggested an expression for the affect of BOD_5 and TSS in septic tank effluent on the development of the clogging mat at the SWAS-soil interface (Laak-1977). This expression could be used to calculate the increase in infiltrative surface area required for strong wastewater or the decrease in such area where reliable enhanced pretreatment is provided.

An "adjustment factor", based on the Laak expression, can be used to determine the leaching surface application rate to be used for high-strength (or low strength) wastewater. This factor is derived from the mathematical expression shown below (Laak-1977), which relates the five-day Biochemical Oxygen Demand (BOD_5) and Total Suspended Solids (TSS) concentrations in such wastewaters, to the average concentrations of BOD_5 and TSS found in the effluent of septic tanks receiving household wastewater:

$$\text{LTAR Adjustment Factor} = [250/(BOD_5 + TSS)]^{1/3}$$

In the preceding mathematical expression, the BOD_5 and TSS are expressed in milligrams per liter, and represent the values of these constituents in the pretreated wastewater discharged to the SWAS.

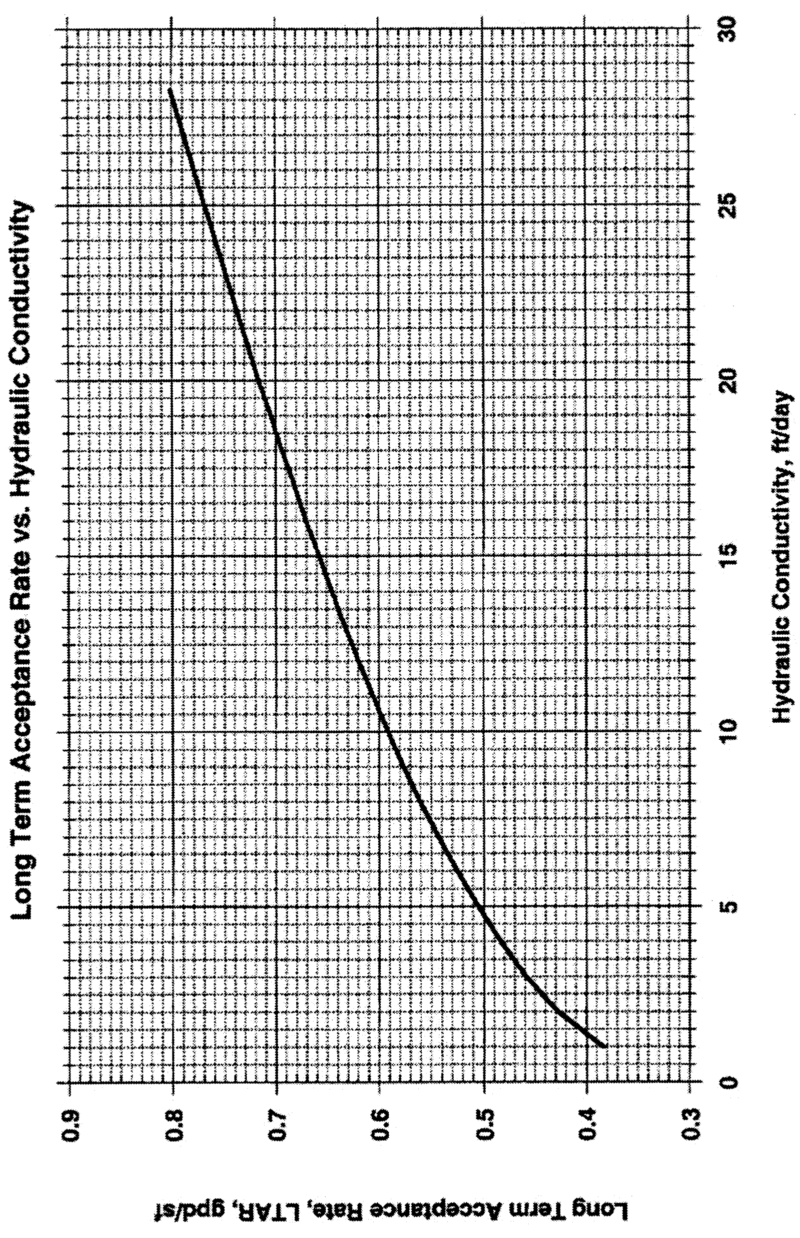

Figure LTAR-1

Thus, for wastewaters having BOD_5 and TSS values higher (stronger) than normal domestic wastewater, the LTAR value is decreased, and for wastewaters having lower (weaker) values, the LTAR value is increased. Where the septic tank effluent does not receive additional treatment prior to discharge to a SWAS, the maximum LTAR recommended = 0.8 gpd/sf of effective infiltrative area (ELA). Where additional treatment is provided, the maximum LTAR value recommended is 1.2 gallons per day per square foot of effective bottom area only. This limiting value is used to ensure the unsaturated soil conditions necessary in the soil beneath the SWAS for effective removal/inactivation of bacteria and viruses.

2. Results of Additional Research

Considerable research has been conducted since the current method for determining LTAR was developed. (Anderson, et al-1981; Otis, R.J.-1984; Siegrist, et al-1984a&b; Siegrist-1987a & b; Tyler and Converse-1989; Jensen and Siegrist-1991; Tyler and Converse-1994; Loudon, et al-1998; Loudon-1999; Matejcek, et al-2000; Erlsten and Bloomquist-2001; Tyler-2001). Of considerable interest with respect to long term acceptance rates for wastewater strengths considerably higher than household wastewater are the very recent studies by Matejcek, et al-2000 and Erlsten and Bloomquist-2001.

Matejcek et al (2000) conducted a thorough and well-documented study on long term acceptance rates for restaurant wastewater. Wastewater physical and chemical characteristics were determined for 133 samples of septic tank effluent from fifteen randomly chosen restaurants in Florida.

Failure occurred primarily in the lysimeters with two feet of unsaturated soil that were dosed with medium and high strength wastewater. Twenty-four lysimeters failed during the 112-day study with 20 failures occurring between 20 and 47 days. No failures were recorded in lysimeters dosed with low strength wastewaters, which received a daily mass loading (BOD_5 and TSS) of 0.0015 $lb/ft^2/day$. In addition, the cumulative mass loaded on the low strength columns exceeded the cumulative mass loading of the failed columns dosed with medium strength wastewater.

Conclusions reached by Matejcek et al. (ibid.) with respect to long term acceptance rates for restaurant wastewater were as follows:

1. Hydraulic loading alone does not cause drainfields to fail. Effluent concentration and hydraulic loading both contribute to clogging and formation of biomat, resulting in failure.

2. Fine sand soil columns receiving less than 0.0015 $lb/ft^2/day$ of contaminant mass (sum of BOD and TSS) did not fail. Similar columns receiving 0.0043 $lb/ft^2/day$ did fail. Therefore, there is a possible threshold at which drainfields fail due to daily mass loading. In this case, it appears to be between 0.0015 and 0.0043 $lb/ft^2/day$ for the fine sand soil.

A similar case can be made for all four soil types. Below the thresholds, drainfields appear to be able to adequately treat the daily load and are poised for the next application with no apparent permanent failure.

Recommendations made by Matejcek et al. (ibid.) with respect to long term acceptance rates included:

1. Limits should be established for restaurant effluent with concentrations to be in the low wastewater strength category (similar concentrations to those of wastes from domestic systems).

2. Drainfield sizing should include mass loading rates and hydraulic loading rates based on soil properties. Mass loading rates should not exceed 0.0015 $lb/ft^2/day$, but this value may need to be reduced based on soil properties.

However, Erlsten and Bloomquist (2001) reported on subsequent phases of the University of Florida's Onsite Sewage Treatment and Disposal Systems and Long Term Acceptance Rate study. In phase 2, the mass loading threshold was shown to lie between 0.0015 and 0.0024 $lb/ft^2/day$ of combined $CBOD_5$ (carbonaceous BOD_5) and TSS loading. The purpose of the phase 3 study was to further refine the apparent threshold above which lysimeter failure occurred consistently. The results obtained from the phase 3 study confirmed the upper limit established in the phase 2 study.

3. <u>Calculating LTAR</u>

The data on which Healy and Laak based their LTAR expression was obtained from residential sites discharging to stone filled trenches and were adjusted to a one foot ponding depth. If the infiltrative surface area hydraulic loading rates determined from the Healy and Laak LTAR expression are to be used for design of large scale on-site systems receiving a higher organic strength wastewater, the organic loading rates should be adjusted to that of household septic tank effluent. If it is assumed that the "strength" of household septic tank effluent (concentrations of BOD_5 + TSS) = 250 mg/L, the equivalent "strength" loading, at 1 gpd/ft^2, = 91 lbs./acre/day or 0.0021 $lbs/ft^2/day$. At the maximum allowable LTAR (hydraulic loading rate) of 0.8 gpd/ft^2, this equivalent loading rate becomes 72.6 lbs/acre/day, or 0.0017 $lbs/ft^2/day$. This falls within the mass loading threshold range of 0.0015-0.0024 $lbs/ft^2/day$ found by Erlsten and Bloomquist (2001). The upper end of that range (0.0024 $lbs/ft^2/day$) would be representative of a wastewater strength of about 360 mg/L. The mid-point of that range is 0.0020 $lbs/ft^2/day$.

The 250 mg/L value for the sum of household septic tank BOD_5 + TSS came from Laak (1977) and apparently was based on household wastewater characteristics determined several decades ago. Additional data that has become available since that time appears to indicate that this value may be a little low. This may be partially due to the reduced flow fixtures that have been on the market for almost two decades, including both the 3.5 gallon per flush toilet and the newer 1.6 gallon per flush toilet, plus reduced flow lavatory and shower head fixtures. This reduction in flow can be expected to result in a corresponding increase in the septic tank effluent pollutant concentrations. However, a decrease in flow should show an increase in septic tank efficiency, and thus the effects of decreased flow may cancel each other.

A method has been developed for adjusting the LTAR by using the Laak formula with the values obtained therefrom truncated when they exceed a mass loading of 0.0020 lbs./sf/day. A graph entitled "Adjustment of LTAR based on Wastewater Strength" is shown in Figure LTAR-2.

The adjusted LTAR determined from Figure LTAR-2 is then further adjusted on the basis of the concentration of TN anticipated to be found in the pretreated wastewater discharged to the SWAS. This will account for the increased oxygen demand (nitrogenous oxygen demand) exerted by the bacteria that oxidize the TN to nitrates where the TN concentration exceeds the TN concentration found in household wastewater.

Thus, where the TN concentration in the pretreated wastewater is greater than 56 mg/L, the adjusted LTAR based on wastewater strength is multiplied by the following factor:

$$\text{TN adjustment factor} = \frac{\text{56 mg/L[typical septic tank effluent]}}{\text{Pretreated Wastewater TN concentration, mg/L.}}$$

[The 56 mg/L is based on an upper limit of TN for raw residential wastewater of 70 mg/L and a removal rate of 20% in the septic tank. (70 mg/L *(1-0.20) = 56 mg/L)]

The procedures discussed above provide a means for determining the infiltrative surface loading rates based both on hydraulic and organic loading rates.

ADJUSTMENT OF LTAR BASED ON WASTEWATER STRENGTH

[Wastewater Strength = Σ (BOD_5 and TSS), mg/L]

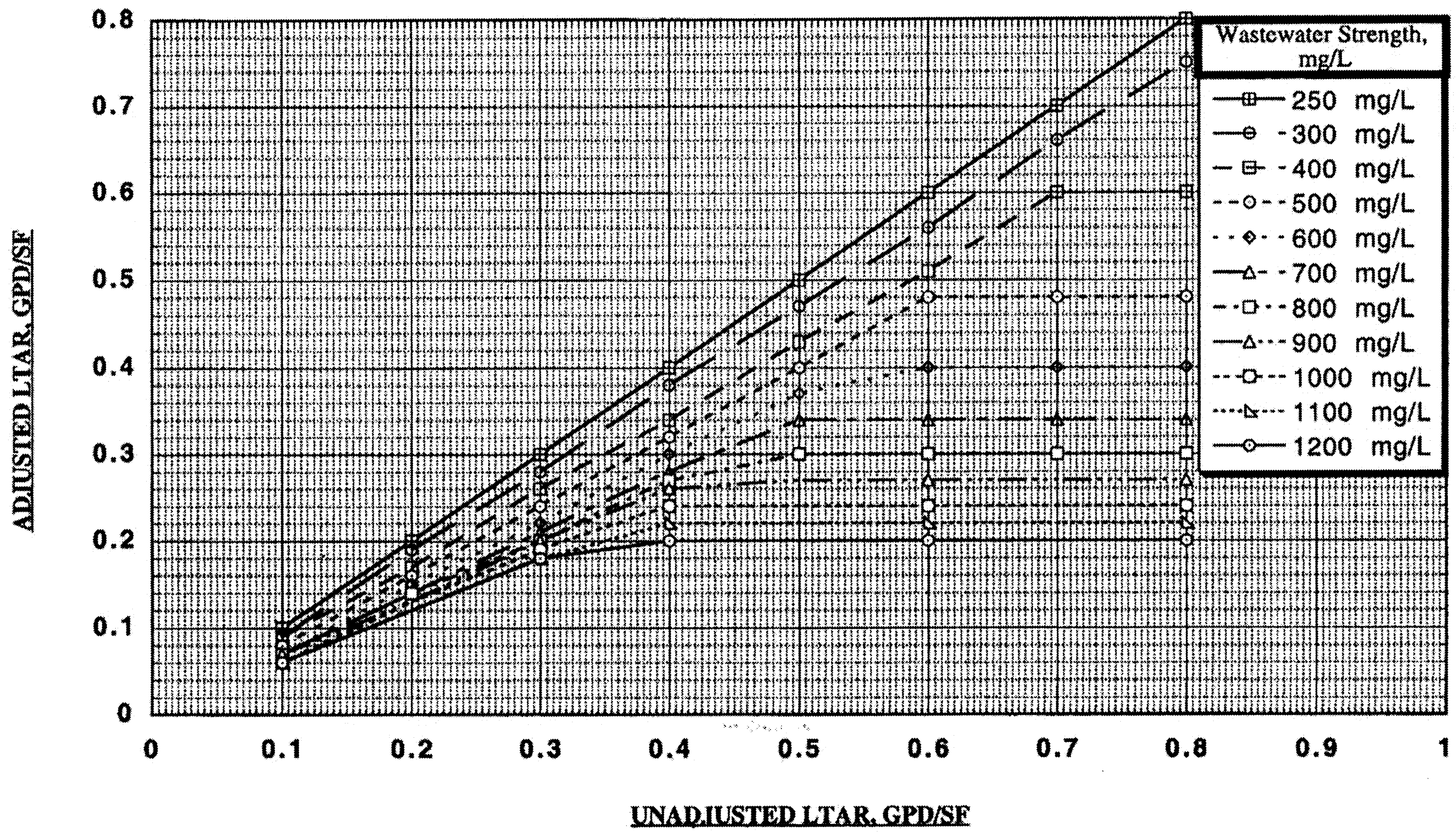

FIGURE LTAR-2

D. Effective Leaching Surface Area

1. General

The effective leaching (infiltrative) surface area (ELA) of a SWAS is the interface area between the soil and the facilities used for applying the pretreated wastewater to the soil. The wastewater application facilities, commonly referred to as leaching systems, may consist of:

1) flow distribution piping embedded in a coarse aggregate (commonly referred to as stone, broken stone or "gravel") filled trench,
2) a row, or rows, of precast concrete gallery units or plastic chamber units with open bottom and coarse aggregate placed along the sides of the units and flow distribution piping installed within the units,
3) flow distribution piping embedded in a coarse aggregate leaching bed, but only where enhanced pretreatment is provided, or
4) other wastewater leaching units that are approved by the Department.

As previously discussed under subsection C, the Healy and Laak expression for LTAR was based on a stone-filled trench ponded to a depth of one foot. Thus, the unit value (per linear ft. of trench) for ELA was the trench bottom contact area plus the sidewall contact area (one ft of height on each side of the trench).

Several investigators have determined that, where gallery or chamber units are installed without coarse aggregate placed between the units and the soil interface (so called "gravel-less leaching systems"), infiltration of the pretreated wastewater into the soil is considerably more efficient. They attribute this increased efficiency to the lack of the "masking (shadowing) effect" of the broken stone or natural gravel. The masking effect on the infiltrative surface area by stone or gravel has been discussed for many years (Bouma and Magdoff -1974; Siegrist - 1987; Tyler, Converse and Milter-1991, Siegrist and Van Cuyk. 2001.). Recent studies have indicated that gravel-less leaching systems can be loaded at rates equal to 1.7 to 2.0 times the loading rate of systems using gravel. (Hoxie and Frick-1984; Tyler, Converse and Milter, ibid; Siegrist and Van Cuyk, ibid).

On the other hand, while White and West (2003) agreed that gravel-less systems are more efficient in permitting the infiltration of wastewater through the biomat, they disagreed with the masking concept. The results of their studies indicated that it is the fines associated with the "gravel" aggregate that eventually slough off the aggregate and accumulate at the infiltrative surface that cause a reduction in leaching capacity. Their premise was later refuted by Siegrist, et al. (2004).

Amerson and others (1991) stated "the presence of fines is the predominant factor in infiltration rate reductions. One to four percent of gravel fines by weight resulted in a significant reduction in infiltration rates by 35 to 65 percent."

While most state regulatory agencies require that the "gravel" be washed prior to use, in practice washed gravel is not always used. Even after washing, gravel used in constructing a SWAS still contains a small amount of fines (typically 3 to 5 percent), ranging in size from 2 mm to less than 20 µm. Over a short period of time, the fines wash from the gravel and settle at the bottom of the trench. Fines are a significant problem as they significantly reduce flow rates (White and West-ibid.).

Regardless of whether it is the lack of fines, the absence of the "masking effect", or both, that results in the observed increase in infiltrative efficiency of gravel-less systems, the increase appears to have been validated by several detailed studies. Therefore, the Department has determined that "gravel-less" systems can be allowed a higher ELA than that allowed for a leaching system where gravel is used and has adopted a factor of 1.5 for computing the unit value for ELA for gravel-less leaching systems.

2. Calculation of Effective Leaching Area (ELA)

The following formula should be used to calculate the unit value for ELA/lf. The formula takes into account both masked and unmasked infiltrative surface areas, the hydraulic head on the infiltrative surfaces and an allowance for reserve storage area.

ELA/lf = [1.5 x inside clear (unmasked) bottom area of leaching unit + 1.0 x effective stone-masked bottom area] + [1.0 x effective height of stone-masked sidewall areas of leaching units*]

Where:

Leaching Unit = stone-filled trench, concrete gallery unit, plastic chamber unit, or other type of unit approved by the Department

Effective Sidewall Height = from Leaching Unit bottom to wastewater inlet invert, in ft, but not more than one foot (30 cm).

* For gallery and plastic chamber units, inclusion of sidewall height in calculating the ELA will only be permitted if the wastewater can flow into the sidewall areas through openings in the sidewalls that are less than one foot from the bottom of the unit.

Stone-masked Sidewall ELA, sf/lf = 2 x Effective Sidewall Height, in ft.

Stone-masked Bottom ELA, sf/lf = Bottom contact area of stone placed beneath or on sides of Leaching Unit (1 ft. maximum either side of Leaching Unit), in ft. (Maximum allowable width of Leaching Unit plus sidewall stone = 6 ft)

Where a stone-bottomed leaching bed is used in a Lateral Sand Filter, the entire bed bottom area should be considered stone masked.

Unmasked Bottom Area, sf/lf = average inside clear bottom area of Leaching Unit/lf.

[It is acknowledged that additional sidewall height will provide additional ELA when the depth of ponding above the bottom of a Leaching Unit exceeds one ft (30 cm); however this is considered to be a safety factor and is not used in computing the unit value for ELA.]