SOIL EVALUATION AND DESIGN SELECTION FOR LARGE OR CLUSTER WASTEWATER SOIL ABSORPTION SYSTEMS

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Presented at On-Site Sewage Treatment - The Fourth National Symposium on Individual and Small Community Sewage Systems. December, 1984. ASAE.

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Soil absorption wastewater disposal systems for flows greater than expected for a single family home are becoming more common as soil absorption is used for small communities, clusters of homes, and small businesses. Soil and site evaluation procedures must provide the information necessary to predict the operation of larger systems and therefore act as the basis for design selection, sizing recommendations, construction plans, maintenance schedules and monitoring schemes. Problems have been encountered using the soil and site evaluation procedures outlined for the single family home for larger wastewater soil absorption systems.

Physical and chemical processes affecting absorption and treatment of wastewaters are similar for all soils, wastewaters, and designs. The successful selection of a soil absorption wastewater disposal system design depends on knowing the soil and site conditions needed to evaluate each of the processes affecting system performance, identifying those that are controlling and limiting, and establishing the best design parameters. Because many of the processes influencing system performance of small absorption systems are camouflaged in rules for small systems, these processes have been forgotten until recently. Unfortunately, insufficient research and monitoring have been conducted concerning large soil absorption systems to establish sound site evaluation and design selection procedures.

This paper establishes the basis for procedures used for soil and site evaluation for wastewater soil absorption system design selection and defines large and small systems based on the operating processes and principles. It also provides terminology for the criteria established, and reports case studies demonstrating application of selected concepts.

SOIL ABSORPTION SYSTEM OPERATION

Treatment of wastewater nutrients and organisms by soil absorption has been studied. A major portion of the nitrogen is transported with the percolating waters, however, nitrogen losses may occur in the soil. Phosphorus will be retained in the soil and migrate very slowly (Sikora and Corey, 1975). Other chemical pollutants possible in household wastewater are only intermittently present and their fate in soil absorption wastewater disposal systems has been studied very little. The treatment of organisms in soil absorption systems is better as the depth of unsaturated flow increases (Cogger, 1984). After infiltrating into the soil and percolating through more than 60 cm of unsaturated soil, bacteria and viruses are greatly reduced (Tyler, et al. 1977). Suspended solids and degradable organics are also decomposed in soil . However, very rapid transport of the wastewater

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because of rapid soil permeability, high dispersion or saturated flow through soil result in lower levels of treatment (Bouma, 1979). To reach a predicted and known level of treatment as now defined requires that about a metre of permeable, unsaturated, aerobic soil with low flow dispersion be available below the system infiltrative surface. Soil and site evaluation procedures must provide information to predict these soil conditions.

Absorption of wastewater, often septic tank effluent, into the soil or a selected fill is from a volume of gravel supporting the distribution network. At the soil or mound fill infiltrative surface a black, slimy, organic clogging layer develops (fig. 1). The flux or flow rate of the wastewater infiltrating and passing through the clogging layer and soil is a function of the nature of both the clogging layer and the underlying soil. The flux has been defined (Bouma, 1975) and depends on the ponding height of wastewater in the trench, the conductivity and thickness of the clogging layer, and the soil moisture tension of the underlying unsaturated soil.

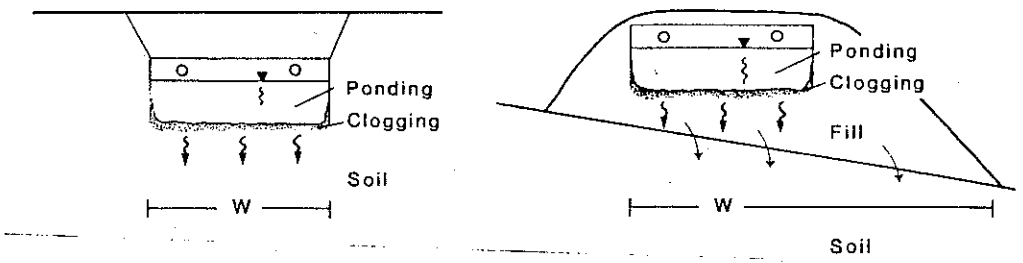

Fig. 1. Cross section of a subsurface (A) and mound (B) soil absorption system showing wastewater flow type and application width (w). Infiltration into the soil is through a clogging layer from a subsurface system and through the base of the mound.

Zones of soil saturation in close proximity to the infiltrative surface will affect the magnitude of the soil moisture tension, reduce the hydraulic gradient and flow through the clogging layer. The water may come from natural sources as groundwater or perched precipitation or as perched wastewater. The site evaluation must give information to estimate the natural moisture conditions and those expected after system operation has been initiated so the depth of unsaturated soil and the infiltration through the clogging layer can be predicted. With sufficient thickness of unsaturated soil, infiltration is independent of the groundwater.

Conditions affecting the conductivity or thickness of the crust will affect the absorption of the wastewater. Conductivity and thickness of a clogging layer or clogging layer formation is not well understood. This layer composed primarily of bacterial slimes, also may be partially due to entrapment of suspended solids and soil slaking. The intensity and thickness of clogging has been related to the wastewater quality and soil environmental conditions (Otis, 1984). Soil saturation close to the layer may intensify clogging development and may be related to the lack of aeration of the crust (Siegrist, et al. 1984.). Relating the formation and intensity of the clogging layer to soil conditions is difficult. However, knowing soil physical characteristics and proximity of the zone of soil saturation for the operating system may be helpful to predict its influence.

Wastewater from the subsurface system or from the base of the mound is conducted through the unsaturated soil zone (fig. 1) primarily downward until it reaches a flow restricting boundary or the capillary fringe of a saturated zone. The unsaturated flow lines in fig 1 correspond to those depicted in figs. 2 and 3 and any combination of application type from fig. 1 in conjunction with saturated flow path from figures 2 and 3 are possible and con-

stitute a system. The application width (w) of the wastewater is the width of the subsurface system or the base of the mound (fig. 1). Since all wastewater applied must leave the system, the flow rate or flux is the same as wastewater flow in the unsaturated zone and the recharge to the groundwater. Water in the saturated zone must continue to move away from the system until it is dispersed into the environment or the soil will become saturated back to the point of application and ultimately result in system failure. Saturated flow horizontally down a slope or through a groundwater mound is important.

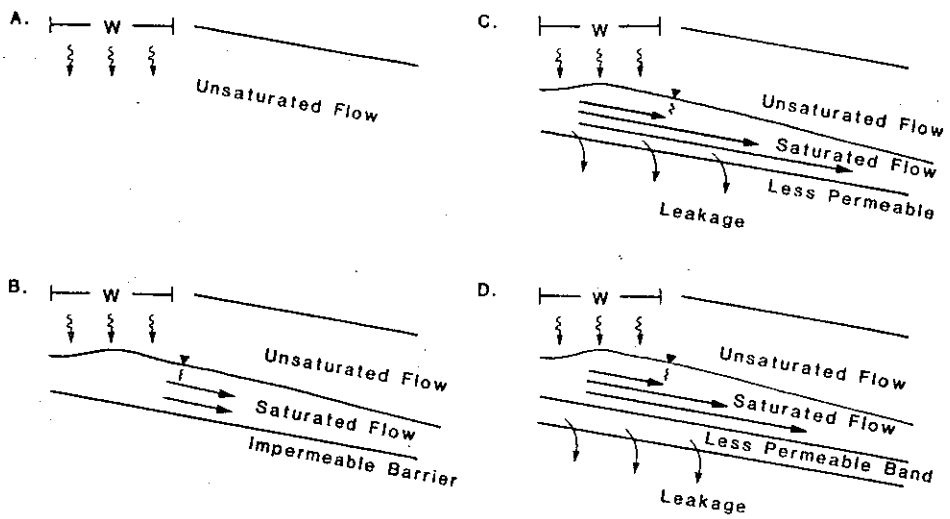

Fig. 2. Horizontal flow through the soil from an application of wastewater.

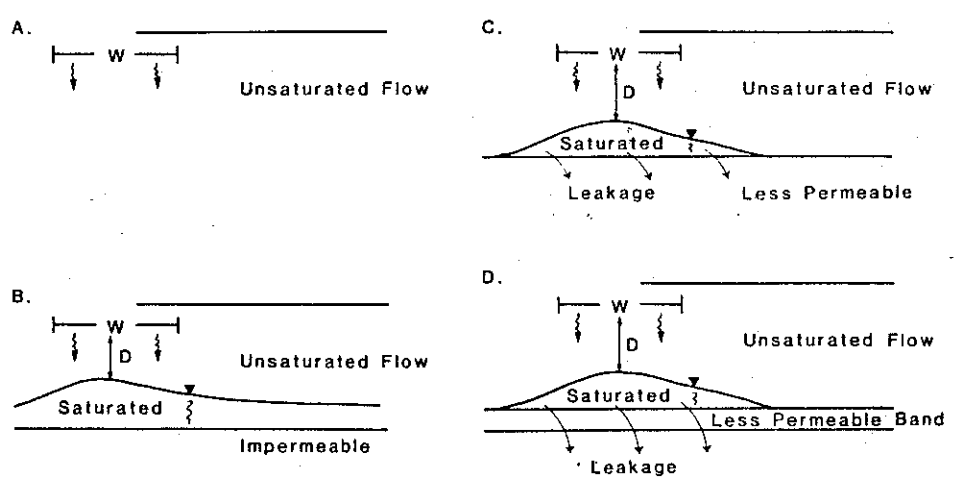

Fig. 3. Groundwater mounding from an application of wastewater.

Figure 2 illustrates horizontal flow conditions expected through the soil. In the absence of a restricting horizon within a determinable depth of the

point of infiltration, horizontal flow will not occur. The horizontal movement of the wastewater in the presence of a restriction can be estimated using the horizontal saturated hydraulic conductivity for the soil horizon, slope of the horizon surface for the gradient and the allowable depth of saturated flow to determine the cross sectional area (Bouwer, 1977). The simplest case (fig. 1b) assumes all water must move horizontally. However, for most site conditions it may be more realistic to account for leakage into the lower horizon of slower permeability (fig 2c) or for leakage through a band of less permeable soil (fig. 2d). These bands may be as thin as a millimetre. Leakage into a horizon may be estimated from the flow rate through that horizon in a similar fashion as that of the basal area for the mound design (Converse, 1978). For the band, the equation for the flow through a clogging zone will apply or the leakage factor of Brock (1976) can be used. If the application rate is lower than leakage, no zone of horizontal flow will be present. Design to keep loading rates lower than leakage rates may result in very large systems.

Figure 3 illustrates the development of groundwater mounds due to the recharge from a soil absorption system. Lacking a flow restricting horizon or groundwater, no mound can form (fig. 3a). In the presence of flow restrictions or groundwater, the height of the mound will be greater the higher the recharge from the system, the wider the application (w) and the slower the horizontal saturated hydraulic conductivity. Mounding over a zone of soil saturation (fig 3b) has been described using models (EPA, 1981). Models have also been used to estimate the height of the groundwater mound with leakage into a slowly permeable horizon (Khan et al. 1976) and with leakage through a band (Brock, 1976). Should the groundwater mound approach the infiltration plane at the base of the system, wastewater flow and treatment will be reduced and more intensive clogging mats formed.

DESIGN PARAMETERS BASED ON SOIL ABSORPTION SYSTEM OPERATION

Infiltration rates are based on soil horizon characteristics and the expected clogging (fig. 1) assuming that the unsaturated soil beneath the infiltrative surface has a unit hydraulic gradient. Because of the unsaturated soil, the infiltration rate is independent of the saturated zone and is determined separately from other design parameters.

At some place away from the system it is assumed all wastewater is assimilated into the environment such that it is not detectable or will not influence the system operation. This is called the system boundary. System boundaries are both horizontally and vertically away from the infiltration zone. The boundary surface could be a surface water discharge point, change in slope, area of convergent flow in the landscape, or the groundwater surface. In some cases it may be close to the point of infiltration while in others far away. The site investigator must determine the location of the boundary during the site evaluation and collect information on the vertical and horizontal area between the infiltration zone and the system boundary.

The boundary acceptance rate is the total volume of wastewater the landscape can accept from the system. It is equal to the sum of all of the wastewater acceptance rates for each portion of the landscape. Assuming a lake is at the right side of the diagram in fig 2c, then the boundary of this system could be the less permeable band and the lake. The boundary acceptance rate would be the amount of wastewater moving horizontally downslope to the lake and leakage through the less permeable band.

Several types of flow zones may be found between the boundary and zone of infiltration. For each flow zone a model or experience is used to predict the flow rate. The zone or zones of the lowest transmission will be the design limiting value.

Assume a depression in the landscape in fig 2c between the application zone and the lake assumed before. The soil beneath the depression cannot handle the same amount of wastewater as the soil up or down slope of the depression. The amount of transmission in this zone will be the horizontal flow acceptance rate for the system. The source of horizontal flow is the toe loading or wastewater passing downslope beneath the edge of the application width (fig. 2). Toe loading is calculated using the horizontal saturated flow equations such as presented by Bouwer (1977).

The minimum horizontal flow calculated plus the leakage from the toe to the point under the depression or the horizontal flow under the toe, whichever is the least, is the maximum toe loading rate. The maximum toe loading rate plus the vertical acceptance rate beneath the application width is the linear acceptance rate for the system or the maximum linear loading rate.

However, with the application of wastewater the location of the zone of saturation rises toward the application site. Groundwater mounding may occur over a flow restricting horizon or groundwater. The flow rate and application width at which the highest level of acceptable saturation is reached may also identify linear loading rate.

Once the linear loading rate has been calculated, the width of the absorption area can be determined using the infiltration rate or loading rate of the soil. Based on system width and the expected total wastewater volume, the length of the system is calculated. From this analysis it follows that the important dimension of a soil absorption system is the width. If the width has been estimated, the length of the system can always be calculated.

Figure 4 illustrates the flow across the system boundary as leakage into a lower horizon. The leakage for both flow restricting horizons depicted is

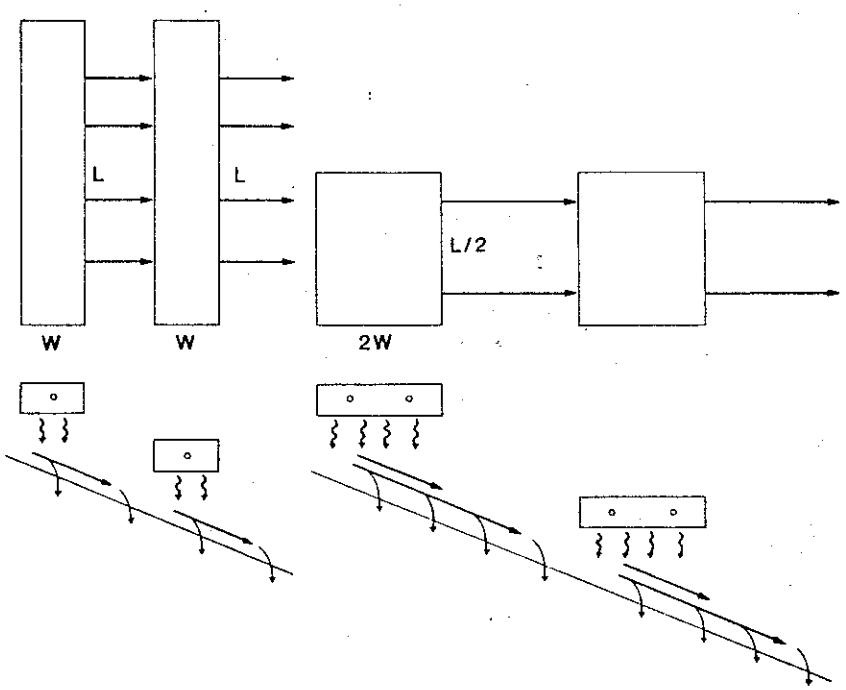

Fig. 4. Relationship of wastewater movement from equal absorption areas of with W and 2W in a landscape with horizontal flow over a leaky subsurface horizon.

the same. A design of width W results in a horizontal flow of half that of a design with a width of 2W. If the soil downslope is shallow, narrow application widths improve the chance of success.

If system length is longer than the landscape, then multiple absorption areas may be needed. Each segment of the multiple system should be placed outside the boundary of other segments. For example, in figure 4 the leakage for the upslope system removes the wastewater before reaching the segment downslope. The wider the systems, the greater the separation distances.

Narrow systems are often very long. Since the application zone must be at the same elevation, system placement is on the contour. Wastewater from systems on complex slopes and with dominant horizontal flow will converge or diverge depending on whether they are in concave or convex landscape positions. The system boundary in concave landscapes is the point of convergence (fig. 5). Wastewater flow through points of convergence may be limiting to system flow. For divergent flow wastewater dispersion into the landscape will be rapid.

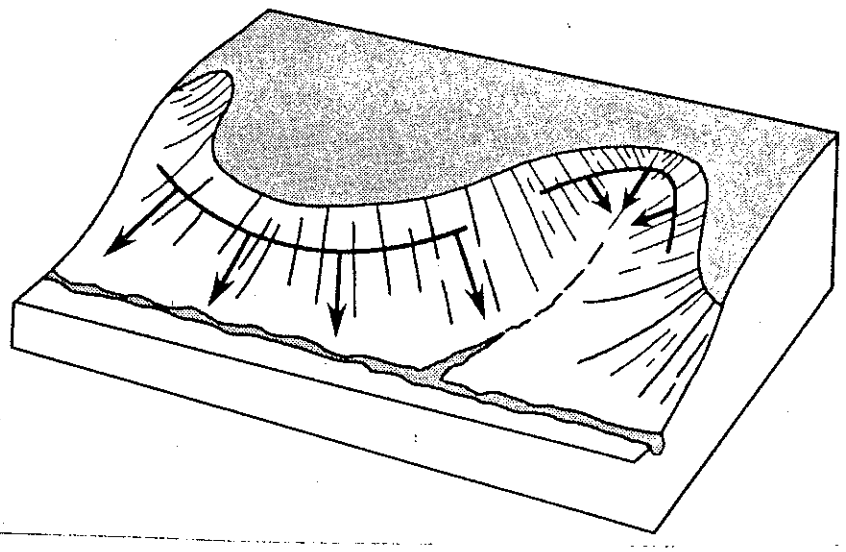

Figure 5. Block diagram of divergent and convergent from wastewater applications in convex and concave landscape positions.

THE SMALL AND LARGE SYSTEM

The small soil absorption system is one that serves the single family home. These systems usually include a soil absorption area less than 200 m^2. Site criteria for small systems have been based primarily on experience with confirmation by recent research. Though not directly considered, the depths to limiting soil conditions include tolerance for groundwater mounding and horizontal flow that would be expected for a system only a few metres wide. In some cases, as for the Wisconsin mound system, the width of the trench was based on soil conditions, loading rates, and groundwater mounding models (Converse, 1978; Bouma, et al. 1975). However, significant mounding is not likely under the typical individual system (Finnermore and Hantzche, 1983).

Assume a soil absorption system was to be used at a site with 2 m of permeable soil over a less permeable horizon as shown in fig. 3c. The base of the absorption area is to be installed at a depth of 0.6 m and the separation between the base of the area and any zone of soil saturation is to be 1 m. Therefore, saturation could be at 0.4 m above the restricting horizon. The soil infiltration rate or loading rate is 1 cm/d and the same as

the unsaturated hydraulic conductivity, or recharge rate. Using a model of Khan et al. (1976) and a horizontal hydraulic conductivity for the top horizon of 100 cm/d and a vertical hydraulic conductivity for the less permeable horizon 0.5 cm/d. an 8 m wide trench application will result in a 0.4 m groundwater mound. For this soil a system wider than 8 m would not meet small system goals. Assuming 1,800 L of wastewater, the length of the 8 m wide system would be 22 m. A square system for this soil and the same volume of wastewater would be 13 m on a side and therefore have a groundwater mound higher than 0.4 m. The zone of saturation would be within 1 m of the infiltration zone.

A system that can meet the goals of wastewater disposal and use the current soil and site criteria for small systems may be considered small. Since the infiltration width defines the operation, then any wastewater volume may be applied to the soil as long as the system is narrow. System design for large wastewater flows limited in width to that of the individual home system could be used with current soil and site criteria. Using this logic a system would never get the name large, however the systems could be very long.

A system that cannot meet the goals of wastewater disposal using current soil and site limits and design criteria is defined as large. The application width and linear loading rates are greater than the acceptance rate of the landscape. Assuming the most difficult site conditions acceptable for small systems and modelling for larger and larger wastewater flows, the flow rate at which hydraulic or treatment failure would occur defines the lower limit of a large system. Using this method, systems on the most severe sites for large homes would be considered large. Classifying systems as large based only on the total wastewater volume does not recognize that the most limiting condition for the large system is soil absorption.

COLLECTING SOIL AND SITE INFORMATION

Small system design selection is based on identification of specified landscape limits believed to insure successful operation of all possible designs. Large system design selection is based on defining the maximum acceptance of the landscape and designing within those limits. Procedures for collecting soil and site information to be used as a basis for the design selection of the large system is the same as for the small system. However, the extent and detail needed for an adequate large system site evaluation will probably be much greater than for small systems and more information about the saturated zone is necessary. As outlined (EPA, 1980), the process should include the client contact, reveiw of resource information, field testing, and organization of the data. The evaluation should provide all information needed to define all processes of system operation leading to the design parameters.

The boundary of the system must be established early in the site evaluation process therefore defining the extent of the site evaluation. For example, if a clay horizon more than three metres thick was found underlying three metres of suitable soil, the boundary plane could be considered the surface of the clay layer with the assumption that the leakage rate is zero and wastewater is dispersed horizontally. Continued investigation, except to confirm the presence of the clay layer, below three metres would not provide additional information. On the other hand evaluations of large volumes of soil may be necessary on some sites particularly in areas of permeable soil and rapidly moving groundwaters. Establishing standard testing depths and horizontal distances for large system evaluation, as is usually done for small systems, may lead to inadequate evaluations in some cases and excessive work in others.

Landscape conditions including vegetation, surface waters, slopes and landforms are described. Direct observation of soil horizons should give color, texture, structure, special features and other data including the presence of salts and the clay mineral family (SCS, 1981). Boundaries between horizons need definition. Changing textures, even from one sand to another, may be important to the flow of the wastewater. As shown earlier, bands, even very thin discontinuous ones, can create perched mounded groundwater. Bands can be identified as separate horizons or within larger horizons. Direction of flow and hydraulic gradients of groundwaters should be determined using wells to define the piezometric surface when appropriate. The type, depth and aerial extent of bedrock must be mapped.

The site information collected using these procedures should be adequate to establish surface water conditions, infiltration rate, vertical and horizontal saturated hydraulic conductivity, unsaturated hydraulic conductivity for the clogging layer expected, zones of permanent and perched water tables and the groundwater conditions for each of the soil horizons present. The data can then be used to conceptually or mathematically model the wastewater flows.

The statistical confidence limits on estimated or measured soil hydraulic characteristics are often broad and the lower confidence limits should be used in the models. For example, the confidence limits for the hydraulic conductivity of C horizons for some Wisconsin soils is two orders of magnitude (Jaynes and Tyler, 1984). The lower limit of this range should be used for modelling and design. To determine valid hydraulic characteristics from data based on field measurements, as many as 100 determinations may be needed (EPA, 1977). Conservative estimates based on interpretation of soil morphology may provide adequate values to be used in establishing the design parameters from the site information.

A table showing soil conditions and the estimated infiltration rates and conductivities for each horizon identified is helpful when applying the site information to the selection of design parameters. A map indicating the location of all of the soil conditions surface slopes and slopes of subsurface horizons should be prepared. Also, the groundwater conditions and piezometric surface should be on the map. Based on the information the design parameters can be determined as outlined in previous sections.

Collecting soil and site information and making wise estimates of the values needed to predict design parameters is a difficult task and requires creative, trained, and experienced people. Since matching the conditions of the natural environment with the engineered system is the most critical task for selection of wastewater soil absorption systems every effort should be made to have a quality evaluation.

CASE STUDIES

Large soil absorption systems designed and constructed according to guidelines and rules for small systems are known to have failed. Few large wastewater soil absorption systems constructed using concepts outlined here have been monitored to provide data to verify design concepts. Some recent monitoring has been done (Anderson et al., 1983; Chan and Sykes, 1984, Siegrist et al., 1983). The objective of this study was to conceptually design and then construct and monitor large wastewater soil absorption systems to provide data to test current concepts.

Materials and Methods

Research sites meeting large system definition were identified in cooperation with the Bureau of Plumbing, Department of Industry, Labor and Human Relations, State of Wisconsin; County zoning staff; and private businesses.

Each site was visited to establish site boundaries and set site evaluation criteria. Detailed soil evaluation was completed by a Certified Soil Tester (CST) as designated by the State of Wisconsin.

Design concepts based on predicted landscape, horizontal, toe, and vertical acceptance rates, infiltration rates and groundwater mounding were evaluated from the site information. Detailed designs were prepared by consultants using the loading estimates.

System loading, performance, and groundwater elevations are being monitored. Installations are recent and system performance data is not available to be used as a basis for the evaluation of the soil and site conditions. Therefore, only the conceptual processes used during the site evaluation are presented.

Results

Site one is approximately four hectares of land with a 10% simple slope. Vegetation was alfalfa and grass hay with spots of poor alfalfa corresponding to observed springs. Springs surfaced in several locations across the site during wet portions of the year in about the locations indicated on the soil map. The soil is the Manawa sandy loam--a fine, mixed, mesic Aquollic Hapludalf. Soils have silty clay loam surface and silty clay subsurface textures. Structures are medium and strong subangular blocky throughout the horizon. Mottles are found just below the A horizon at most locations. Gravelly lense locations corresponded to the locations of the springs.

The soil is very limited for wastewater absorption. It is similar in hydraulic conductivity but shallower to groundwater than neighboring soils used for mounds (Converse and Tyler, 1984). If the groundwater could be lowered with an interceptor drain, a narrow mound system could be designed. A water diversion ditch and interceptor drain were installed, eliminating the springs and lowering the soil saturation to 0.5 to 1.5 m below ground surface during the wettest portion of the year.

Based on experience with systems on similar soil and site conditions and conceptual models, estimates of boundary, toe, and vertical acceptance rates, and groundwater mounding were made and a linear loading rate established. This process is extremely difficult because the site is not uniform, the soils are not homogeneous and isotropic, and the values for the models are variable. Only reasonable estimates could be made of the design parameters. It is believed that the mound will be used close to the design limits and therefore provide data for site evaluation testing.

The mound constructed has a linear loading rate of 170 L/m/d or slightly larger than normally used for an individual residence. The basal acceptance rate was estimated below 1 cm/d with the actual design basal loading rate of 0.84 cm/d and therefore an application width (fig. 1) of just over 20 m. Since 20,000 L of wastewater per day was estimated, the basal area length was about 120 m. Bed loading is 5 cm/d and therefore to accommodate the 171 L/m/d the bed width is 3.2 m wide. A mound of this length was constructed along one contour downslope of an interceptor drain.

Site two is a wooded area of about three hectares. The landscape is a slightly convergent headslope with slopes of 6-8%. The soil is mapped as the Rockton silt loam--a fine-loamy, mixed, mesic Typic Argiudoll. The Rockton soil is a loamy soil underlain by dolomitic bedrock at 50 to 100 cm below the ground surface. The soil as described at the site is generally a well structured silt loam, over a clay loam and loam subsurface. Soil mottles were noted at some locations below 60 cm, and bedrock depths are greater than one metre in most of the area.

The linear loading rate was determined in a similar fashion to that of site 1 and estimated at 230 L/m/d. The basal acceptance rate was estimated at 2 cm/d and therefore the width of applicaiton is 11.5 m. The estimated wastewater volume was 61,650 L/d and therefore the total length of the system is 268 m. This is much longer than any contour on the site and the mound was divided so that it could be placed in parallel strips along the slope. Since the vertical leakage into the bedrock below the mound should minimize the toe loading, the downslope separation distance between mounds is not great (fig. 6).

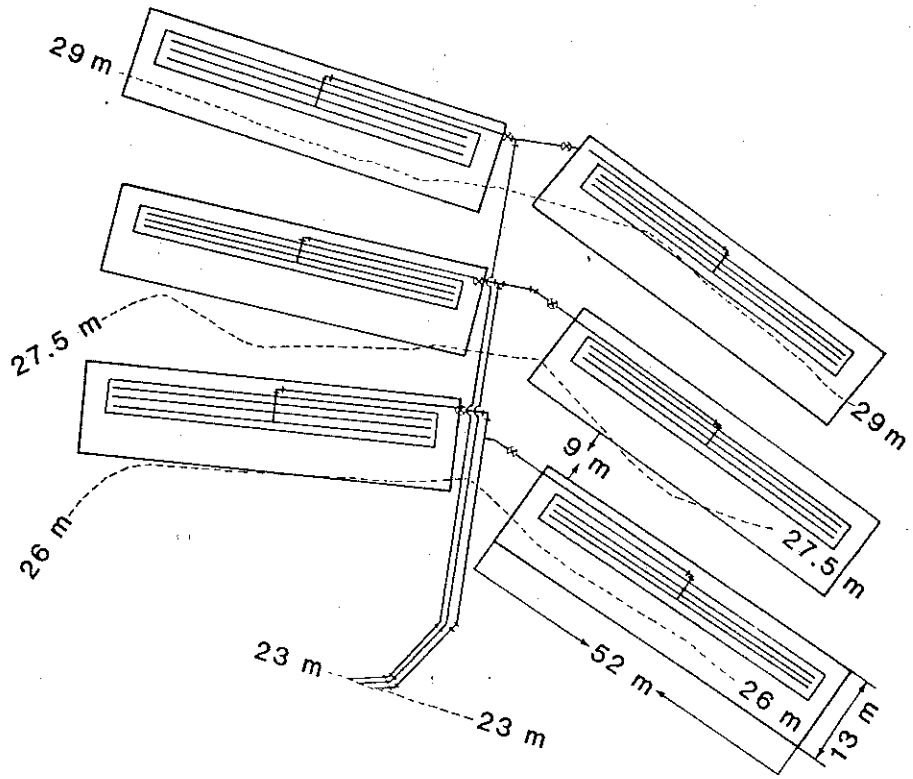

Fig. 6. Separated mounds of a large system.

The case studies demonstrate that site evaluation data is critical to the estimation of wastewater soil absorption sytem design parameters but it is recognized that it is extremely difficult to apply specific models to the systems being designed. More field information about the operation of large soil absorption systems is needed. However, using the best estimates and design concepts should provide for successful soil absorption of wastewaters.

SUMMARY AND CONCLUSIONS

Large wastewater soil absorption system design selection is based on defining the maximum acceptance of the landscape and landscape segments and designing within those limits. Small system design selection is based on identification of specified landscape limits believed to insure successful operation of all possible designs. A large system is one that will fail using the site evaluation and design selection guidelines for a small system. Systems serving big homes may be large; however, small system concepts may apply to large wastewater flows if system widths are narrow.

Procedures for collecting soil and site information to be used as a basis for the design selection of the large system are the same as for the small system. However, the extent and detail needed for an adquate large system site evaluation will probably be much greater than for small systems and more information about the saturated zone is necessary. Collection of the information inside the system boundaries, needed to estimate infiltration, saturated vertical and horizontal hydraulic conductivities, and zones of soil saturation must be based on a knowledge of soil absorption system operation and soil science.

Applying the soil evaluation information to the concepts of the operation of the systems will offer more reliable system designs than using the guidelines for small systems. Expecting low tolerance of calculated design values based on site evaluation information is unrealistic for most sites. In some cases design based on the concepts with limits set by experience may be adequate. Personnel doing site evaluation for large system design selection must understand the principles and processes for successful soil absorption of wastewaters.

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