SSWMP PUBLICATION #10.7

INNOVATIVE ON-SITE SOIL DISPOSAL AND TREATMENT SYSTEMS FOR SEPTIC TANK EFFLUENT[1/]

J. Bouma[2/]

1. Introduction

The conventional soil absorption system for on-site disposal of septic tank effluent has worked very well for many years in many different soils (10, 16). Successful functioning can only be achieved if the soil surrounding the absorption bed or trench absorbs the amount of effluent produced and purifies it adequately by processes of filtration, absorption and oxidation that occur as effluent moves through the soil pores. Current health codes assume that a certain minimum volume of soil should be available for percolation to achieve adequate purification. An arbitrary 3 ft of unsaturated, sufficiently permeable, soil is required to be present between the bottom of any seepage system and the bedrock or groundwater level (21, 25). Soil permeability is expressed as the percolation rate in min/inch and measured values should be faster than 60 min/inch. Establishment of these limits did not result from a thorough analysis of physical, chemical and biological processes associated with absorption and purification of septic tank effluent in different soils. Rather, these largely empirically derived classifications represent a reaction to an observed need, in which context they are quite valuable. More specific data are becoming available now regarding processes of on-site liquid waste disposal, showing not only that different soils have different potentials in terms of initial suitability but particularly that construction and management techniques are essential in obtaining satisfactory systems in any soil, whether it is being considered currently as a "problem" soil or not. An independant approach to the development of soil-systems that provide satisfactory on-site disposal and treatment of domestic liquid waste has to consider the following aspects: (i) Definition of the desired degree of purification; (ii) Determination of the full range of hydraulic conditions that can occur in the soil both naturally and induced by man; (iii) Selection of hydraulic conditions most appropriate to achieve the defined purification within a limited volume of soil; and (iv) Design of field systems, incorporating construction and management techniques, which will allow achievement of aspect (iii). This paper will more specifically discuss these points in the following sections summarizing research results of the Small Scale Waste Management Project to date.

2. Criteria for on-site disposal and treatment

2.1. Purification

Septic tank effluent presents a direct health hazard when introduced into domestic wells or following surfacing due to inadequate soil infiltration. In the latter case the BOD and the nutrients could also contribute to undesirable eutrofication of surface waters. Removal of pathogenic organisms and excess nutrients in the soil is therefore required and two aspects have to be considered: (i) the level to which removal has to occur, and (ii) the volume of soil and its boundaries, required to achieve removal.

1/ Contribution from the Small Scale Waste Management Project, Univ. of Wis. funded by the EPA (Grant No. R802874-01-0) and the State of Wisconsin.

2/ Associate Professor of Soil Science, Dept. of Soil Sci., College of Agr. and Life Sci., Univ. of Wis. and Wis. Geol. and Nat. Hist. Surv., Univ. Ext.

The latter is important because any judgement as to whether or not a soil disposal system works adequately in terms of purification has to be based on analyses made in a defined volume of soil. The level of required purification varies for different components. Occurrence of pathogenic bacteria is generally indicated by determining concentrations of fecal indicators (3, 13). However, some of these may occur naturally in the soil (13) and levels to which reduction should take place depend on the use that will be made of the reclaimed effluent. Partial body contact with the liquid, for example, allows higher contents of fecal indicators than use for drinking water (1). Use of reclaimed water for human consumption requires nitrate contents below 10 mg/l (ppm) expressed as NO_3-N (45 ppm NO_3). Generally, pathogenic bacteria and viruses should be completely removed within a specified soil volume and the BOD, suspended solids and N and P concentrations should be lowered to concentrations that would allow human consumption and addition to surface waters without creating adverse affects.

Column experiments and field monitoring data have shown that only three feet (90 cm) of soil *can* be very effective to remove fecal indicators and pathogenic viruses (14, 18). Flow through the soil at unsaturated conditions is preferable, but relatively low flow rates near saturation can be also effective in relatively slowly permeable silt loams and clays, but only, of course, if hydraulic gradients allow adequate movement to occur.

2.2. Hydraulic conditions

The percolation test is inadequate for describing the capacity of a soil to absorb and conduct liquid in quantitative terms (2, 3). Introduction of better defined hydraulic conductivity (K) values should not be restricted to saturated soil (15) but include consideration of unsaturated soil as well. Modern physical tests and monitoring techniques are available now that can be used *in situ* to obtain hydraulic conductivity and moisture retention data for unsaturated soil (7), which, in turn, can be used in flow models to predict hydraulic conditions in any soil material not only as a function of natural conditions but also, more importantly, as a function of system management (3, 4). In addition, natural hydraulic conditions during the year can be monitored *in situ* around seepage systems with tensiometry (3). Such tests are highly preferable to relatively short-term measurements on soil cores because they show the accumulated effects of many years of operation. Representative K-curves as determined in four important soil types are shown in Fig. 1. Preliminary data derived from a widespread application of the crust test to soils in Wisconsin show that hydraulic conductivity characteristics of many soils can, at least tentatively, be classified into these four broad groups as conductivity types. This is important because tests are technically complicated and time consuming and application at any new disposal site would be too costly. The relatively low variability within each of the observed groups (which is due to the relatively low variability of hydraulic conductivities of unsaturated soil of a given texture), can probably be associated with certain types of soils (soil series) as distinguished in the national soil mapping program of the Soil Conservation Service. Further development of this procedure is expected to be quite useful to reduce the necessity of extensive on-site tests.

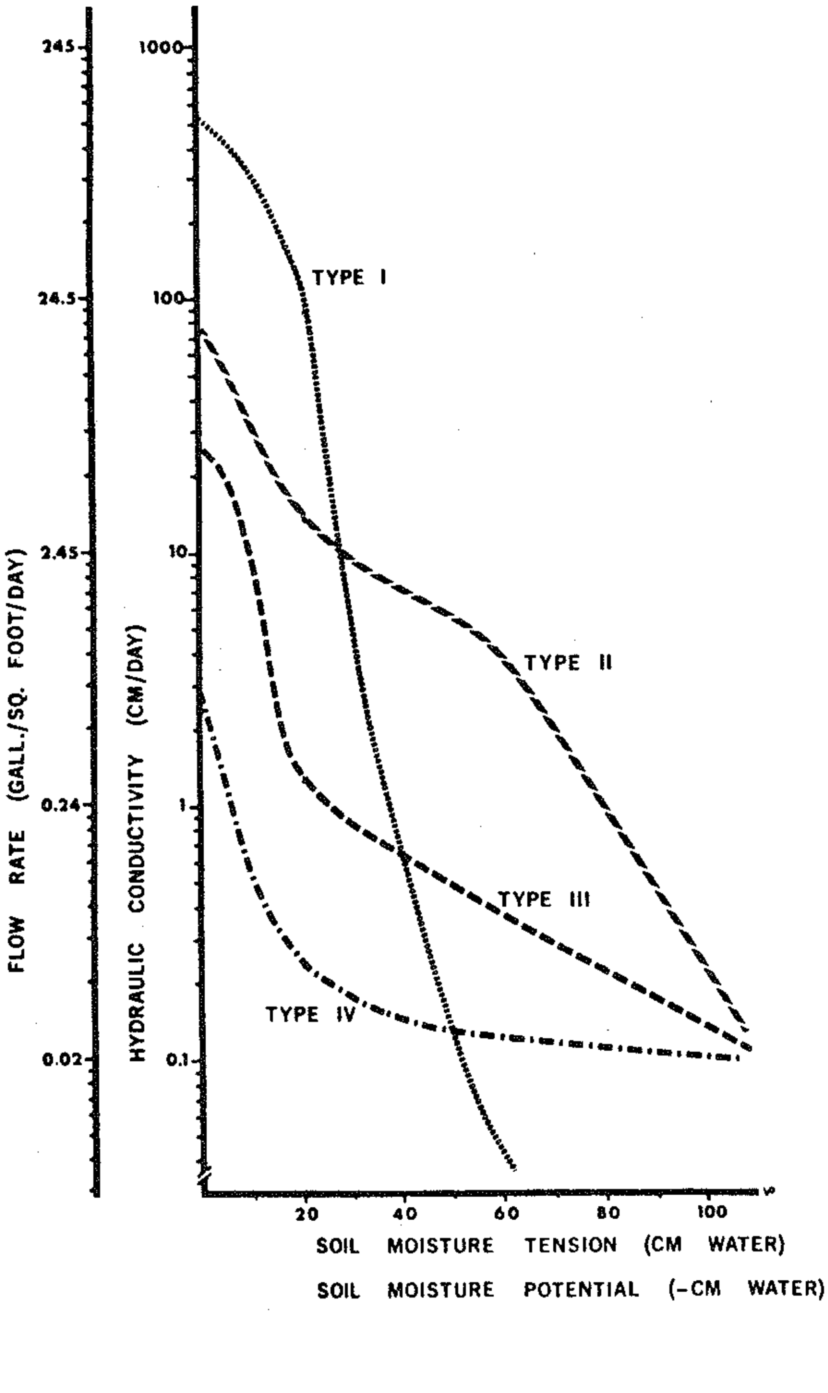

Fig. 1. Hydraulic conductivity (K) curves for four major types of soil (see text).

2.3. Optimum hydraulic conditions

The widely used term "soil permeability" is generally associated with saturated soil in which liquid moves relatively fast through larger pores if the hydraulic gradient is sufficiently large. Slower movement through finer pores, as occurs during unsaturated flow, is more favorable for achieving filtration and absorption (3, 4). Moreover, unsaturated soil contains air in the larger pores which may induce oxidative processes. However, hydraulic conductivities decrease strongly as soils become unsaturated (see Fig. 1) and very low flow rates may result at still relatively high moisture potentials (low moisture tensions). For example, the hydraulic conductivity (which is equal to the flow rate at a hydraulic gradient of 1 cm/cm) at a moisture potential of -20 cm (tension of 20 cm) was approximately 80 cm/day for the C horizon (Type 1, Fig. 1) of a Plainfield loamy sand (at saturation: 500 cm/day) and 2 mm/day for the B2 horizon (Type 4, Fig. 1) of a Hibbing clay (at saturation; 3 cm/day). The lower the flow rate, the larger the required seepage area at any given loading rate. For example, at a flow rate of 1 cm/day (0.24 gals/sq ft/day) an area of 1200 sq ft is needed to dispose of 300 gals of effluent. Optimum hydraulic conditions have therefore to be defined for each soil material, balancing the need for low flow rates (purification) on the one hand and higher flow rates (small seepage area) on the other. Desirable unsaturated flow in soils surrounding seepage beds can occur due to two mechanisms (3, 9): (i) Formation of barriers to flow at the surface of infiltration. The effect of barriers is to reduce the infiltration rate into the soil, as a function not only of the hydraulic resistance of the barrier itself but also of the capillary properties of the underlying soil which are expressed by the K-curve (7, 9) as follows:

$$q = K_{s(M)} = \frac{M + Z_b + H_o}{R_b}$$

where q = infiltration rate which is equal to K of subsoil at matric potential of -M cm (to be read from K curve: $K_{s(M)}$ at a hydraulic gradient in the subsoil of 1 cm/cm); M = matric potential in soil below barrier; Z_b = thickness barrier; H_o = hydraulic head on top of barrier and R_b = barrier resistance (= Z_b/K_b where K_b = hydraulic conductivity of barrier). Common barriers are clogged layers formed by accumulation of suspended solids and associated bacterial growth or compacted and smeared layers formed during constructing beds in clayey, wet soils (9, 19); (ii) application of effluent to the soil at a rate which is lower than the saturated hydraulic conductivity (7). These aspects will be further discussed in the following section where innovative systems for different soils groups will be presented.

3. Design of field systems

Four types of soil with deep groundwater tables and two types with groundwater closer to the soil surface will be discussed. Reference will be made to more specific publications.

3.1. Permeable soil over bedrock within 5 ft below the soil surface

A distinction has to be made between creviced, permeable, bedrock such as many limestones and compact, impermeable, bedrock such as granite. Occurrence of the latter type usually results in perched water tables and these conditions will be discussed in Section 3.5.

Shallow permeable soils over creviced bedrock provide inadequate purification. A mound system, in which a soil covered seepage bed is built on top of two feet of sandfill deposited on the original soil surface, has been proposed as an alternative (5). Effluent is intermittently applied to the bed several times a day through an innovative pressure distribution system (11) which ensures equal distribution over the entire seepage area thus avoiding local overloading and associated poor purification (3). Column studies have indicated that two feet of sandfill and one foot of natural topsoil can remove pathogenic bacteria and viruses (14, 18). Nitrogen, however, is oxidized to nitrates which move freely into the water table. Phosphorous is retained initially, but may reach the ground water later when the limited absorption complex of fill and topsoil is saturated. The ground water in these systems forms thus a part of the disposal system because of its diluting action. This is not attractive because flow patterns may be unpredictable and high nitrate contents, particularly in shallow wells, may present health hazards (23, 24). In addition, excess nutrients may accellerate eutrophication of lakes and streams and restrictions on the number of systems to be allowed in a river basin or watershed may be necessary (24). Experiments are in progress now to improve nitrogen and phosphorous removal (20).

3.2. Conductivity-Type I (sands)

These soils, with percolation rates generally faster than 10 min/inch, are considered to be suitable for effluent disposal (21, 25) but nitrogen and phosphorous purification problems may occur as discussed in 3.1 (23, 24). *In situ* monitoring of subsurface seepage systems has indicated the occurrence of ponding of effluent due to clogging of the infiltrative bottom and sidewall surfaces. However, clogging did not stop infiltration, but reduced flow rates to approximately 5 cm/day (2"/day) corresponding with subcrust moisture potentials of around -25 cm (3, 23). Clogged layers in the bottom of beds and trenches had an average R_b of 6.2 days and those on sidewalls of 13 days. Matric potentials in surrounding soil in wet periods can become inadequate under Wisconsin conditions to allow lateral movement through the sidewall (9) and sizing of beds or trenches in sands should therefore preferably be based on bottom area only using a representative flow rate of 5 cm/day (1.2 gals/sq ft/day). Hydraulic heads (H_o) should preferably not exceed 30 cm. Removal of fecal indicators occurred within 4" below the infiltrating surface in clogged sand systems (3) and clogging in sands can therefore be considered to be valuable. Failures of seepage systems in sands, observed as surface seepage of effluent, are generally due to inadequate system size.

3.3. Conductivity-Type II (sandy loams, loamy sands, loams)

These soils, considered suitable in current classifications, have generally percolation rates between 10-30 min/inch. The degree of aggregation is weak and pores between sand grains are finer than in the sand (3). The structural stability is usually relatively low due to a rather low clay content, and larger pores, such as root and worm channels collapse more quickly than the ones formed in more clayey soils. Clogging of seepage systems in these soils is a major problem (9). *In situ* measurements around different seepage trenches of ages of 2, 5 and 5 years, respectively, in sandy loam glacial tills indicated occurrence of clogging, inducing soil moisture tensions of 66, 80 and 120 cm respectively, corresponding with infiltration rates of 2 cm/day (0.8") 5 mm/day (1/5") and 0.3 mm/day (0.01"). Hydraulic heads (H_o values) were 1 cm, 30 cm and 120 cm, respectively. Corresponding R_b values of 34, 270 and 9000 days demonstrate a much wider variation than in clogged sands. Research is in progress to more specifically define the causes for this variation, considering also research results obtained elsewhere (17). In any case, infiltration rates apparently can become too low to allow for adequate infiltration and alternative ways have to be defined to more efficiently utilize the potential of these soils (many of which have K_{sat} values of up to 80 cm/day) to accept effluent. Application of dosing and equal distribution by using innovative liquid distribution systems (11) can be used to avoid local overloading which stimulates rapid clogging (3, p. 149). Dosing allows intermittent "resting" of the clogged infiltrative surfaces, which can reduce the resistance to flow, as becomes obvious during the next dosing (3, 19). The soil does not accept effluent during the "resting" period and the "average" infiltration rate calculated for both dosing and resting periods has been shown to be lower in some soils than the infiltration rate in continually clogged and ponded systems (17). The latter data, however, were derived in column studies and field monitoring data characterizing the physical effects of dosing have demonstrated that overall infiltration can be significantly increased in a clogged system using dosing and equal distribution (3, p. 182).

3.4. Conductivity-Type III (silt loams, silty clay loams)

The hydraulic behavior of many porous silt loam soils is characterized by a relatively high conductivity at saturation (due to worm and root channels and planar voids) which drops very strongly upon desaturation because pore sizes inside the structural units are very small (3). Large quantities of effluent can be absorbed in these soils if all pores contribute to flow. Many systems function well and have not ponded seepage beds. However, on-site studies have revealed that many systems in these soils are ponded and that surface seepage of raw effluent in wet seasons is common. This is due to mechanical compaction and puddling of bottom and sidewall areas of seepage systems during construction. These soils stay wet for long periods of time during drainage and moisture contents are well above the lower plastic limit for many months during the year. A common mistake made by installers is to drive with excavating equipment on the infiltrative surfaces on the bottoms of seepage beds. Moisture tensions measured below such puddled and compacted seepage beds, which were full of effluent and failing, were approximately 35 cm, corresponding with low flow rates of approximately 7 mm/day (R_b = 70 days). Manually puddled silt loam soil material as such had about similar R_b values of 60 ± 10 days, which confirms the significance of the puddling process (9). Construction of seepage trenches is preferable to construction of beds because driving in the bottom of narrow trenches is impossible. Trenches can be excavated to varying depths, thereby varying the sidewall area available for infiltration. Sidewall areas are effective in absorbing septic tank effluent (19), *but only if horizontal hydraulic gradients--based solely on the matric and* <u>*not*</u> *on the gravitational potential--are sufficiently large.* The latter may be low in wet periods under midwestern weather conditions and little effluent can be absorbed laterally. Moreover, a ponded bed does not offer much additional capacity for storing effluent, so chances for failure increase. Finally, natural moisture contents are generally lower for a longer period of time at shallow depth as compared with greater depths. This implies that smearing and compaction, even when constructing trenches, is more likely to occur when constructing deep trenches. The most attractive solution for these soils would therefore be to construct shallow trenches (max. 18" depth) with unsmeared surfaces and to apply effluent by a daily, equally distributed, dose. The relatively high K_{sat} value may allow reduction of the required seepage area following this regime (6). Many of these soils have large vertically continuous wormholes which may cause short-circuiting of effluent and this factor should be considered in designing experimental systems (6). Worms can play an important role in maintaining a porous infiltration surface.

Dosing of effluent, which includes a relatively long period of "rest" in which the soil is not flooded, may be particularly important in these soils to stimulate biological activity.

3.5. Conductivity-Type IV (some silty clay loams, clays)

Hydraulic conductivities are low and occurrence of clogging or smearing and compaction can easily reduce the infiltration rate to unacceptable low levels. Puddling effects in these soils can be very severe. Puddled clay soil material as such, had R_b values of 500 ± 80 days. A barrier composed of such materials reduces infiltration levels to very low values. Column experiments, using large *in situ* cores from the Almena silt loam showed that infiltration rates into unsmeared horizontal surfaces were reduced to levels below the saturated hydraulic conductivity, but not lower than about 6 mm/day (R_b = 20 days) (12). Theoretical considerations, to be discussed elsewhere (9), indicate that naturally clogged layers with low R_b values, such as the ones formed on sand (R_b = 6) do *not* affect infiltration into clay soils at all. Seepage trenches in these soils can therefore potentially function if the absorptive bottom area is adequately large. Factors discussed in 3.4 relating to excavation techniques and trench depth are very relevant for these soils. One additional characteristic to be considered for these soils is the occurrence of a seasonally perched water table at depths within 2 ft below the soil surface. Observations made in several soils in the Spring of 1974 indicate that this phenomenon is more widespread, even in non-mottled soils, than anticipated. A subsurface seepage system cannot function adequately when submerged in ground water. The system may function hydraulically, perhaps, as the effluent moves with ground water (15) but purification processes are not very effective (3, 19) and the occurrence of a large volume of effluent with a high polluting potential close to the soil surface is clearly not acceptable. Two alternatives are possible: (i) Construction of a mound system in which soil covered seepage trenches are built on top of 2 ft of sandfill, covering the plowed original soil surface. This system is, in fact, a covered sand filter which allows on-site soil absorption. Dimensions of the trenches inside the mound are such that the ground water will not rise into the mound in wet periods and the bottom area of the mound is sufficiently large to allow absorption of effluent into the slowly permeable subsoil (8); (ii) Construction of drainage systems around a shallow trench system as discussed in 3.4. Deep, closely spaced, drainage tiles are needed because of the low K_{sat} values. Deep, narrow, seepage trenches in these soils are not attractive because they would seasonally fill with water if the soils were undrained and they would require unpractical, closely spaced, very deep drainage tiles if drainage were to be provided. Electrical-analogs have to be used to design proper dimensions of these systems.

3.6. High ground water

Seasonally perched water tables were discussed in the context of slowly permeable soils in Section 3.5. Soils with permanently high ground water should preferably not be used for home construction because of the many other problems associated with home construction. Predictions of groundwater levels are difficult to make, because they may vary considerably during the year and the observer is usually not in a position to make many observations. The soil mottling phenomenon is widely used in the Soil Survey Program to estimate groundwater levels (22). Although generally successful, wrong predictions have been made either because low-chroma mottling ("gleying") does not indicate significant saturation in some soils (22) or because *lack* of mottling does not necessarily imply lack of saturation for a significant amount of time. Intensive monitoring

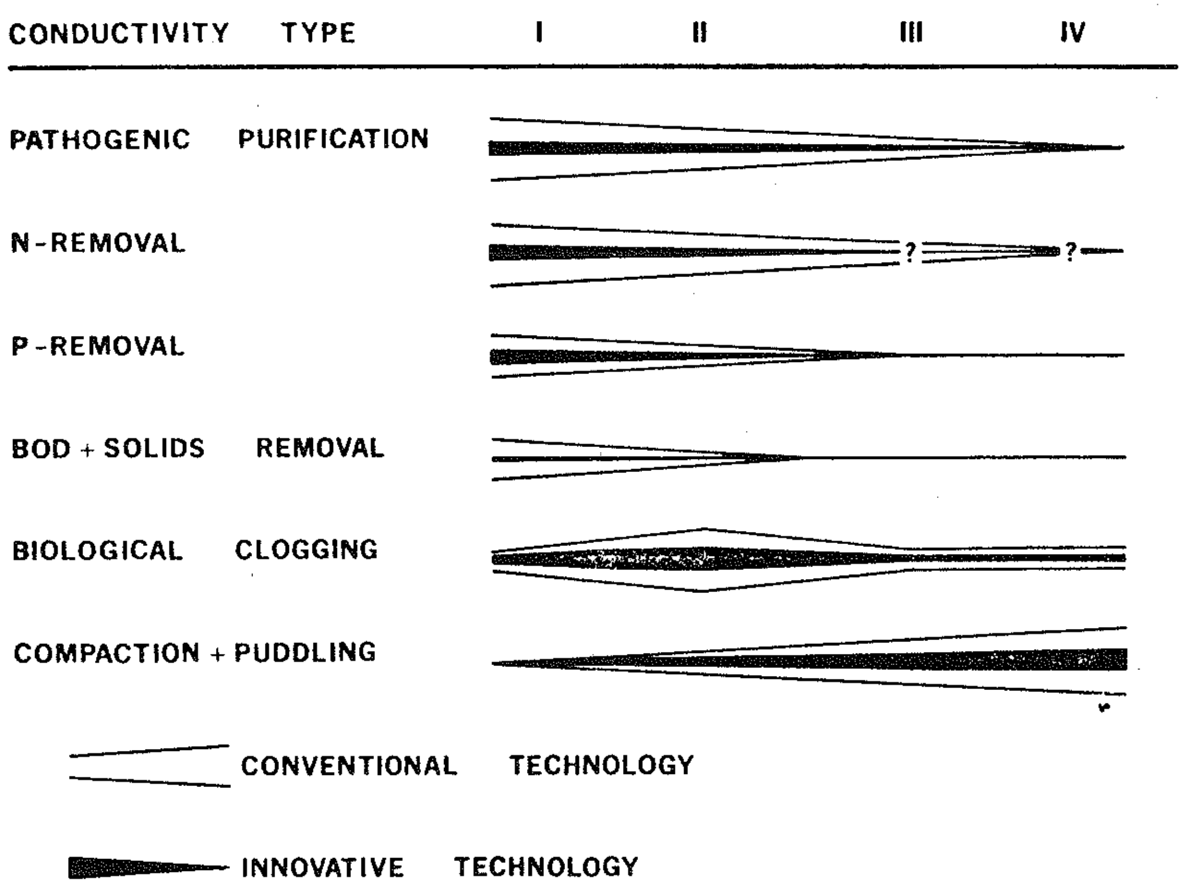

Fig. 2. Schematic diagram of different soils showing limitations(characterized as conductivity types) for achieving different processes of purification as a function of construction and management (technology) procedures. Potential limitations and problems increase as bands widen.

programs are needed to more strictly identify natural soil moisture regimes. Technical alternatives for soils with high ground water are mound systems or shallow trench systems with drainage, as discussed in 3.5.

4. Conclusions

Soil *in situ*, or soil materials used in a mound, can be very effective for disposal and purification of liquid waste. Knowledge about basic physical characteristics of the soil materials and field soil moisture regimes are essential for designing operational field systems. Processes of absorption and purification vary for a single soil material as a function of system construction and management, and different soil materials have different potentials for achieving purification in terms of removal of a variety of components, and for creating physical conditions allowing adequate infiltration. This is schematically illustrated in Fig. 2, comparing conventional and innovative procedures as discussed. Sands (conductivity-Type I) are potentially poor purifiers when overloaded (3, 14). However, well constructed and managed systems can provide excellent purification except for N and, perhaps, P removal. Biological clogging does occur, but only to a predictable level. Some systems may be undersized following criteria of current codes. Compaction and puddling are very unlikely due to the low clay content. Interpretations for the other conductivity types summarize discussions presented in Section 3. Generally, the purification potential and the probability of clogging and compaction increase as the clay content of the soils increases. Biochemical clogging appears to have the greatest impact in loamy, poorly structured soils as discussed in Section 3.3. This paper has only considered use of septic tank effluent. Effluent quality can be improved by mechanical pretreatment, but our experiments so far have not demonstrated clear advantages that would justify advocating replacement of the reliable septic tank with more vulnerable mechanical pre-treatment devices (12).

This paper has only considered soil absorption of effluent, ignoring the effect of evapotranspiration which may remove significant quantities of liquid in the growing season. However, a long winter season with very low natural evapotranspiration, as occurring in the midwest of the U.S.A., does not allow complete reliance on evapotranspiration as a continuing means to dispose of septic tank effluent. Soil absorption will therefore have to remain the principal means of effluent disposal, effective during the entire year.

Literature Cited

1. American Public Health Association. Am. Water Works Assoc. and Water Pollution Control Federation. 1971. Standard methods for the examination of water and waste water. 13th Ed.

2. Bouma,J. 1971. Evaluation of the Field Percolation Test and an Alternative Procedure to Test Soil Potential for Disposal of Septic Tank Effluent. Soil Sci. Soc. Amer. Proc., Vol. 35, No. 6: 871-875.

3. Bouma, J., W. A. Ziebell, W. G. Walker, P. G. Olcott, E. McCoy and F. D. Hole. 1972. Soil Absorption of Septic Tank Effluent. Information Circular No. 20. University of Wisconsin - Extension. Geological and Natural History Survey. 235 p.

4. Bouma, J. 1974. Use of improved field techniques for measurement of hydraulic properties of soils. Rural Environmental Engineering Conference. Warren, Vermont. (Proceedings in press).

5. Bouma, J., J. C. Converse, W. A. Ziebell and F. R. Magdoff. 1974. An experimental mound system for disposal of septic tank effluent in shallow soils over creviced bedrock. Proceedings International Conference on Land for Waste Management. Ottawa, Canada.

6. Bouma, J., J. C. Converse and F. R. Magdoff. 1974. Dosing and resting to improve soil absorption beds. Proceedings ASAE, Vol. 17: 295-298.

7. Bouma, J., F. G. Baker and P. L. M. Veneman. 1974. Measurement of water movement in soil pedons above the water table. Information Circular 27, Wis. Geol. Nat. Hist. Surv. Univ. Ext. Madison, Wisconsin. 116 p.

8. Bouma, J., J. C. Converse, R. J. Otis, W. G. Walker and W. A. Ziebell. 1975. A mound system for on-site disposal of septic tank effluent in slowly permeable soils with seasonally perched water tables. J. Env. Qual. (in press).

9. Bouma, J. 1975. Unsaturated flow phenomena during subsurface disposal of septic tank effluent. J. Amer. Env. Eng. Div. ASCE (in press).

10. Clayton, J. W. 1973. An analysis of septic tank survival data in Fairfax County, Virginia 1952-1972. Ground Water Journal. May-June 1973: 29-32.

11. Converse, J. C., J. L. Anderson, W. A. Ziebell and J. Bouma. 1974. Pressure distribution for improving soil absorption systems. This symposium.

12. Daniel, T. C. and J. Bouma. 1974. Column Studies of Soil Clogging in Slowly Permeable Soils as a Function of Effluent Quality. J. Env. Qual.: 3, No. 4: 321-326.

13. Geldreich, E. G. 1966. Sanitary significance of fecal coliforms in the environment. Cincinnati Water Research Laboratory, Water Pollution Control Resea-ch Series Publication No. WP-20-3. 122 p.

14. Green, K. M. and D. O. Cliver. 1974. Removal of virus from septic tank effluent by sand columns. This symposium.

15. Healy, K. A. and R. Laak. 1973. Sanitary Seepage Fields - Site Evaluation and Design. Paper CE 73-61. Univ. of Conn., Dept. Civil Eng.

16. Hill, D. E. and C. R. Frink. 1974. Longevity of septic tank systems in Connecticut soils. Bulletin 747. Conn. Agr. Exp. Sta. 22 p.

17. Kropf, F. W., K. A. Healy and R. Laak. 1974. Soil clogging in subsurface seepage systems for liquid domestic wastes. Paper presented at 7th Conf. of Intern. Assoc. of Water Pollution Res., Paris, Sept. 7.

18. Magdoff, F. R., D. R. Keeney, J. Bouma and W. A. Ziebell. 1974. Columns representing mound-type disposal systems for septic tank effluent. II. Nutrient transformations and bacterial populations. J. Env. Qual., Vol. 3, No. 3: 228-234.

19. McGauhey, P. H. and R. B. Krone. 1967. Soil mantle as a wastewater treatment system. SERL Report No. 67-11, University of California, Berkeley. 200 p.

20. Sikora, L. J. and D. R. Keeney. 1974. Laboratory studies on stimulation of biological denitrification. This symposium.

21. U.S. Public Health Service (USDHEW). 1967. Manual of Septic Tank Practice. Publication 526. 93 p.

22. Vepraskas, M. J., F. G. Baker and J. Bouma. 1974. Soil mottling and drainage in a Mollic Hapludalf as related to suitability for septic tank construction. Soil Sci. Soc. Amer. Proc., 38:497-501.

23. Walker, W. G., J. Bouma, D. R. Keeney and F. R. Magdoff. 1973. Nitrogen Transformations During Subsurface Disposal of Septic Tank Effluent in Sands: I. Soil Transformations. J. Env. Qual., Vol. 2, No. 4: 475-479.

24. Walker, W. G., J. Bouma, D. R. Keeney and P. G. Olcott. 1973. Nitrogen Transformations During Subsurface Disposal of Septic Tank Effluent in Sands: II. Ground Water Quality. J. Env.Qual., Vol. 2, No. 4: 521-525.

25. Wisconsin State Board of Health. Administrative Code H62.20. Private Domestic Sewage Treatment and Disposal Systems.