Predicting Water Mounds Under Subsurface

Disposal Drainfields

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Introduction

When liquid is placed below the ground surface in subsurface absorption systems (SAS) it will move downward, under the influence of gravity, and horizontally under the effects of pressure (head) differences. The driving force which causes the liquid to move laterally away from the SAS can be predicted by Darcy's Law, provided several assumptions (collectively known as the Dupuit—Forcheimer assumptions) are made: (1) vertical flow below the drainfield is ignored; (2) all flow in the aquifer is horizontal and laminar; and (3) flow is uniformly distributed with depth. The head which develops between a point below the drainfield and another point some distance away on the water table supplies the driving force that moves water away from the area. The difference in heads between these two points is referred to as the "groundwater mound" (Bouwer 1978, Fielding 1977). The maximum height of the water mound is equal to maximum elevation difference between the heads.

The most critical site factors effecting head differentials (and therefore, groundwater mounding) are the various hydraulic conductivity values ("K") of the soils underlying the drainfield area, the depth of the unsaturated soils (vadose zone), and the depth of saturated soils (aquifer). The accuracy of any prediction of a groundwater mound height is directly related to the accuracy of the measurements of these parameters. Other factors effecting water mounding include slopes, trench depths, and the geometric shape of the drainfield. All these factors are addressed in the mounding equations.

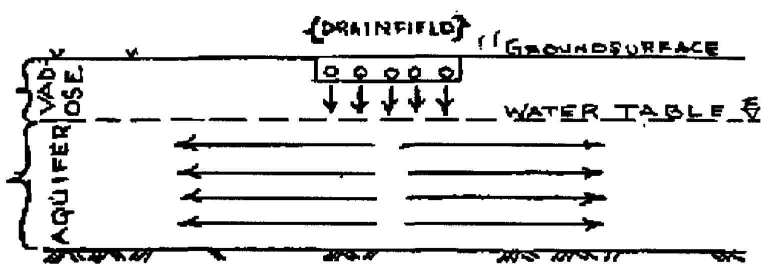


Figure 1

Groundwater Mound Formation

According to Darcys Law, the velocity of the fluid mass transport within the soil is a function of both the vertical and horizontal hydraulic conductivities of the soil(s). Different conductivity values will yield different velocities and consequently, a variable mass of water will move through any given soil area over fixed time periods.

If, all other things being equal, the hydraulic conductivities of the soil(s) in the vadose zone are greater (i.e. soil is more porous) than those in the aquifer, then effluent will reach the aquifer faster than it can leave. Pressure differential will increase and the water will begin to rise (i.e. "mound") above the groundwater surface. If, all other things being equal, the conductivities in the vadose zone are less than those in the underlying aquifer than only the upper zones need to be evaluated for mounding above the perching strata.

Health Implications Associated with Water Mounding Below SAS's

State Health Department concerns with water mounding beneath drainfields are threefold:

1) If the pressure differentials (due to differing "K" values) are large, then the mound may rise high enough to submerge the drainfield system or break out onto the ground surface; the occurrence of either one of these events being defined as system failure. Exposure of sewage on the ground surface is a health hazard.

2) The lateral extent of the water mound indicates the potential extent of encroach of effluent upon surrounding features such as wells, streams, basements, roadway ditches, et cetera, and the contamination with microbiological or chemical pollutants of these features. The depth of the vadose zone and its associated horizontal conductivity values, as well as the slope and direction of any hydraulic gradients, are the major parameters effecting this phenomenon.

3) All the soil(s) within the water mound (as well as the aquifer) are saturated, and renovation of the wastewater is retarded. Anaerobic conditions develop under saturated soil conditions. Micro-organisms can travel longer distances and survive for longer times under these conditions and therefore, their health significance also increases.

Evaluation of Water Mounds

Any analysis of water movement in soils and underlying geologic materials is of necessity approximate at best, due to the complex geometry and large variability of earth materials (Parker, 1982). Several authors (Bouwer, Fielding, Brock, and Hantush) have carried out extensive analysis of groundwater mounding and computer based solutions to predict groundwater mounding exist.

However, the simplistic solutions deal with seepage beds and do not address SAS's and the computer models are too complex to serve as a useful feasibility tool. Accordingly, the Department informally requested technical assistance from VPI&SU to see if they could help provide us an evaluation of mass drainfield proposals. Dr. J. C. Parker, Assistant Professor in the Agronomy Department developed a series of equations designed to predict the phenomenon under different site and soil conditions. An empirical review by the Bureau of Wastewater Engineering of Dr. Parker's equations indicated that they predict reasonable values and, therefore, until further research indicated otherwise, Dr. Parker's equations will be utilized to evaluate water mounding potential below subsurface drainfields. A summary of Dr. Parker's work is contained in Appendix A.

Current Criteria for Evaluating Water Mound Potential Beneath Mass Drainfields

1) Separation distances from the trench bottom to the maximum mound height (H_0) shall, as a minimum, meet the requirements of Table 12.2 of the Sewage Handling and Disposal Regulations. An unsaturated zone of at least 3 to 6 feet below the drainfield is desirable.

2) The allowable lateral extent (L_d) of the water mound shall be evaluated using the requirements of Table 12.1 "Minimum Separation Distances" of the Regulations.

3) Prior to final approval of mass drainfield values for hydraulic conductivities should be either measured in situ or in the laboratory by a person qualified to perform these tests. Values should be determined for each soil horizon below the proposed trench bottom down into the unconfined aquifer, bedrock or sea level.

4) The "effective" depth (W) of the unconfined aquifer shall be considered to equal the effective width (L_c) of the drainfleld.

5) The vadose zone (D) shall be considered to equal the depth from the ground surface to either the seasonal water table as indicated by grey mottles (chroma 2 or less on the Munsell Chart) or free water is reached.

Design Analysis

If preliminary analyses show promise, more detailed site Investigations should be undertaken to proceed with system design.

A. Fixed parameters

   Values of minimum depth of vadose zone (D Min), and maximum allowable lateral extent of water mound, slopes, aquifer depths,

B. Site parameters

   The site investigation should involve augering a sufficient number of holes uniformly dispersed over the proposed SAS site to a depth of 30 ft. or to a layer of high hydraulic resistance (e.g. rock or dense clay) or to sea level, whichever is less. A visual description of the texture, structure and consistence of the material should be made by a qualified soil scientist, engineer or sanitarian. Measurements of hydraulic conductivity should be made in each textural layer below the depth D min or at depths no further apart than 3 ft., for holes of 10 ft depth or less and 6 ft. apart, for holes deeper than 10 ft. Measurements may be made in situ using any accepted methods (see references) or In the laboratory on core samples taken with a sampler having a wall thickness to sample diameter ratio of no greater than 0.07. Conductivity values for each depth used In calculations of L_c shall be the arithmetic mean of the individual values for that depth. (Parker, 1982)

   The average minimum water table depth will be taken as D min (equal to the depth to the grey mottles). From the absolute water table elevations, both water table slope and flow hydraulic gradients will be estimated.

C. Calculations

   Calculations are performed using the same equations developed by Dr. Parker. The permit applicant should have the option of using more sophisticated numerical models if he chooses; however, these results should be evaluated on a site-by-site basis and should include a comparison with the method employed in these recommendations.

References for Saturated Hydraulic Conductivity Measurements

In situ:

Boersma, L. 1965. Field measurement of hydraulic conductivity below a water table. In C. A. Black (ed.) Methods of Soil Analysis. ASA No. 9 2:222-233.

Boersma, 1. 1965. Field measurement of hydraulic conductivity above a water table. In C. A. Black (ed.) Methods of Soil Analysis. ASA No. 9. 1:234-252.

Laboratory:

Klute, A. 1965. Laboratory measurement of hydraulic conductivity of saturated soil. In C. A. Black (ed.) Methods of Soil Analysis. ASA No. 9 1:210-221.

References

Bouwer, H. 1978 Groundwater Hydrology (Chp. 2 & 3) McGraw-Hill Book Co. New York, N.Y.

Hantush, M.S. 1967 "Growth and Decay of Groundwater Mounds in Response to Uniform Percolation." Water Resources Research, Vol. 3, No. 1 (referenced in Bouwer).

Fielding, M.B. "Groundwater Mounding Under Leaching Beds."

Parker, J.C. 1982 "Analysis of Water Table Mounding and Recommendations for Mass Drainfield Design" unpublished correspondence.

Appendix A

Predicting water table mounding (after Dr. J. C. Parker's November 22, 1982 report "Analysis of Water Table Mounding and Recommendations for Mass Drainfield Design").

Dr. Parker developed a series of equations to predict water mounding under various site conditions (Figures 2, 3. 4 and 5). These equations are summarized on page A-2; identification of the terms in these equations follows:

Term	Definition
H_0	Maximum height of water mound, ft (m).
a	Ratio of drainfield length to drainfleld width, L_f/L_c.
J	Total volume of effluent applied to the drainfield per unit time, ft^3/day (m^3/d)
K_1	Hydraulic conductivity in vadose zone, ft/d (m/d).
K_2	Hydraulic conductivity in aquifer, ft/d (m/d).
	Note: $K_1 = K_2 > 10$ and $q/K_1 < 0.2$ (where q = volume per unit time per unit area) for equation 1 to be valid.
	Weighted mean conductivities $K(Z)= \frac{\Sigma L_i}{\Sigma L_i/K_i}$
	Where K_i = conductivity of layer i.
	Where L_i = thickness of layer i.
L_c	Width of drainfield, ft.(m)
Lc	Total effective width of drainfield area, ft (m).
L_f	Length of drainfield, ft. (m)
L_f	Total effective length of drainfield area, ft (m).
L_d	Lateral extent of water mound from edge of drainfield, ft (m).
W	Aquifer thickness, ft (m).
B	Difference in elevation between the local topographic high and average drainfield elevation, ft (m).
Z	Average soil depth to an impermeable lower boundry, ft (m).
N	Correction factor, equals 1 for ($B/Z \geq 1$) or $N=2 - B/Z$ for ($B/Z <1$)

Appendix A continued

D	Depth of vadose zones ft (m).
S	Fractional slope.
F	Depth of percolation line
Θ	Angle of effluent spreading (typically 30°)

Equations

Equation 1 $$H_o = \frac{(1 + a^2)^{1/2}}{2a^2} \left[\frac{J^2}{K_1 K_2 L_c^2} - \frac{aJ}{K_1} \right]^{1/2}$$

Equation 2 $$L_d = J/aL_cK_2 - L_c/2$$

Equation 3 $$Ho = \frac{(1 + a^2)^{1/2}}{2a^2K_1} \left[\frac{J^2L_d}{H_oL_c^2} + \frac{J^2}{2\ H_oL_c} - aJK_1 \right]^{1/2}$$

Equation 4 $$L_d = L_c2/4W - L_c/2 = \frac{L_c^2}{4W} - \frac{L_c}{2}$$

Equation 5 $$L_c = \frac{2\ J\ L_d\ (1 + a^2)^{1/2}}{A^2 K_1 N} \left[H_o^2 + H_o\ (2W + L_d\ S) + 2\ L_d\ W\ S \right]^{-1}$$

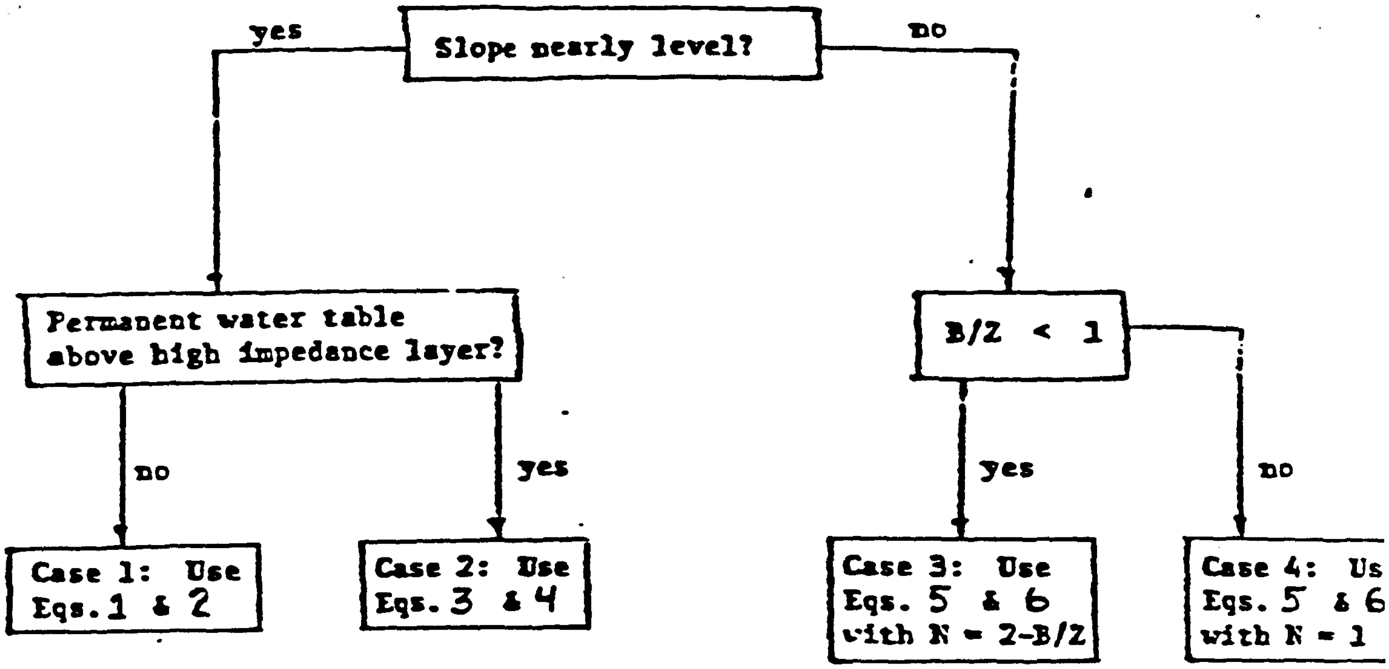
Equation 6 $$L_d = L_c\ 2/2\ NW - L_c/2 = \frac{L_c^2}{2WN} - \frac{L_c}{2}$$

Equation A $$L_c = L_c' + 2(D - F - \frac{Ho}{2})\ Tan\ \theta$$

Equation B $$L_f' = \frac{x-c}{1-c}\ ;\ [C= [1 + \frac{Lc'}{2}\ (D - F - H_o/2\ \tan\theta]^{-1}$$

MOUND = EQUATION 1

MOUND 3 = EQUATION 3



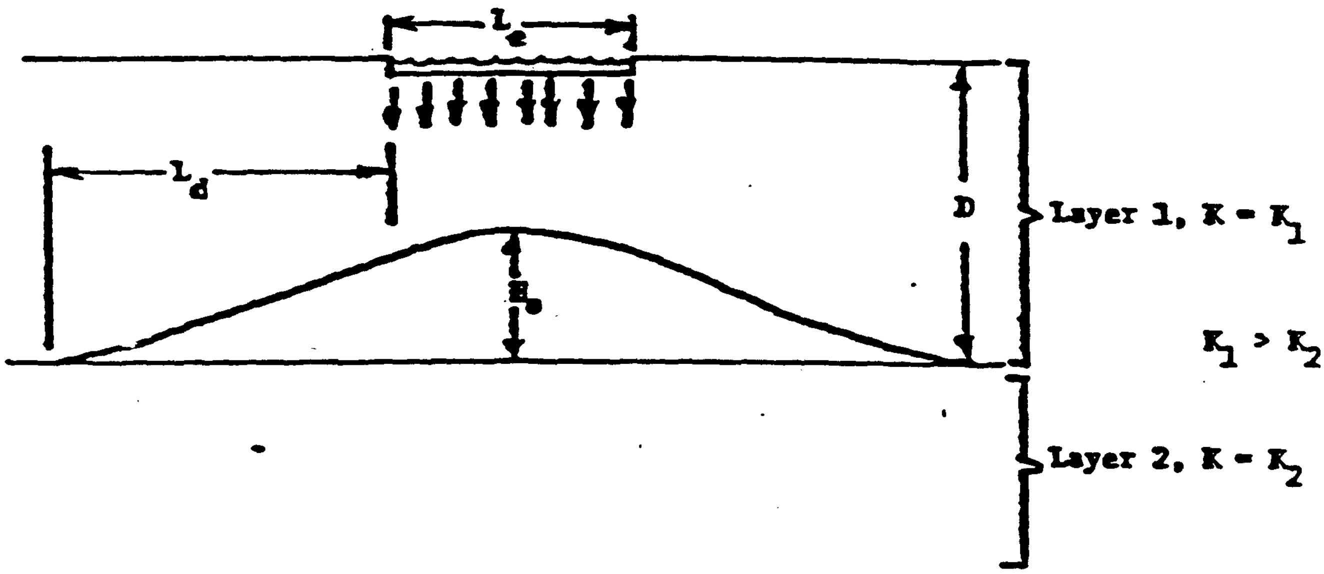


Fig. 3 Geometry of perched groundwater mound.

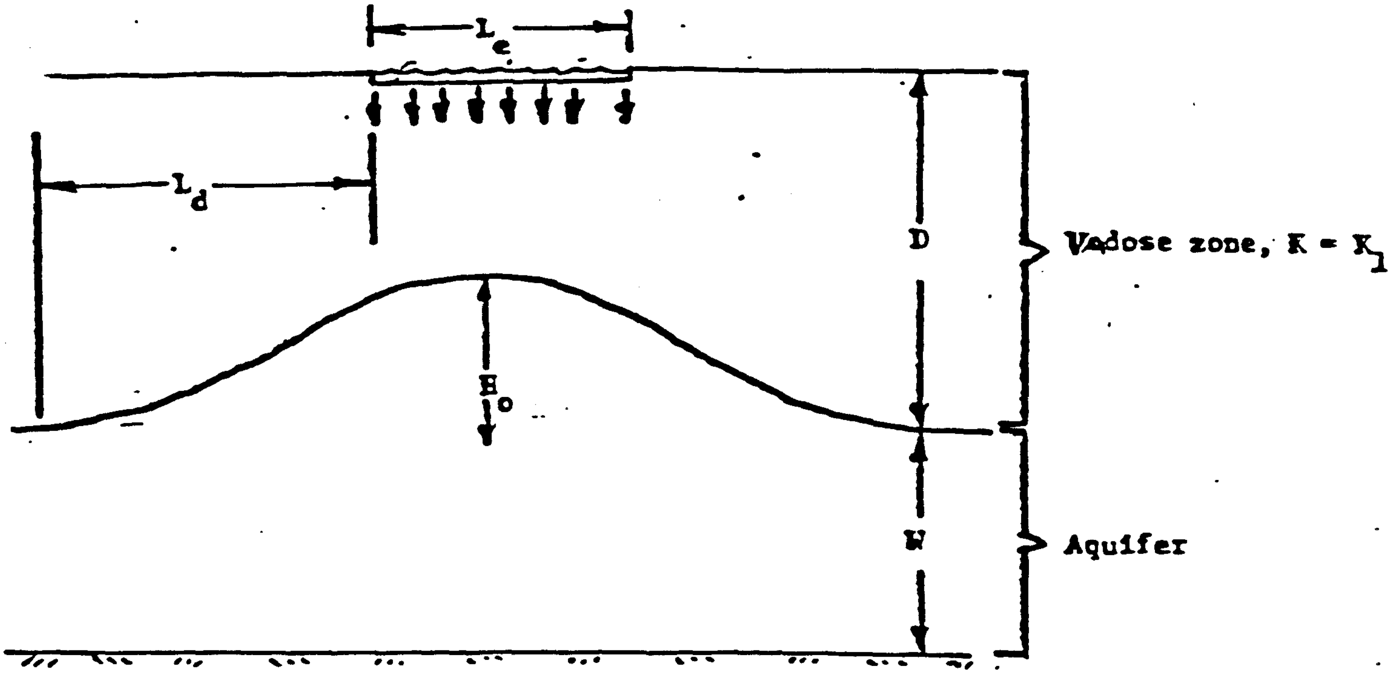
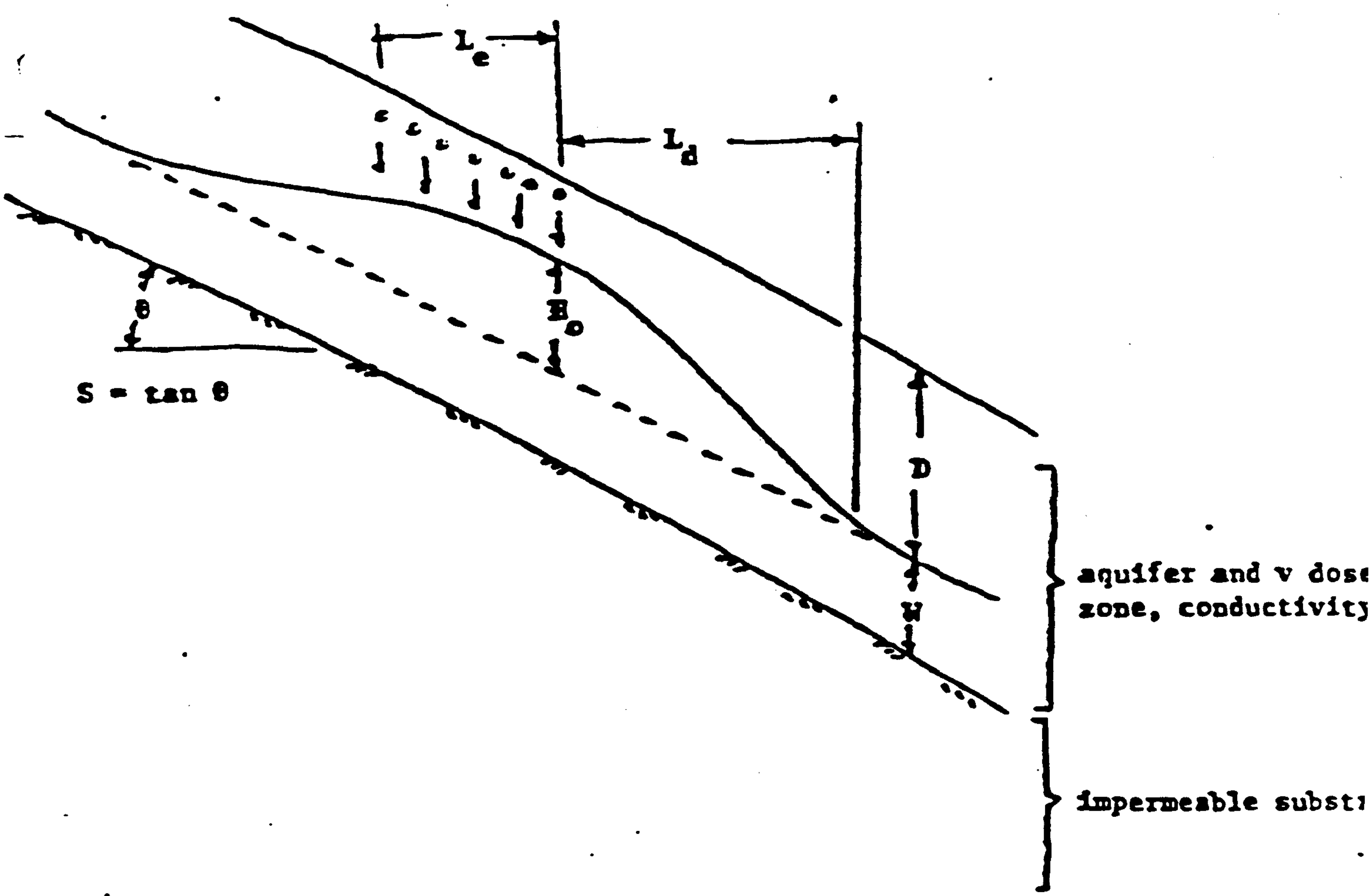


Fig. 4 Geometry of mounding above permanent water table.



Appendix B

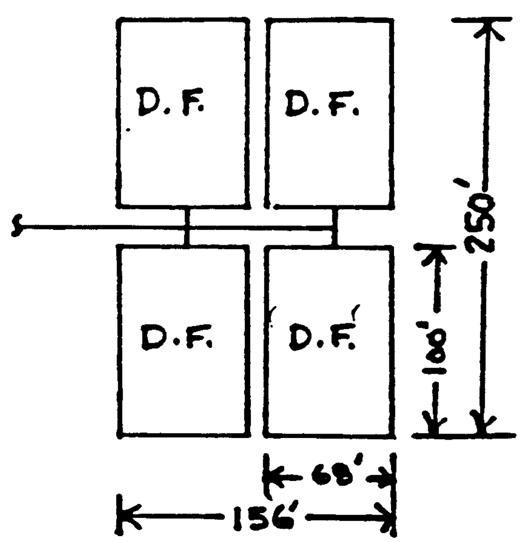
Predicting Water Mounds – Example Problems[1]

Case I

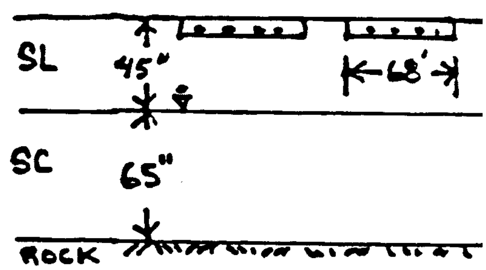
Flow = 5,500 GPD

Sandy Loam from 0–45"; Sandy Clay from 45" to bedrock a: 110". There is a fragipan at 45" and a seasonal water table also exists at the pan. The estimated percolation r: for the Sandy loam is 30 min/inch.

The following disposal scheme is proposed. Evaluate the potential for mounding:



PLAN VIEW



PROFILE

Each drainfield (D.F.) has Twelve 2.0 FT x 100.0 FT trenches. Enhi ced flow distribution will be used & a reserve area is available.

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1. Refer to Fig. 2, pg A-4 for case conditions

A) Evaluate an individual D. F. using Equations 1 & 2 or page A-3.

PARAMETERS REQUIRED

$$L_c = [2^{FT} \times 3 \times (12-1)] + 2^{FT} = 68^{FT}$$

$$L_s = 100^{FT}$$

$$a = \frac{100}{68} = 1.47$$

$$Q = J = \frac{5{,}500 \text{ GAL/DAY}}{4 \text{ D.F.}} \times .13368 \frac{FT^3}{GAL} = 184 \frac{FT^3}{DAY - D.F.}$$

$$\left.\begin{aligned} K_1 &= 5 \frac{FT}{DAY} \\ K_2 &= .02 \frac{FT}{DAY} \end{aligned}\right\}$$ THESE VALUES MAY REQUIRE FIELD VARIFICATIO

SOLVE FOR MOUND HEIGHT, H_o

$$H_o = \frac{(1+a^2)^{1/2}}{2a^2} \times \left[\frac{J^2}{K_1 K_2 L_c^2} + \frac{aJ}{K_1}\right]^{1/2} \qquad \text{Equation}$$

Substitute in parameters

$$H_o = \frac{(1+1.47^2)^{1/2}}{(2)(1.47^2)} \times \left[\frac{184^2}{(5)(.02)(68^2)} - \frac{(1.47)(184)}{5}\right]$$

$$= \frac{(3.16)^{1/2}}{(4.32)} \times \left[\frac{33{,}856}{462.4} - \frac{270.48}{5}\right]^{1/2}$$

SEE NOTE 2

$$= (0.41 \times 4.37)$$

$$\boxed{H_o = 1.74 \text{ FT}}$$

Solve for Length of Mound

$$L_d = \frac{J}{aL_cK_2} - \frac{L_c}{2} \qquad \text{Equation 2}$$

$$= \frac{184}{(1.47)(68)(.02)} - \frac{68}{2}.$$

$$\boxed{L_d = 58^{FT}}$$

B.) Evaluate Entire Site & Determine Which Drainfie Configuration is most critical

<u>parameters required</u>

$L_c = 156^{FT}$

$L_f = 250^{FT}$

$a = \frac{250}{156} = 1.60$

$J = 5{,}500 \text{ Gpd} \times 0.13368 = 735.2 \frac{FT^3}{day}$

$K_1 = 5 \frac{FT}{day}$

$K_2 = 0.03 \frac{FT}{day}$

May require field varification

NOTE 2. The symbol "$(\quad)^{1/2}$" is equal to the symbol "$\sqrt{\quad}$", ie. take the square root.

Solve for H_o

$$H_o = \frac{(1+a^2)^{1/2}}{2a^2}\left[\frac{J^2}{K_1 K_2 L_c^2} - \frac{aJ}{K_1}\right]^{1/2}$$

Substitute and solve

$$H_o = \frac{(1+1.6^2)^{1/2}}{(2)(1.6)^2} \times \left[\frac{735.2^2}{(5)(.03)(156^2)} - \frac{(1.6)(735.2)}{5}\right]^{1/2}$$

$$= 0.36 \times \sqrt{-87.2}$$

A negative number indica
no mound formation. Equa
can not predict decreases.

$$\boxed{H_o = \text{ZERO}}$$

CHECK ASSUMPTIONS $L_c' = L_c$ & $L_f' = L_f$ SEE NOTE 3

USE EQUATION A to evaluate L_c

" parameter Required

$D = 45'' = 3.75^{FT}$

$F \leq D - H_o \leq (3.75 - 1.74) \leq 2.01$ say $2.^{FT}$

$\theta = 30°$

$$L_c = L_c' + 2\left(D - F - \frac{H_o}{2}\right)\tan\theta$$

Substitute:

$$L_c = 68 + 2\left(3.75 - 2 - \frac{1.74}{2}\right)\tan 30°$$

$$= 68 + 2(.88)\tan 30°$$

$$= 68 + 2(.88)(.577)$$

$$= 68 + 1.016$$

$$\boxed{L_c = 69.02^{FT}}$$

L_c' is within 2% of L_c and the assumption was valid.

$$L_f' = \frac{a-c}{1-c} \quad \& \quad c = \left[1 + \frac{L_c'}{2}\left(D - F - \frac{H_o}{2}\tan\theta\right)\right]^{-1}$$

Solve for "c" $\quad c = \dfrac{1}{1 + \frac{L_c'}{2}\left(D - F - \frac{H_o}{2}\tan\theta\right)}$

Substiting $\quad c = \dfrac{1}{1 + \frac{68}{2}\left(3.75 - 2 - \frac{1.74}{2}\tan 30°\right)}$

$$= 0.054$$

Solve for L_f'

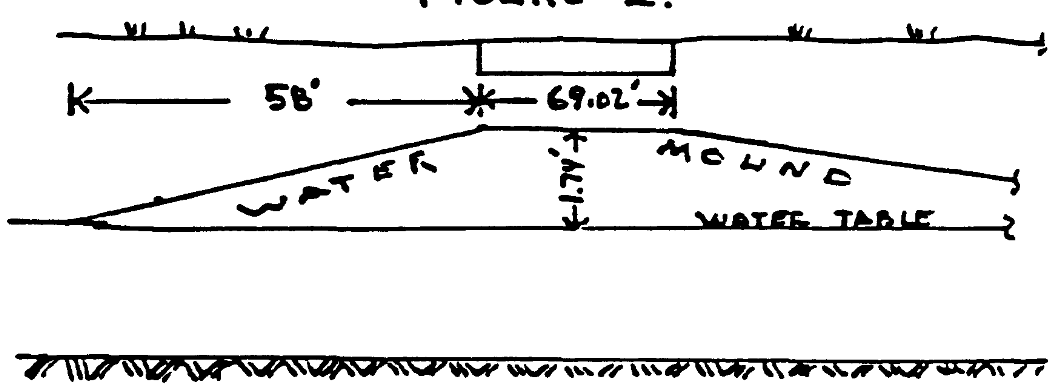
$$L_f' = \frac{1.47 - .054}{1 - .054} = 1.498$$

Solve for L_f

$$L_f = (L_c' \times L_f') = (68)(1.498) = \underline{\underline{99.82 \text{ FT}}}$$

C.) Conculsion

FIGURE 1.



Not to Scale

Note 3. The initial assumption was that the effective width, L_c = the actual width, L_c'. We must check this assumption to make sure L_c is not greatly larger than L_c'. Also check L_f & L_f' are within reason.

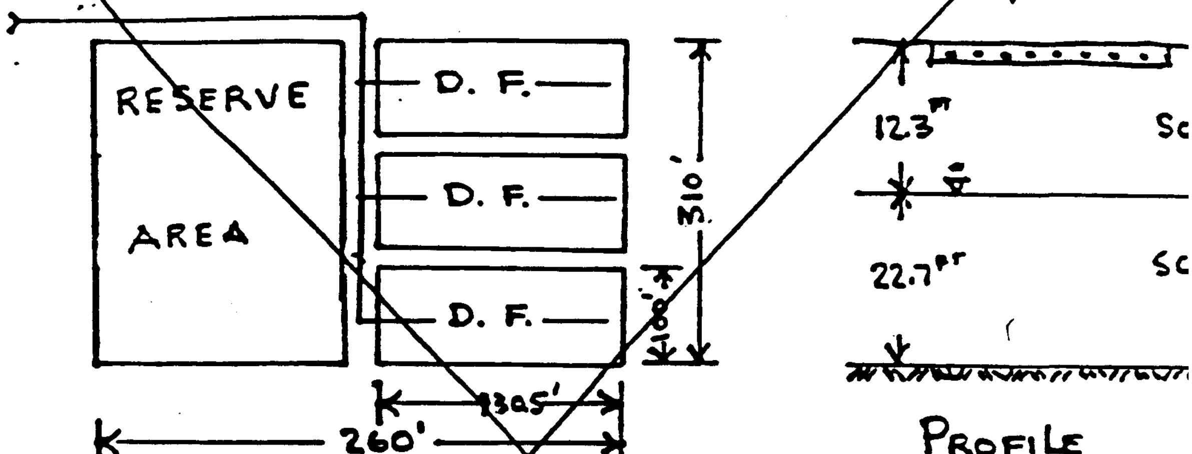
TRENCH DEPTHS MUST NOT EXCEED 24" (3.75'-1.74') if the water mound is not to encroach upon the percolation lines. Any wells, lakes, streams, roadway ditches, etc. should be at least 58 FT away from any adsorption trench.

Case II

FLOW = 7,200 GPD

Tight, Sandy clay Loam from ZERO TO 35 FEET, Water table at 12.3 FEET, ESTIMATED percolation rate is 45 min/INCH.

The Following low pressure distribution scheme is proposed.



NOT TO SCALE

EACH D.F. CONSISTS OF TWENTY 2.25 FT ~~2.25~~ x 100.0 FT TRENCHES. The RESERVE AREA IS NOT SHOWN FOR CLARITY. EVALUATE THE ENTIRE SYSTEM FOR WATER MOUNDING POTENTIAL.

A.) Evaluate system using Equations 3 & 4 on page A-3

Parameters Required

$L_c = [2.25^{FT} \times 3 \times (20-1)] + 2.25^{FT} = 130.5^{FT}$

$L_d = 100.0^{FT}$

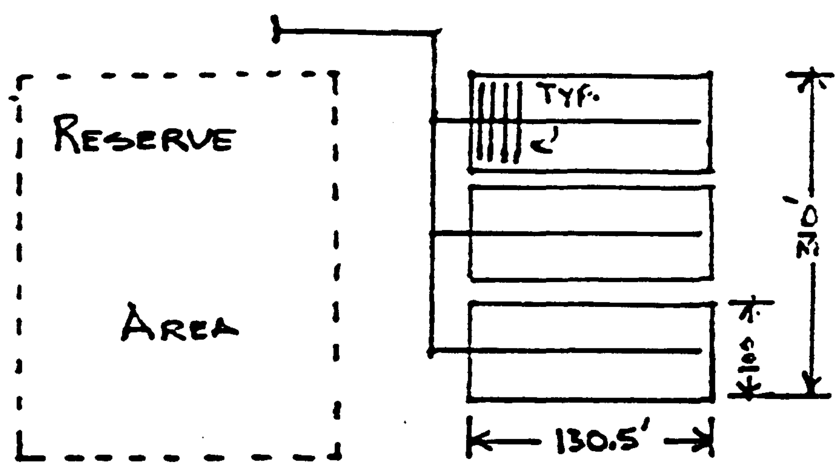
Case II

Given the following information, evaluate the potenti for water mounding below the drainfield.

REPRESENTIVE SOIL PROFILE

Appling Series			Perc. Rate	Conductivity Value (Appendix
Ap	0- 6"	(2.5 YR 4/2) sL		
B1	6-15	(7.5 YR 5/6) scL	45 min/in	FT/day
B2	15-24	(5 YR 5/6) cL	50	6
B22	24-35	(5 YR 5/6) cL with (2.5 YR 4/8) and (7.5 YR 5/6) streakes	50	2
B3	35-50	(5 YR 4/6) cL with (7.5 YR 5/6) and (7.5 YR 7/8) mottles	60	1
C	50-110	(5 YR 4/6) scL with (10 YR 5/4) and (7.5 YR 5/6) mottles.	45	10

Applicant proposes to dispose of 7,200 gpd of sewage utilizing low pressure distribution.
Each drainfield system consits of 40, 2.25 FT x 50.0 FT Ft lines with the manifold running down the center of the drainfield.



SITE PLAN
(not to scale)

a) <u>Determine avg. K value</u>

$$K(z) = \frac{\Sigma L_i}{\Sigma \frac{L_i}{K_i}} \; *$$

parameters needed
(trench will be at 18")

$$\left.\begin{aligned} &LB_2 \left(\tfrac{24-15}{12}\right) = .75^{FT} && K=6 \\ &LB_{22} \left(\tfrac{35-24}{12}\right) = .91 && K=2 \\ &LB_3 \left(\tfrac{35-50}{12}\right) = 1.25 && K=1 \\ &Lc \left(\tfrac{110-50}{12}\right) = \underline{5.0} && K=10 \end{aligned}\right\} K(z) = \frac{7.91}{\left(\frac{.75}{6}\right)+\left(\frac{.91}{2}\right)+\left(\frac{1.25}{1}\right)+\left(\frac{5}{10}\right)} = 3$$

$$\Sigma L_i = 7.91^{FT}$$

b) <u>Determine Length (L_d) of water mound</u>

$$L_d = \left(\frac{L_c^2}{4W} - \frac{L_c}{2}\right)$$

parameters needed

$L_c = 130.5^{FT}$

$W = \left(\frac{110"-35"}{12}\right) = 6.25^{FT}$

$$L_d = \left(\frac{130.5^2}{4 \times 6.25} - \frac{130.5}{2}\right)$$

Equation 4

$$= \frac{17,030.3}{25} - 65.3$$

$$\boxed{L_d = 6\cancel{44}.3 \; FT}$$

616

* See Appendix A, pg A-1. "Σ" means "ADD UP."

c:) Solve for Mound Height (H_o)

$$H_o = \frac{(1+a^2)^{1/2}}{2a^2 K}\left[\frac{J^2 L_d}{H_o L_c^2} + \frac{J^2}{2 H_o L_c} - aJK_1\right]^{1/2} \quad \text{Eq!}$$

parameters needed

$L_c = 130.5$ FT

$L_f = 310.0$ FT

$a = \frac{310}{130.5} = 2.37$

$J = Q = 7200 \text{ GPD} \times 0.13368 \frac{FT^3}{GAL} = 962.5 \frac{FT^3}{day}$

$K = 3.39 \frac{FT}{day}$

$L_d = 644.3$ FT

Substituting into Equation 3

$$H_o = \frac{(1+2.37^2)^{1/2}}{2\times 2.37^2 \times 3.39} \times \left[\frac{962.5^2 \times \cancel{644.3}\ 616}{H_o \times 130.5^2} + \frac{962.5^2}{2\times H_o \times 130.5} - 2.3\right.$$

$$\left. 962.5 \times 3.39\right]^{1/2}$$

$$H_o = \frac{\sqrt{6.61}}{38.08} \times \sqrt{\frac{\cancel{596,883,546.8}\ 5.70,666,25\times 10^8}{17,030.3\ H_o} + \frac{926,406.3}{261\ H_o} - 7,6}$$

$$= 0.067 \times \sqrt{\frac{\cancel{36,597.6}\ 33\,508.9\ \cancel{[illegible]}\ 3549.4}{H_o}\ \ \ H_o - 7,687.4}$$

Square all terms

$$H_o^2 = .067^2 \times \left(\frac{\cancel{36,547.6}\ 37,058.3}{H_o} - 7,687.4\right)$$

$$H_o^2 = \frac{\cancel{173.27}\ 166.35}{H_o} - \cancel{34.50}\ 34.51$$

Set equation equal to ZERO

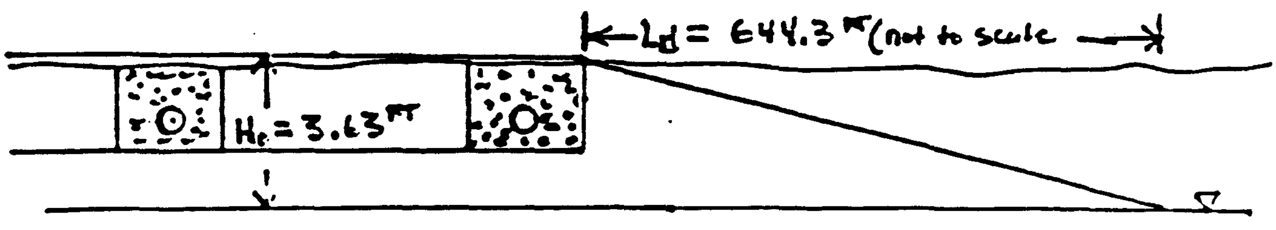
$$\left(H_o^2 - \frac{173.27}{H_o} + 34.5 \right) = 0$$

Solve using a trial & error method

H_o	solved equation equals	Actual H_o
5.0	$5^2 - \frac{173.27}{5} + 34.5 = 24.85$	too Large
4.0	$4^2 - \frac{ETC}{4}$ + ditto = 7.19	too Large
3.0	$3^2 - \frac{ETC}{3}$ + ditto = −14.25	too small
3.5	$3.5^2 - \frac{ETC.}{3.5}$ + ditto = −2.75	too small
3.7	$3.7^2 - \frac{ETC.}{3.7}$ + ditto = 1.36	too Large
3.6	3.6^2 − " + " = −.66	too ~~Large~~ small
3.65	3.65^2 − " + " = .36	too Large.
3.63	3.63^2 − " + " = −.047	OK

$$\boxed{H_o = 3.63^{FT}}$$

Ho = 3.4'



AQUIFER at 35" to 110"

SCALE VERTICLE 1" = 4.0'
Horizontal NO SCALE

SUMMARY

Because the depth of the vadose zone (35'
is less than the mound height (43.56"), the propose
system ~~[illegible]~~ will fail and the project is denied

Appendix C

ESTIMATED HYDRAULIC CHARACTERISTICS OF SOIL[1]

Soil Texture	Permeability ft/day	Percolation min/in.
Sand	>12.0	<10
Sandy loams Porous silt loams Silty clay loams	0.4-12.0	10-45
Clays, compact	<.4	>45

[1]From "DESIGN MANUAL ONSITE WASTEWATER TREATMENT AND DISPOSAL SYSTEMS (October 1980)

U.S. ENVIRONMENTAL PROTECTION AGENCY, Office of Water Program Operations, Office of Research and Development, Municipal Environmental Research Laboratory