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TECHNICAL NOTES

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EVAPOTRANSPIRATION BED DESIGN

By Arthur F. Beck,[1] F. ASCE

INTRODUCTION

Evapotranspiration (ET) beds are used in lieu of drain fields in disposing of septic tank effluent in areas where the soil can not absorb water or where water is absorbed so rapidly that there is a possibility of contamination of underground water.

FIELD DATA

Twice daily field measurements of water depth in 12 experimental ET beds were made from April 1976–March 1977 in San Antonio, Tex., by Raba and Associates, Inc. (1). In addition, measurements were also made of temperature, rainfall, and pan evaporation. Some of the important findings of this study were:

1. When the water level in an ET bed is 13 in.–15 in. (330 mm to 380 mm) below the top of bed, the ET rate is less than the pan evaporation rate. As water rises in an ET bed, the ET rate increases and in some instances can be as much as 10 times the pan evaporation rate.
2. ET occurs in beds that have no vegetative cover, on days when it rains, and on days when it is cold enough to freeze water in the evaporation pan.

DATA ANALYSIS

An analyses of data in the Raba report with special attention to measurements made when the water level was close to the surface, produced enough data points for analysis by regression. Conditions producing the lowest ET rates occurred on both bare soil and St. Augustine grass covered beds during rains on consecutive days in April and May in which the average daily rain was computed to be 0.86 in. (22 mm). Greatest ET rates exceeded 0.14 gal/sq ft/day (0.0057 m^3/m^2/day). Table 1 contains coefficients for the aforementioned conditions for use in Eq. 1:

$$\text{Depth} = A + B \log \text{ET} \qquad (1)$$

in which depth, in inches, is the distance from the top of bed at edge of bed

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to water level; ET = evapotranspiration rate, in gallons per square foot per day; and A and B are equation coefficients.

BED DESIGN

The criteria used in sizing an ET bed is: (1) Daily input must equal daily evapotranspiration; (2) depth to water in bed must not be less than depth required for a 1-day input; and (3) depth of sand layer must be equal to or greater than depth to water on day of greatest pan evaporation. Criteria 1 is simply recognizing that an equilibrium state is being sought by natural processes and makes a convenient standard for design. To find the depth at which equilibrium is achieved requires a trial-and-error method, solving Eqs. 2 and 3 until the assumed and calculated bed areas are equal:

TABLE 1.—Equation Coefficients

Descriptions (1)	Average pan evaporation, in inches per day (2)	A (3)	B (4)
Bare soil (spring rain)	0.076	2.07	−8.745
St. Augustine grass (spring rain)	0.076	1.89	−10.026
St. Augustine grass (pan evaporation > 0.14 gal/sq ft/day)	0.162	7.06	−9.670

Note: 1 in. = 25.4 mm.

$$\text{ET rate} = 10 \exp \left[\frac{\left(\dfrac{\dfrac{C}{7.48} \dfrac{1}{0.16} 12}{D} \right) - A}{B} \right] \quad \text{(2)}$$

$$D' = \frac{C}{\text{ET rate}} \quad \text{(3)}$$

in which ET rate = evapotranspiration rate, in gallons per square foot per day; A = equation coefficient = 2.07 used in example; B = equation coefficient = −8.745 used in example; C = daily input, in gallons per day; D = assumed bed area, in square feet; and D' = calculated bed area, in square feet.

Any input, C, can be used to determine the ET rate since the rate remains constant for all bed sizes, for the selected values of A and B. In Eq. 2, the value 0.16 is a porosity value as found in the Raba experiment. Apparently not all the pores were filled with water thus making this value less than half of what might be expected for void content of a sand.

After determining the ET value at which $D = D'$, one can use Eq. 3 to determine bed sizes for various inputs C. Using Texas Department of Health

(TDH) criteria for input, we get the bed areas shown in Table 2 for two-, three-, and four-bedroom houses.

The second design criteria is an arbitrary requirement designed to keep bed from overflowing in case of simultaneous occurrence of inputs greater than C and unusual weather conditions.

Using Eq. 1 and values of A, B, and ET given previously, the depth is computed to be 4.84 in. (123 mm). This is compared to the calculated depth required to hold a 1-day input as given by Eq. 4. Since Eq. 4 also produces a depth of 4.84 in. (123 mm), the second criteria is considered to be met. Thus

$$\text{Depth of 1-day input} = \frac{\dfrac{C}{7.48}\,\dfrac{1}{0.16}\,12}{D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

The third criteria is designed to keep the bed water level in the sand layer where evaporation is greater than it is in a gravel layer. Coefficients A and B for this condition are $A = 7.06$ and $B = -9.67$. Using these values in Eq. 5, with previously determined input and bed area, will give a depth of 10 in. (250 mm). Thus

TABLE 2.—Bed Areas—Bare Soil (Spring Rain) $A = 2.07$; $B = -8.745$

House size (1)	Input, in gallons per day (2)	ET rate, in gallons per square foot per day (3)	Bed area, in square feet (4)
Two bedroom	375	0.482	777
Three bedroom	500	0.482	1,037
Four bedroom	625	0.482	1,295

Note: $A = 2.07$ and $B = -8.745$. 1 gal = 0.0038 m^3; 1 sq ft = 0.093 m^2.

$$\text{Depth} = \log\left(\frac{C}{D'}\right) B + A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Below the 10-in. (250-mm) deep layer is a 6-in. (152-mm) deep zone containing gravel and 4-in. (100-mm) perforated distribution pipes. To reduce the cost of the bed, gravel is placed only around the pipes and the remainder of the 6-in. (152-mm) zone is filled with sand. Butcher paper is placed over the gravel to keep the sand from intruding into the gravel during construction.

The bed must be level for even distribution of water input to bed. The top of bed is sloped at 1/2 in./ft (13 mm/m) from the center to shed rain. It is recommended that the bed be not over 12 ft (3.7 m) wide so as to keep the center height to a maximum of 3 in. (76 mm). Two beds may be necessary to keep the length from exceeding available site. Fig. 1 shows a suggested layout and cross section for a three-bedroom house. In porous sand or fissured rock, a waterproof liner is required to keep from contaminating the ground-water supply. Such a liner is not required in clay soils since advantage should be taken of soil absorption in addition to evapotranspiration.

Ideally, septic tank effluents should flow by gravity to the ET bed. This may not be possible because of site conditions and pumping is required. It is recommended that the pump discharge into a center well as shown in Fig. 1. The cost of an ET bed for a three-bedroom house in Dallas in 1978 is estimated at $1,200.

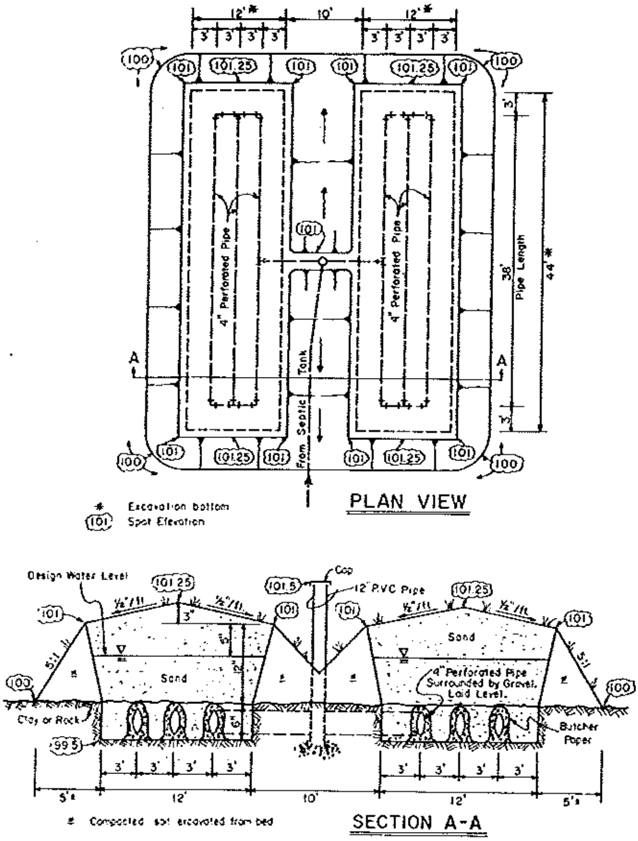

FIG. 1.—Plan View and Typical Cross Section of Evapotranspiration Bed for Three-Bedroom House (1 ft = 0.305 m)

UNUSUAL WEATHER CONDITIONS

Will the bed function in rainy weather, snow, and freezing conditions? The Raba experiment demonstrated that evapotranspiration beds do function during rainy periods and the design procedure presented herein is based upon rainy conditions. Bed overflow is a concern but it is reasoned that rainwater enters from the top of the bed and flows down until it meets the water table in the bed. Additional rain will flow off the bed surface when the bed is full of water. There should be little intermingling of rainwater with septic tank effluent since the rain enters from the top and effluent enters from the bottom and there is no mixing within the soil structure.

As additional effluent is added to a fully saturated bed, the water table rises forcing rainwater out the top. When the rains cease, evaporation commences and the bed begins to dry out. Even under consecutive days of rain, Raba found that evapotranspiration occurred.

As for snow, the Raba experiment did not encounter this condition, however, it is reasoned that if the bed has a green grass cover (winter rye grass in Dallas) and is kept clear of snow, then there should be ample evapotranspiration to keep the bed functioning. Because sewage enters the septic tank at a temperature above 70° F (21° C) and cools little in underground tanks, it is reasoned that the bed will stay above freezing even when the air temperature is below freezing. During the winter, humidity is low and this also helps in the evapotranspiration process. Therefore, it seems reasonable that as long as the ground does not freeze and bed surface is kept clear of snow, evapotranspiration will continue throughout the winter.

Adjusting the design equations for climate conditions other that those in San Antonio is not necessary because the design equations are based upon minimum pan evaporation rates that are found on some days even in the most arid parts of the state as well as in the wettest parts of the state.

CONCLUSIONS

ET bed areas ranging from 777 sq ft–1,295 sq ft (72 m^2–120 m^2) can adequately serve two- to four-bedroom houses. Beds should be shallow to reduce construction costs and take advantage of high ET rates near the ground surface. Bed must be level and the top of the bed must be mounded to keep rainwater from ponding over the bed. A thick grass growth on surface of bed is desirable but not necessary. ET beds function on rainy days but it is doubtful they can be used in areas where the bed surface freezes.

APPENDIX.—REFERENCE

1. Rugen, M. A., Lewis, D. A., and Benedict, I. J., "Evapotranspiration—A Method of Disposing of Septic Tank Effluent," Raba and Associates, San Antonio, Tex., 1977.

RAINFALL QUALITY, LAND USE, AND RUNOFF QUALITY

By William G. Characklis,[1] Calvin H. Ward,[2]
Joe M. King,[3] and Frank L. Roe[4]

Previous investigators have indicated that air quality may contribute to surface water pollution through rainfall or dry fallout, or both, even to the extent that pollutants travel via the air from industrial and agricultural regions may be deposited in undeveloped areas (2,3). Data collected from a heavily developed area in Houston and a forested area 40 miles north were used to estimate the contribution of rainwater quality to stream pollution (1). The results presented in Table 1 indicate a substantial nutrient and chemical oxygen demand (COD) content in rainwater at both sites. Predictably, NH_3-N and NO_3-N concentrations were significantly higher in the urban watershed. Soluble COD in rainwater from the forested area is attributed to vegetative emissions that result in nonmethane hydrocarbons as high as 7.6 ppm (5). The same study found no NO_x in the forested watershed compared to high NO_x levels in Houston.

Fig. 1 compares rainwater concentrations to runoff concentrations for the two watersheds. The forested watershed apparently serves as a sink for nutrients transported by rainwater. Hunting Bayou, the urban watershed, contains large areas of impervious surface (21%), which contribute more nutrients originating from dry fallout and other urban activities. In addition, the pervious urban areas do not have the absorption capacity of the forest soils.

Table 2 indicates the results of soil leaching studies. Four soil samples from different locations were dried and weighed. The samples were extracted with demineralized water until no further NH_3 was measured in the extract, then equilibrated with 30-ml portions of 1 mg N/l (ammonium sulfate). After centrifugation, NH_3-N was determined and the supernatant discarded. This was repeated until no further adsorption occurred. Results indicate that greatest NH_3-N is adsorbed by undisturbed forest soils from where it can be metabolized by plants or nitrified and denitrified by soil microorganisms, or both. In an urban area receiving the same ammonia rainwater load, impervious area and soils with low NH_3-N adsorption capacity increase the NH_3-N in runoff. Dry fallout and other urban activities also contribute to higher nutrient runoff loads.

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As of this writing, the forested site is being intensely developed. The treated wastewater from the development is recycled to a man-made lake system provided for esthetics, recreation, irrigation, and stormwater retention. The wastewater treatment plant includes phosphorus removal facilities provided to minimize algal growth in the lakes. Algal bioassays were conducted with lake water following the procedures described by Ward, et al. (4). These tests indicate that phosphorus is the limiting nutrient in water collected during dry weather (Fig. 2), while

TABLE 1.—Rainwater Quality for Urban (Three Storms) and Forested (Two Storms) Watersheds[a]

Component (1)	Urban (2)	Forest (3)
NH_3-N	0.30 ± 0.12 (85)	0.22 ± 0.09 (19)
NO_3-N	0.52 ± 0.56 (111)	0.31 ± 0.17 (20)
PO_4-P	0.012 ± 0.014 (52)	0.039 ± 0.056 (19)
Soluble COD	14.1 ± 13.7 (69)	15.4 ± 7.1 (20)

[a] Mean values, standard deviations, and number of samples are listed. All units in milligrams per liter.

TABLE 2.—Ammonia Nitrogen Adsorption Capacity in Soils from Different Locations

Location (1)	Milligrams of NH_3-N adsorbed per gram of soil (2)
Golf course	0.027
Roadside	0.022
Drainage swale	0.017
Undisturbed forest	0.043

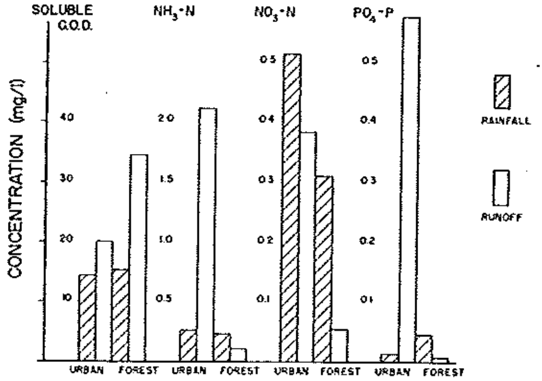

FIG. 1.—Comparison of Rainwater and Runoff Quality for Urban and Forest Watershed

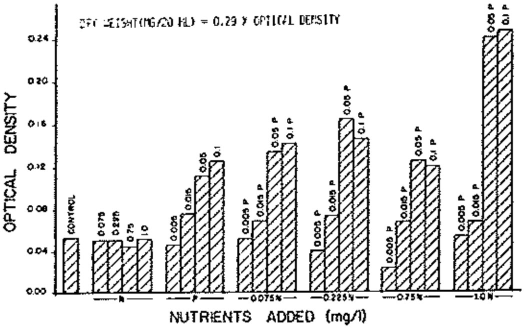

FIG. 2.—Growth of *Selenastrum capricornutum* in Water Collected from Lake During Dry Weather

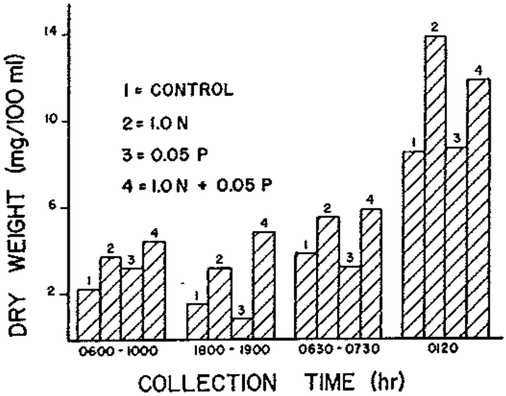

FIG. 3.—Growth of *Selenastrum capricornutum* in Water Collected from Lake During Period of Surface Runoff [Water Samples Filtered (0.45 μm) Prior to Testing and Dry Weight Refers to Algal Mass]

nitrogen is the limiting factor in water collected during periods of surface runoff (Fig. 3). As development proceeds, increasing nitrogen from stormwater runoff can be expected and further lake enrichment may result.

ACKNOWLEDGMENTS

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APPENDIX.—REFERENCES

1. Characklis, W. G., et al., "Maximum Utilization of Water Resources in a Planned Community," *Executive Summary, EPA Grant #802433*, United States Environmental Protection Agency, Jan., 1977.

2. Dugan, G. L., and McGauhey, P. H., "Protecting Our Lakes: Wastewater Treatment is Not Enough," presented at the October 1973, 46th Annual Water Pollution Control Federation Conference, held at Cleveland, Ohio.
3. Schicht, R. J., and Huff, F. A., "The Effects of Precipitation Scavenging of Airborne and Surface Pollutants on Surface and Groundwater Quality in Urban Areas, Part II," *NSF No. GK-38329*, National Science Foundation, Engineering Division, Washington, D.C., July, 1975.
4. Ward, C. H., et al., "Algal Bioassay: Evaluation of Eutrophication Potential of Stormwater Runoff," *Developments in Industrial Microbiology*, Vol. 17, 1975, pp. 337–343.
5. Whitehead, L. W., "Some Microclimate and Air Quality Implications of Urbanization in a Southern Coastal Forest," thesis presented to the University of Texas, at Houston, Tex., in 1976, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.