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Field Notes

**Volume 5, Numbers 3 and 4
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Treatment Systems**

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FOREST SERVICE • U.S. DEPARTMENT OF AGRICULTURE

ENGINEERING FIELD NOTES

This publication is a bimonthly newsletter published to exchange Engineering information and ideas among Forest Service personnel.

The publication is not intended to be exclusive for engineers. However, because of the type of material in the publication, all engineers and engineering technicians should read each issue.

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It is intended that the material in the Field Notes be primarily written and used by Forest Service Field Engineers; however, material from other publications may be used.

Field Note material should always be informative and cannot contain mandatory instructions or policy except by FSM references. Manuscripts to be submitted to the Washington Office for publication should be reviewed by the respective Regional Office to see that the information is current, timely, technically accurate, and of interest to engineers Service-wide (FSM 7113). The length of an article may vary from several sentences to several typewritten pages. The Washington Office will edit and prepare the camera copy to accommodate our format and allowable space.

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FIELD NOTES

DESIGN AIDS FOR LAGOON WASTEWATER TREATMENT SYSTEMS

By William C. Kolzow
Sanitary Engineer, Washington Office

INTRODUCTION

The Forest Service has identified over 1800 projects that are possible water pollution sources. Corrective action to abate water pollution on over 200 of these projects is presently underway or has been completed through the current Water Pollution Abatement Program under Executive Order 11507. In Fiscal Year 1974 we will initiate action on some of the remaining 1600 projects through an anticipated \$5 million program, to be followed in later years with a requested program level approximately equal to that for water pollution abatement in FY 1973.

Many of the 1600 plus projects involve the design of possible waste stabilization ponds (or in the vernacular, sewage lagoons) either unaerated or aerated. These lagoons, particularly those that are not artificially aerated, require the use of much land that could otherwise be used for multi-use purposes. Therefore, it is helpful to the design engineer and/or planner to rapidly estimate such land area impacts to be able to vary design from original proposals. Figures 1 through 6 presented for facultative lagoons should aid in such estimates. The charts shown in these figures are intended as design and estimating aids — not as solutions to individual situations.

The charts presented for surface aerated lagoons (figs. 7 and 8) can be applied directly to a portion of treatment system design solutions. The charts graphically solve one of many complex equations the lagoon designer must apply in his work. Used wisely, they should prove time-savers to the designer.

The following figures and accompanying write-ups are intended as design aids only. Each field situation presents an almost totally different and complex problem. The prudent engineer will use the charts as time-saving aids only, and not as substitutes for developed competence or initiative.

Editor's Note: There is a pressing need for more material of the type presented in this article to assist the field engineer in his endeavors to provide safe, sanitary, potable water supplies and effective, efficient wastewater treatment systems. We intend to publish an Engineering Technical Report on this subject in the near future. We solicit your input for this proposed Report. Please send material that you would like included to the WO Division of Engineering.

ESTIMATING FACULTATIVE LAGOON RETENTION TIMES

Figures 1 through 4 are presented for estimating the retention time in unaerated facultative lagoons when such lagoons are square, interior side slopes are constructed at 3:1, and working (water) depths are 3, 5, 7 and 9 feet. The charts are based on the conventional method used for expressing lagoon loading; that is, pounds B.O.D.₅ per acre, or people (population) served per acre.

The volume of any lagoon can be calculated from the equation:

$$V = D(XZ - SDX - SDZ + \frac{4}{3}S^2D^2)$$

where;

V = volume, cu. ft.

D = liquid depth, ft.

X = lagoon width at water surface, ft.

Z = lagoon length at water surface, ft.

S = embankment slope, ratio of horizontal to vertical

Converting V to gallons, and recognizing that X and Z are identical for a square lagoon, yields the following expression:

$$V = 7.48D(X^2 - 2SDX + \frac{4}{3}S^2D^2)$$

Substituting 3 for S (3:1 side slopes) and substituting a dimensional term, A, in surface acres in lieu of X yields:

$$V(\text{gallons}) = 7.48D [(43,560A)^{\frac{1}{2}} - 3.464D]^2$$

Example Problem:

A waste treatment system is to be designed to serve 250 persons per day. Per capita design organic and hydraulic loadings are determined to be 0.1 lbs. B.O.D.₅ and 40 GPCD. Operating experiences in the general area of the site have indicated that a facultative lagoon with a 3-foot operating depth can be effectively operated at an organic loading rate of 20 pounds B.O.D.₅ per lagoon surface acre.

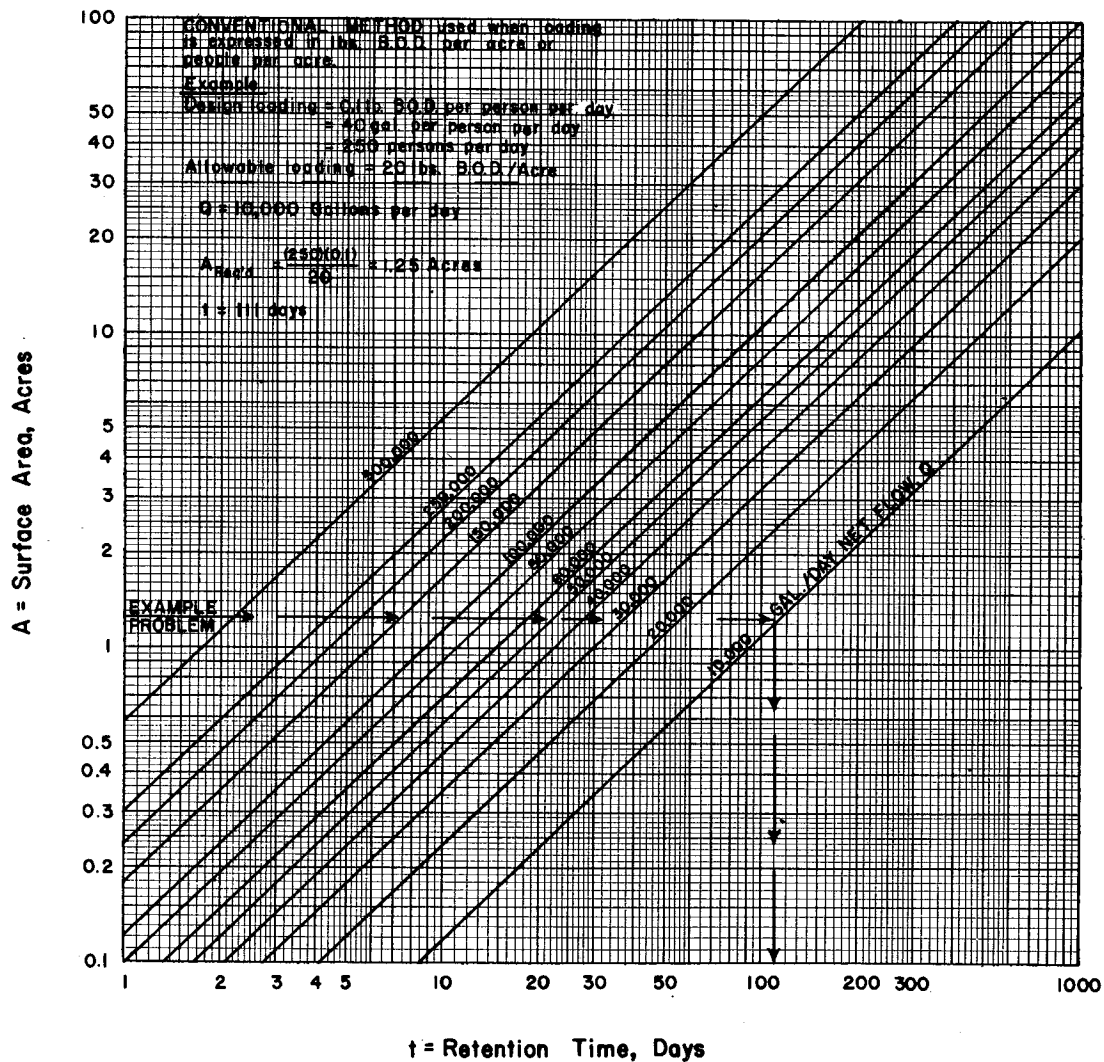
Calculate the net daily flow, Q; the minimum lagoon surface area required, A; and the retention time, t.

$$Q = (40 \text{ GPCD})(250 \text{ persons}) = 10,000 \text{ GPD}$$

$$A = \frac{(250 \text{ persons})(0.1 \text{ lb. B.O.D.})}{20 \text{ lb. B.O.D. per acre}} = 1.25 \text{ acres}$$

$$t(\text{from fig. 1}) = 111 \text{ days}$$

**Lagoon is Square, with 3:1 Side Slopes
Working Depth, D=3 Feet**



*Figure 1.—Retention Time for Unaerated Facultative Lagoon
(Working Depth, D = 3 Feet)*

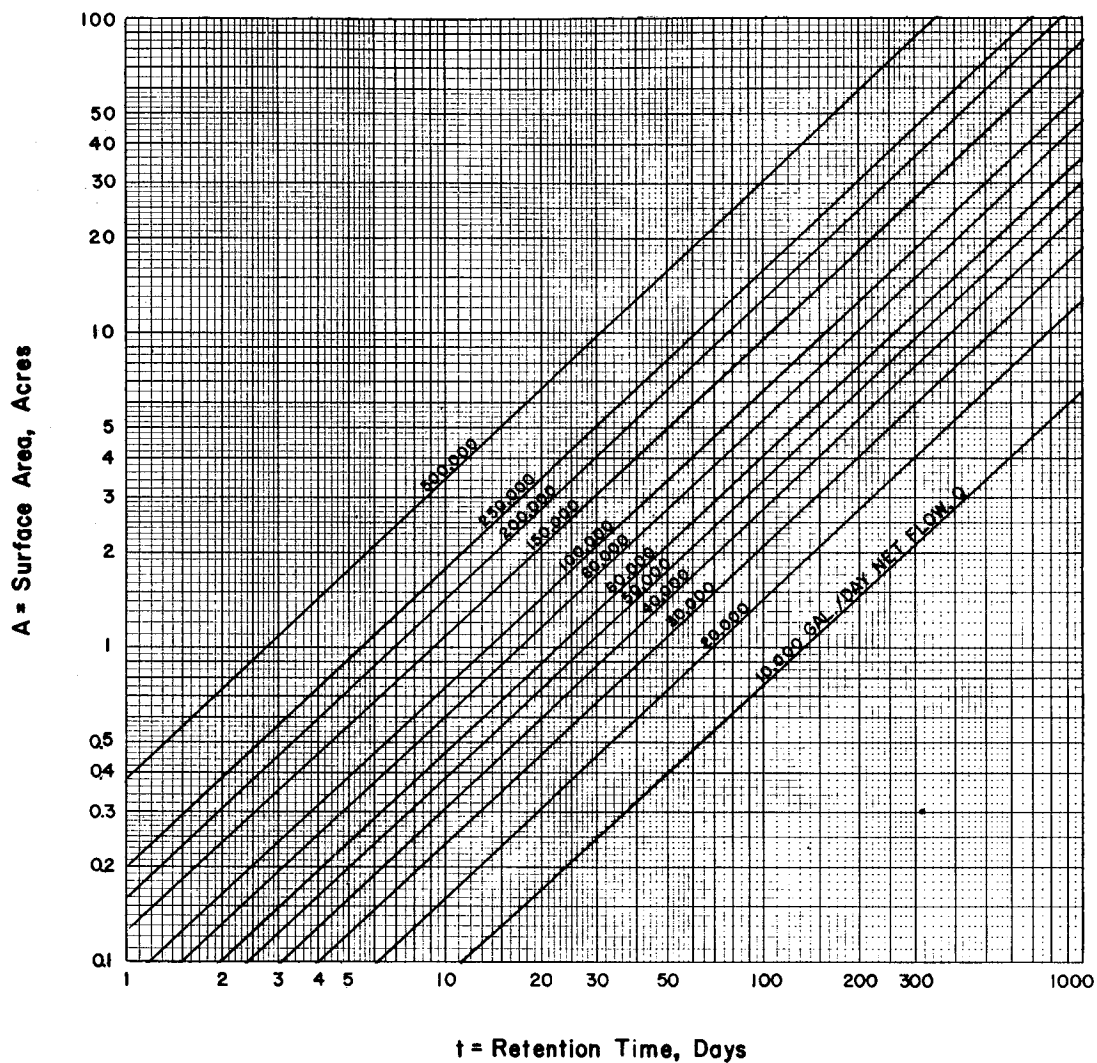


Figure 2.—Retention Time for Unaerated Facultative Lagoon
(Working Depth, D = 5 Feet)

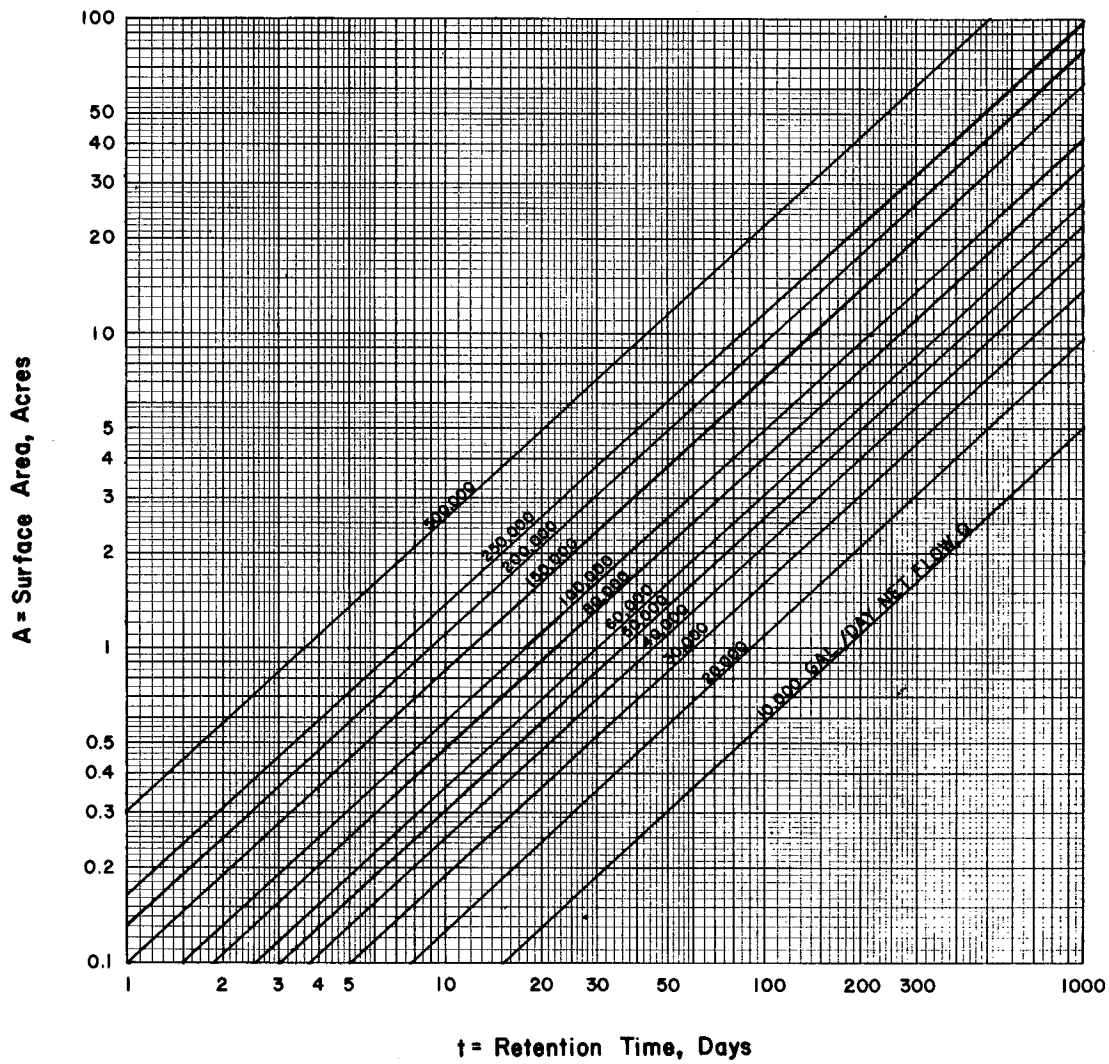


Figure 3.—Retention Time for Unaerated Facultative Lagoon
(Working Depth, $D = 7$ Feet)

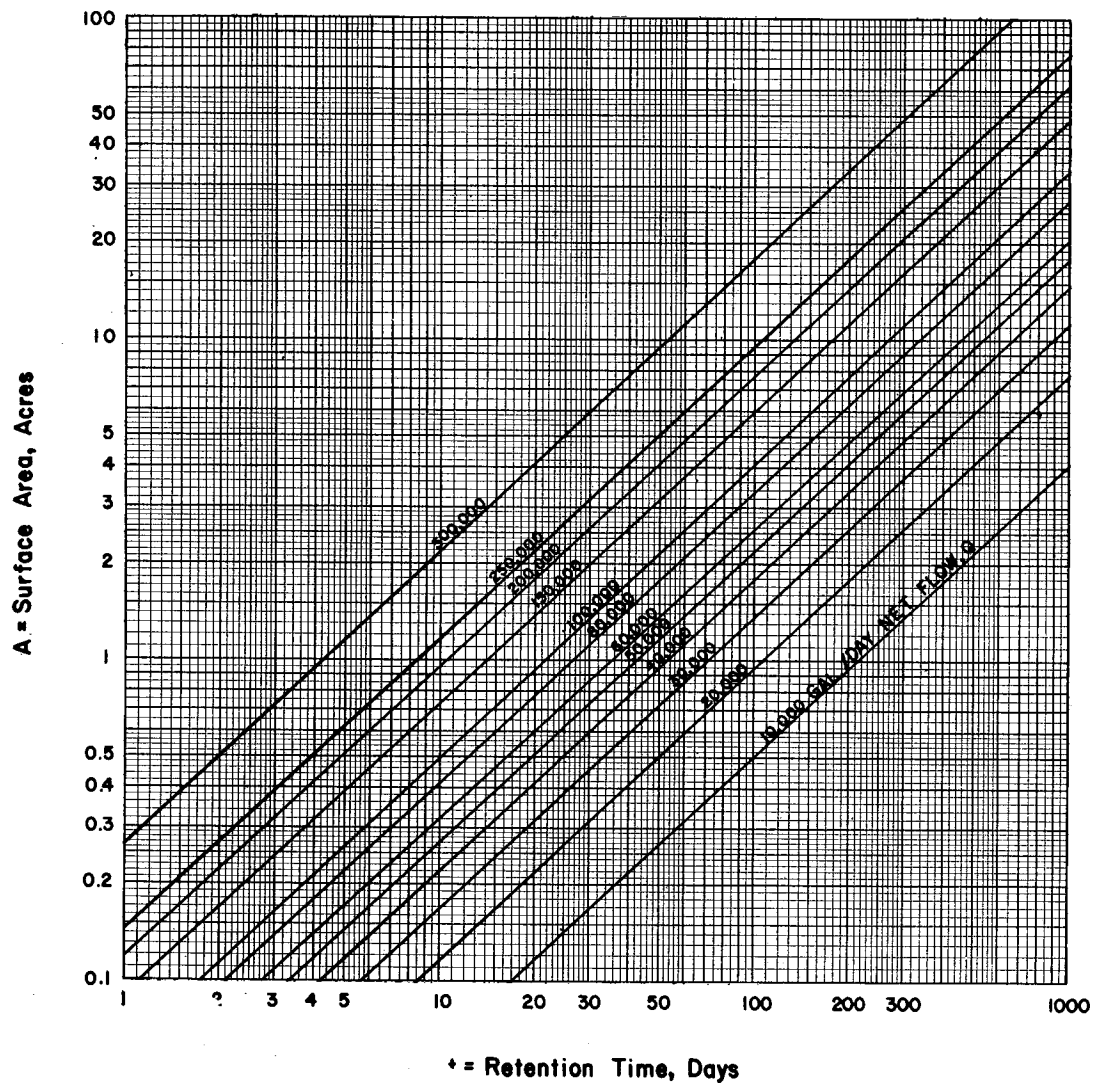


Figure 4.—Retention Time for Underaerated Facultative Lagoon
(Working Depth, $D = 9$ Feet)

UNAERATED FACULTATIVE LAGOON DESIGN

For many domestic wastes, the following empirical relationship will provide a rapid estimate of lagoon size when the effects of temperature are involved:

$$V = CN_p q S_a f f' \Theta^{(35-T)}$$

where,

V = lagoon volume, acre-feet

C = 10.7×10^{-8} (where temperature variations are great and designs are based on a depth of 6 feet; a 5-foot working depth with one extra foot for solids storage)

N_p = population served

q = gpcd

S_a = ultimate influent B.O.D., mg/l; to compensate for a possible sludge effect. (For estimating purposes, one can assume ultimate B.O.D. as 120-125 percent of B.O.D.₅)

f = algal toxicity factor, normally 1.0 for domestic waste

f' = sulfide correction = 1 for SO₄ concentrations less than 500 mg/l

Θ = temperature coefficient, variable from approximately 1.072 to 1.085

T = average temperature of the coldest operating month, °C

but, N_pq = Q = gallons per day daily flow; therefore, substituting the numerical values for C, f and f' yields:

$$V = (10.7)(10^{-8})QS_a\Theta^{(35-T)}$$

If V is expressed in gallons instead of acre-feet,

$$V = (10.7)(10^{-8})(43,560)(7.48)QS_a\Theta^{(35-T)} = 0.035QS_a\Theta^{(35-T)}$$

and,

$$t = \frac{V}{Q} = 0.035S_a\Theta^{(35-T)} = \text{retention time in days}$$

Figures 5 and 6 are presented for rapid estimating of lagoon size, based on retention time. Temperature coefficient, Θ , values of 1.072 and 1.085 were used for developing the charts shown in the two figures.

Example Problem:

Given the following information, estimate the size of facultative pond required:

Ultimate influent B.O.D. = 320 mg/l

Quantity, $Q = 50,000$ GPD

Temperature (mean air, coldest month) = 5°C

Temperature coefficient, $\Theta = 1.085$

From figure 5, $t = 130$ days

Knowing the retention time and total daily flow, and assuming a facultative operating depth of 5 feet (total depth of 6 feet), you can now readily determine surface area and surface loading rate for a number of specific lagoon sections, (figs. 1 through 4),

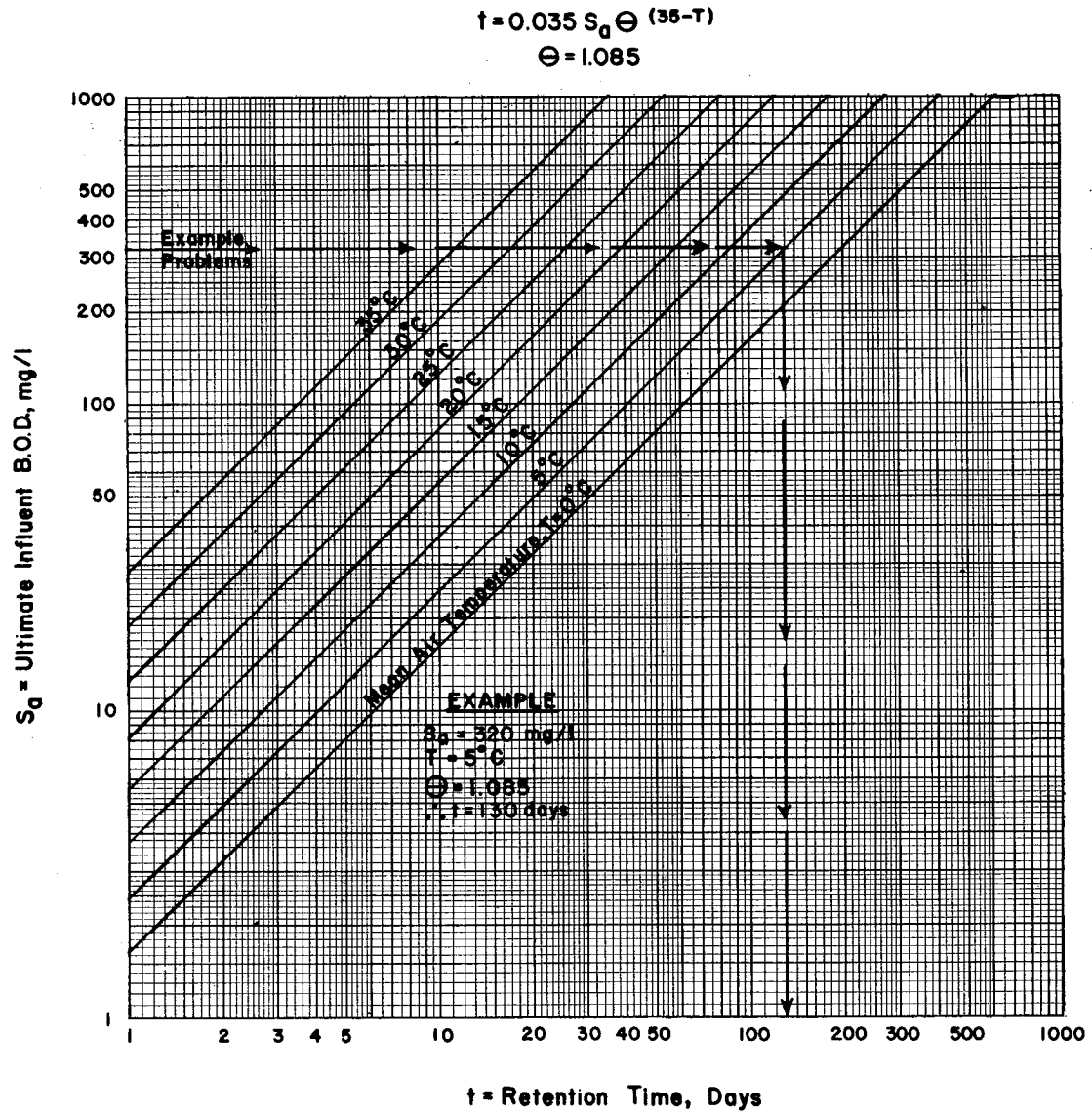


Figure 5.—Unaerated Facultative Lagoons
 $(\Theta = 1.085)$

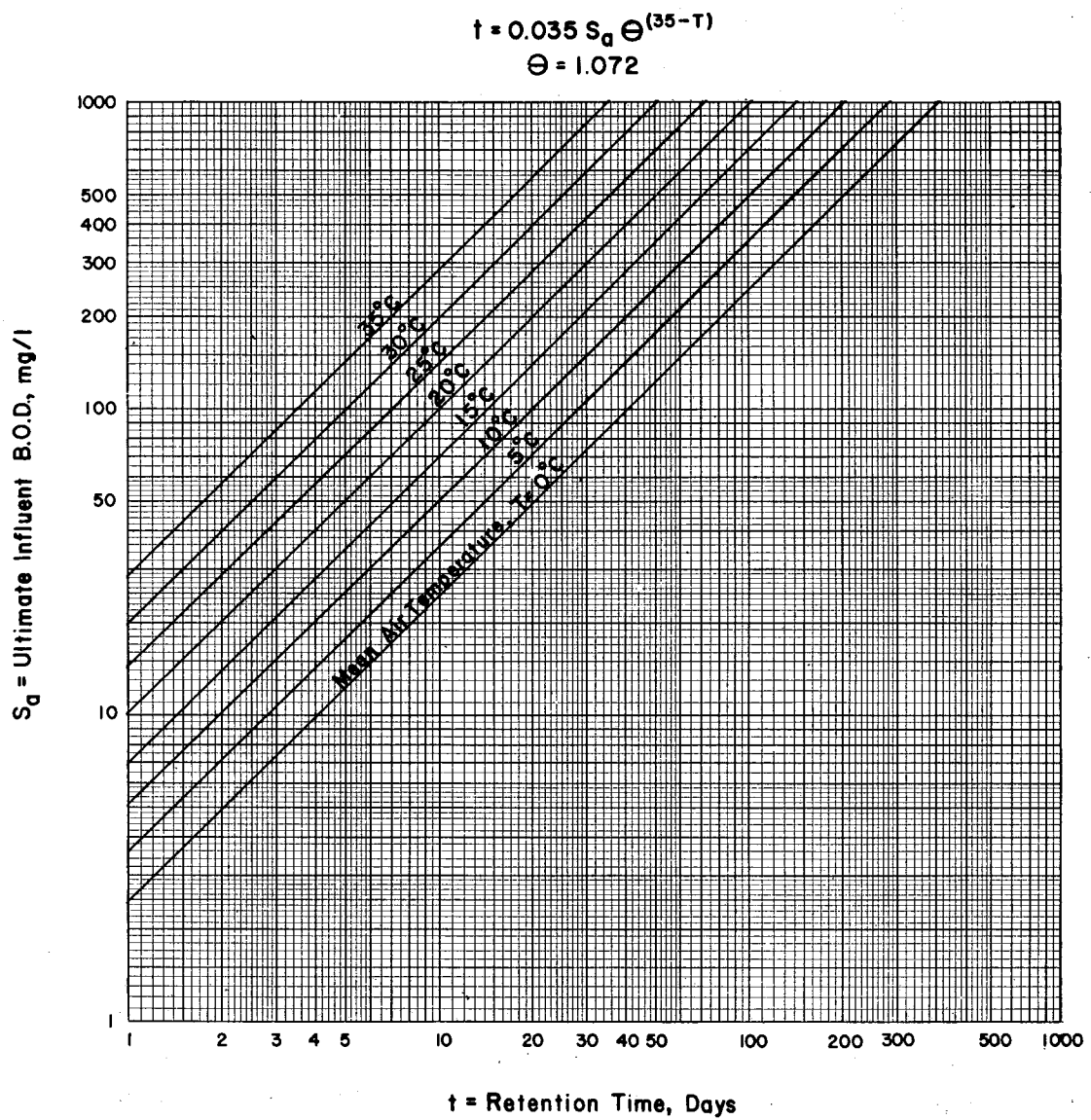


Figure 6.—Unaerated Facultative Lagoons
($\Theta = 1.072$)

AERATION REQUIREMENTS FOR LAGOONS UTILIZING SURFACE AERATION

The oxygen transfer capacity of various aerators is usually reported at standard conditions; that is, 20°C and zero dissolved oxygen in pure water. The oxygen transfer capacity can be converted to any other condition by the equation:

$$N = N_o \left(\frac{F C_{sw} - C_L}{9.17} \right) 1.024^{(T-20)\alpha}$$

where,

N = oxygen transferred per horsepower hour at lagoon operating conditions, lb/hp-hr.

N_o = oxygen transferred per horsepower hour in water at 20°C and zero dissolved oxygen, lb/hp-hr.

F = altitude (pressure) correction factor (see fig. 7).

C_{sw} = saturation of oxygen in the lagoon contents at temperature T , mg/l.

C_L = dissolved oxygen operating level in the lagoon, mg/l.

$1.024^{(T-20)}$ = temperature correction.

T = mean lagoon temperature, °C.

α = ratio of oxygen transfer rates in sewage to oxygen transfer rates in water.

Figures 7 and 8 are presented for graphical solution of the preceding equation. For most practical cases, C_L will be 1.5 to 2.0 mg/l, N_o is approximately 3 lb/hp-hr, and α will vary from 0.7 to 0.9. The value of C_{sw} depends upon the total dissolved solids (T.D.S.) concentration in the liquid, which must be established in the design problem. A rule of thumb applied by some design engineers is that C_{sw} will be 0.9 to 0.95 times the saturation concentration in pure water, but such usage should be cautiously applied.

Example Problem:

Given: Project elevation = 8,000 feet; $F = 0.74$ (from fig. 7)

$$C_L \text{ desired} = 1.5 \text{ mg/l}$$

$$N_o = 3 \text{ lb/hp-hr}$$

$$\alpha = 0.9 \text{ (often used for domestic wastes in the absence of actual data)}$$

$$T = 20^\circ\text{C}$$

$$C_{sw} = 8.7 \text{ mg/l}$$

Calculate:

$$FC_{sw} = (0.74)(8.7) = 6.44$$

$$FC_{sw} - C_L = 6.44 - 1.5 = 4.94$$

Enter figure 8 at $FC_{sw} - C_L = 4.94$; proceed to the α value, 0.9; then to the temperature, T, value of 20°C ; then to the N_o value, 3.0; then read the value of N:

$$\underline{\underline{1.46 \text{ lb } O_2/\text{hp-hr.}}}$$

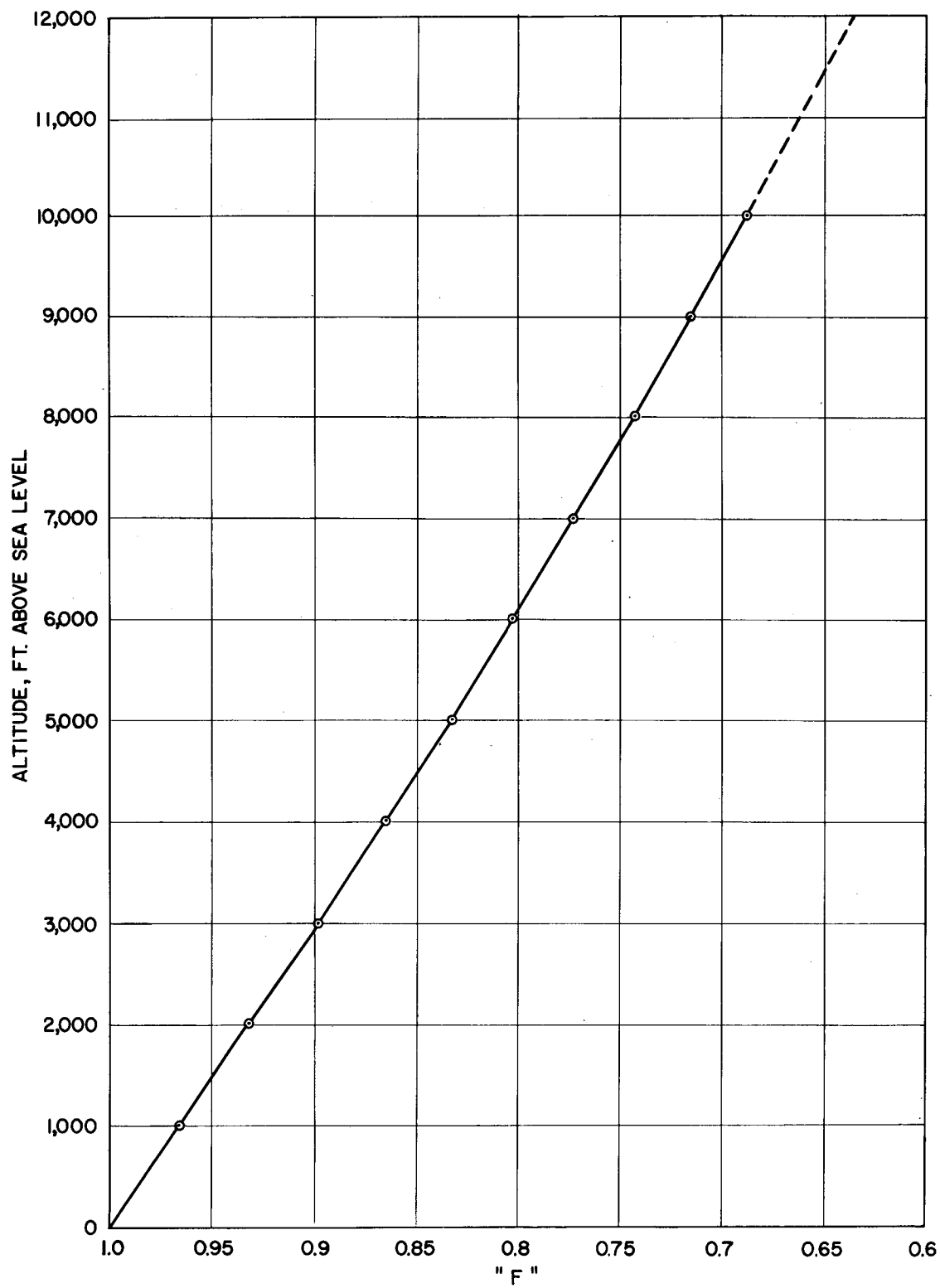
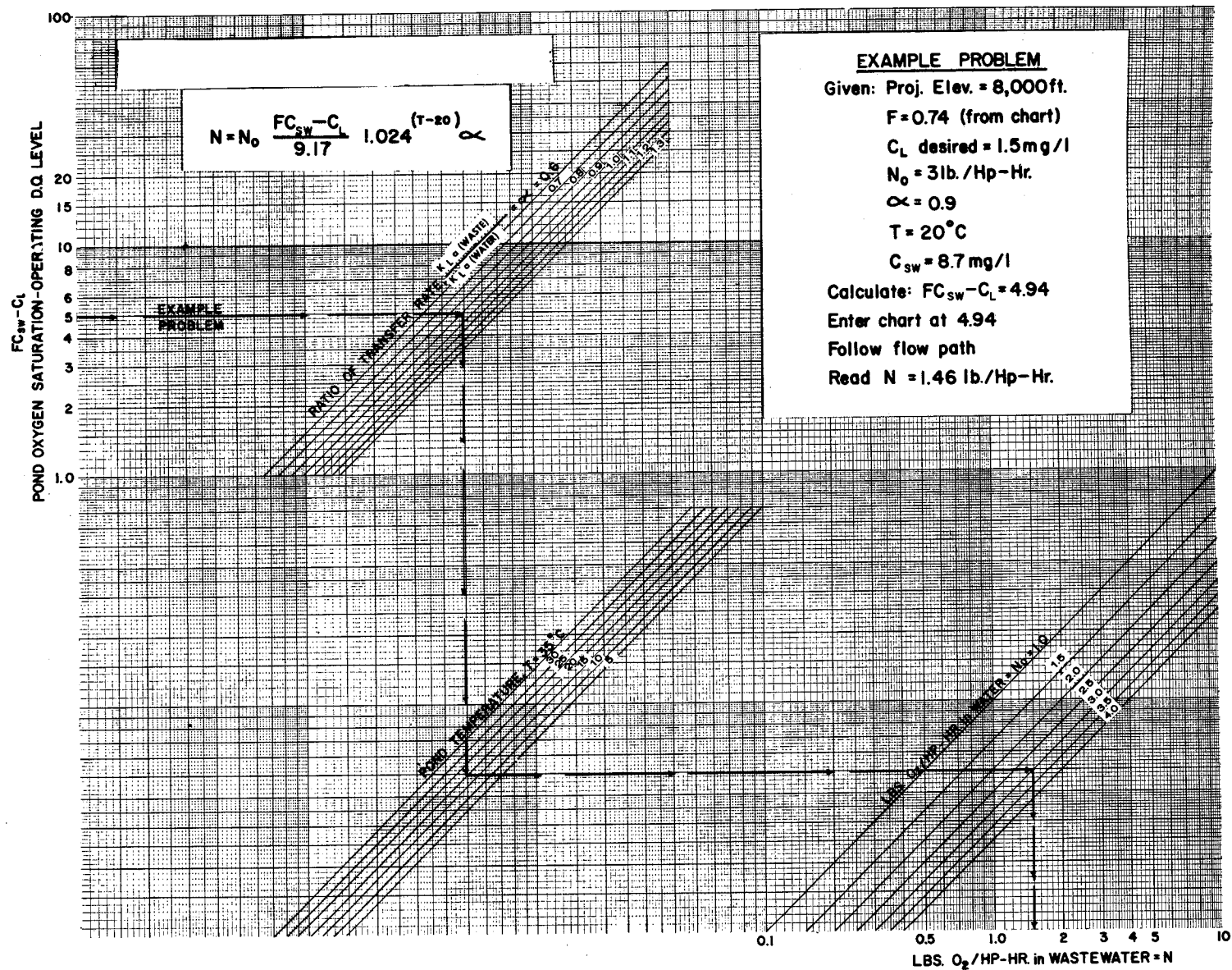


Figure 7.—Altitude Correction Factor "F" vs. Altitude

Figure 8.—Aeration Requirements for Lagoons



AN ECONOMIC ANALYSIS FOR FLOOD RISK COSTS

By John Jakel
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In all our engineering analysis we need to cast up for the decision-maker at every level, a cost of each alternate proposed. Here is one technique of "costing" — the locating of a facility in a flood plain versus other options open to management.¹

Executive Order 11296 requires that:

"(1) All executive agencies directly responsible for the construction of Federal buildings, structures, roads, or other facilities shall evaluate flood hazards when planning the location of new facilities and, as far as practicable, shall preclude the uneconomic, hazardous, or unnecessary use of flood plains in connection with such facilities."

The key words in the above statement are "*evaluate flood hazards*" and "*preclude the uneconomic, hazardous or unnecessary use of flood plains.*" The flood hazards of any particular planned site location within a flood plain must be evaluated independently and subjectively. To thoroughly evaluate the economics of locating a new facility within a flood plain, some basis for determining what is uneconomic must be established. One method of determining only the dollar cost of flood risks is described below.

The value of determining the dollar cost of flood risk is two-fold. The costs can and should be used as an annual cost in the same way any other annual or recurring cost is used in an economic cost comparison of alternatives. It can also be used by line managers to determine the degree of *economic* risks involved in planning construction of Federal facilities on flood plains.

This "cost of flood risk" may be viewed as an annual amount that would be a fair charge for flood insurance. The cost of flood risk(R), or expected damage, is determined by multiplying the probability of a particular storm (i.e., 20-year storm = 1/20) times the damage inflicted by that storm. In this case the damage is assumed to be total. The probability, p, of that damage occurring is the reciprocal of flood frequency, f, which is being investigated (where f = frequency of flood for flood plain; e.g., 5, 10, or 100 year flood; p = probability = 1/f). Algebraically, the relation would be written:

$$R = P(\text{value of structure})p = P(1/f)$$

¹ Comments by the Washington Office Division of Engineering

This equation is true for any particular year, however the analysis is complicated by the fact that P depreciates with time. By assuming straight line depreciation, a 20-year economic life, and interest at 6 percent, an *average* “annual cost of flood risk” may be determined. Thru some algebraic gymnastics which will be outlined subsequently, the following relationship was developed:

$$R_{ave} = P(.620)/f$$

where,

P = initial cost or value of building

f = flood frequency being investigated

i = time rate of money, interest = 6%

n = economic life structure = 20 years

R_{ave} = average annual cost of flood risk

The factor .620 is dependent on the assumptions of i = 6% and n = 20 years, and similar factors could be developed for different interests and economic lives.

To illustrate the relative magnitude of the cost of flood risks, Table I was developed. It assumes various flood frequencies and applies them to a \$10,000 initial structure cost. The derivation of the R_{ave} formula to include the data provided in Table I is summarized in the last section of this article.

TABLE I – Relative Magnitude of the Cost of Flood Risks

Flood Frequency	Initial Structure Cost – P	P/f	$R_{ave}(.620)$
1 year	\$10,000	10,000	\$6,200
5	10,000	2,000	1,240
10	10,000	1,000	620
15	10,000	667	413
20	10,000	500	310
30	10,000	333	207
40	10,000	250	155
50	10,000	200	124
100	10,000	100	62

Using the figures in the right-hand column of Table I, it is possible to quickly estimate the average cost of flood risk for any facility value (P). Simply multiply the listed R_{ave} (.620) figure by $P/10,000$. For instance, if a facility has a P value of \$45,000, the average annual cost of flood risk for a 20-year frequency would be: $R_{ave} = 45,000/10,000 \times .620 = \1395 per year.

The above calculations only give those costs of flood risks associated with the structures or improvements themselves – it does not include possible damage to or loss of the land. However, by using an appraisal value, and assuming no depreciation and total loss of value, a cost for risk to the land can also be determined. Simply use the original relationship $R_{ave} = P/f$ and add it to the R_{ave} value for the structures.

DERIVATION OF THE R_{ave} FORMULA

Using the basic equation, $R = P(1/f) = P/f$, described earlier, and retaining those inputs used in its formulation (i.e., R, P, f, i and n) let's assume that P is depreciating at a straight line rate for 20 years. For the first year $R = P/f$; for the following years P is decreased by the amount $P/20$ each year. Since the basic formula, $R = P/f$, is a simple product, R must also be decreasing each year by an amount equal to P/fn or $P/f \cdot 20$.

Using the general formula for summing a decreasing gradient,² the present worth (PW) of flood risks for 20 years is calculated as follows:

$$PW = R(pwf-6\%-20) - g(gpwf-6\%-20)$$

$$PW = P(pwf-6\%-20)/f - P(gpwf-6\%-20)/f \cdot 20$$

$$PW = P(11.47)/f - P(87.23)/f \cdot 20$$

$$PW = P(7.11)/f$$

Spreading the PW back over the 20 years, for an *average* annual cost of Flood Risk, gives:

$$R_{ave} = P(7.11) (crf-6\%-20)/f = P(7.11) (.08718)/f$$

$$R_{ave} = P(.620)/f$$

² Grant & Ireson, *Principles of Engineering Economy, Fourth Edition*, Page 69

Editor's Note: The procedure stated in the above article is not considered to be a precise solution. This article has encouraged the Division of Forest Economics and Marketing Research to develop a detailed computerized approach to this problem. We hope to publish the results in the near future.

