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APPENDIX F

TRAP EFFICIENCY OF RESERVOIRS

F-1. Introduction.

a. The trap efficiency of a reservoir can be defined as the percentage of the total inflowing sediment that is retained in the reservoir.

$$E - [Ys(in) - Ys(out)]/ Ys(in) \qquad (F-1)$$

where:

E = Trap efficiency expressed as decimal
Ys = Sediment yield in weight units
in = inflow
out - outflow

b. Trap efficiency is of particular importance when determining the annual sedimentation rate or capacity loss as expressed by the equation [9]:

$$C1 = EYs / C \qquad (F-2)$$

where:

C1 = annual sedimentation rate
E = trap efficiency, in percent
Ys = annual net sediment yield from the drainage area
C = original reservoir storage capacity in same units as Ys

c. As sediment is trapped, the reservoir storage capacity is decreased and in turn, the trap efficiency decreases. For practical purposes, the initial trap efficiency can be used as a constant up to 50 percent storage depletion; however, if storage depletion is rapid, the trap efficiency should be updated at time increments with an adjustment of C to reflect the sediment retained.

F-2. Factors Affecting Trap Efficiency.

a. Factors influencing the trap efficiency are hydraulic characteristics of the reservoir and sediment characteristics of the inflowing sediment. The hydraulic characteristics are (1) the ratio of storage capacity to inflow rate, (2) reservoir shape, (3) type of outlets, (4) and reservoir operation. The capacity-inflow ratio is a measure of retention time. The greater the retention time, the lower is the average transit velocity and associated turbulence, and greater the rate of deposition. The shape of the reservoir determines the effective retention time and could cause "short circuiting" in which the effective time becomes much less than the retention time as determined by the capacity-inflow ratio. This means that, because of the shape of the reservoir, portions of the pool have ineffective flow areas. Placement of bottom outlets, particularly if they are timely opened to pass density currents (also referred to as mud or gravity flows) out of the reservoirs, can reduce trap efficiency of clays. Lowering of the pool elevation decreases the retention time which subsequently decreases the trap efficiency. This can be very effective if done during periods of higher flows with its high sediment concentrations. Sluicing and reservoir operations are,

* however, limited by storage and environmental requirements.

b. Sediment characteristics affecting trap efficiency are (a) particle size distribution of the inflowing sediment load, (2) particle shape, and (3) the behavior of fine sediments under varying temperatures, concentration, water chemical composition, secondary currents, and turbulence. Grain size distribution and particle shape determine particle fall velocities, and in conjunction with water depth and detention time, determine the percentage of the sediment that deposits or remains in suspension. Fine sediments (clay and silt sizes) are usually the only sediments that remain in suspension long enough to reach the outlets. Temperature, concentration, and water chemical composition affect the aggregation properties of these fines which determine the resuspension of deposited sediments, and aid in transporting the fines closer to the dam.

F-4. Trap Efficiency Methods

a. Capacity-Watershed Method (Brown's Curve). Brown [9] developed a curve relating the ratio of reservoir capacity (C, in acre-ft) and watershed area (W, in square miles) to trap efficiency (E, in percent). This curve, shown in Figure F-1, can be represented by the following equation:

$$E = 100\ [\,1 - 1/(1 + KC/W)\,] \tag{F-3}$$

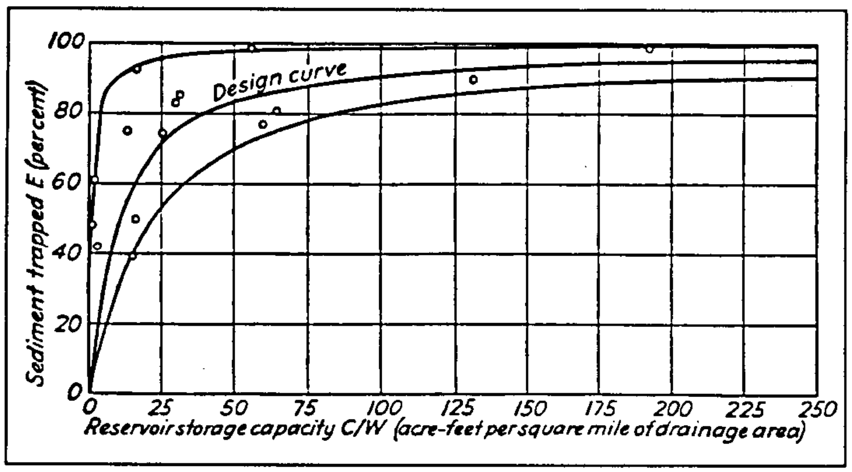

Figure F-1. Trap Efficiency Curve by Brown

The coefficient *K* ranges from 0.046 to 1.0 with a median value of 0.1. *K* increases (1) for regions of smaller and varied retention time (calculated using the capacity-inflow ratio), (2) as the average grain size increases, and (3) for reservoir operations that prevent release of sediment through sluicing or movement of sediment toward the outlets by pool elevation regulation. Variations are mainly due to the fact that reservoirs having the same *C/W* ratio can have different capacity-inflow ratios. Brown's curve is useful if the watershed area and reservoir capacity are the only parameters known.

b. Capacity-Inflow Method (Brune's Curve). Brune [10] developed an empirical relationship between trap efficiency and the ratio of reservoir capacity to mean annual inflow, both in the same volume units. Since the curves, Figure F-2, were generated by the use of data from normal ponded reservoirs, they are not recommended for use in determining trap efficiencies of de-silting basins or dry reservoirs. Dendy [16] added more data to Brunes's curve and developed a prediction equation for the median curve:

$$E = 100 * 0.97 ** 0.19 ** \log(C / I) \tag{F-4}$$

*

* or

$$E = 100\left(0.97^{0.19^{\log C/I}}\right)$$

The variations, as shown by the envelope curves, are due to the same factors that influence the *K* coefficient in Brown's curve; however, Brune's curve is considered to be more accurate than Brown's curve.

c. Sediment Index Method (Churchill's Curve).

(1) Churchill [13] 1948 presented a relationship relating sedimentation index (SI) to trap efficiency. The relationship, shown in Figure F-3, was developed using Tennessee Valley Authority Reservoir data. The sedimentation index of a reservoir is the period of retention divided by the reservoir mean velocity. If the retention time or mean velocity cannot be obtained from field data, approximation can be made by assuming the effective retention time to be equal to the retention time as computed by using the *C/I* ratio. The period of retention (*R*, in seconds) can then be computed by obtaining the capacity (*C*, in cubic feet) of the reservoir at the mean operating pool elevation and dividing by the average daily inflow rate (*I*, in cubic feet per second). The mean velocity (*V*, in feet per second) is obtained by dividing the average daily inflow rate by the average cross-sectional area (*A*, in feet squared) in which the average cross-sectional area is obtained by dividing the capacity by the reservoir length (*L*, in feet, at the mean operating pool elevation). This can be written mathematically as:

$$S.I. = R/V \tag{F-5}$$

$$R = C / I \tag{F-6}$$

$$V = I / A \tag{F-7}$$

$$A = C / L \tag{F-8}$$

$$S.I. = CA/I^2 = (C/I^2)\ (C/L) = (C/I)^2/L \tag{F-9}$$

*

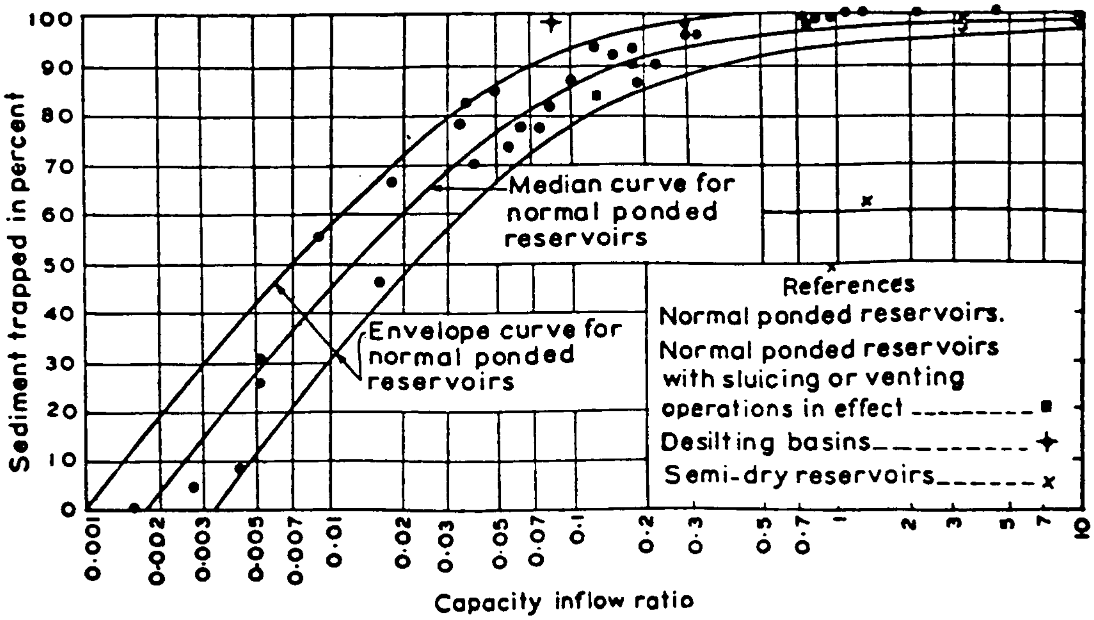

Figure F-2. Trap Efficiency Curve by Brune [10)

(2) The S.I. can be reduced to the C/I ratio squared divided by the reservoir length. It must be noted that Churchill's relationship has "percentage of incoming silt passing through reservoir" on the ordinate, which necessitates determining the difference between the value obtained and 100% to get the trap efficiency. The term "silt" on the ordinate axis meant all the size classes of sediment when Churchill developed this relationship.

d. Comparison of Methods. Brown's method is the simplest relationship because it requires only the reservoir capacity and watershed area. If the annual inflow rate is known, Brune's curves were generally more accurate. Churchill's method requires the additional information of reservoir length. It must be noted that none of these methods include an analysis of sediment characteristics; therefore, judgment must be exercised in the use of these methods if these characteristics have a significant effect on the deposition qualities of the reservoir being analyzed.

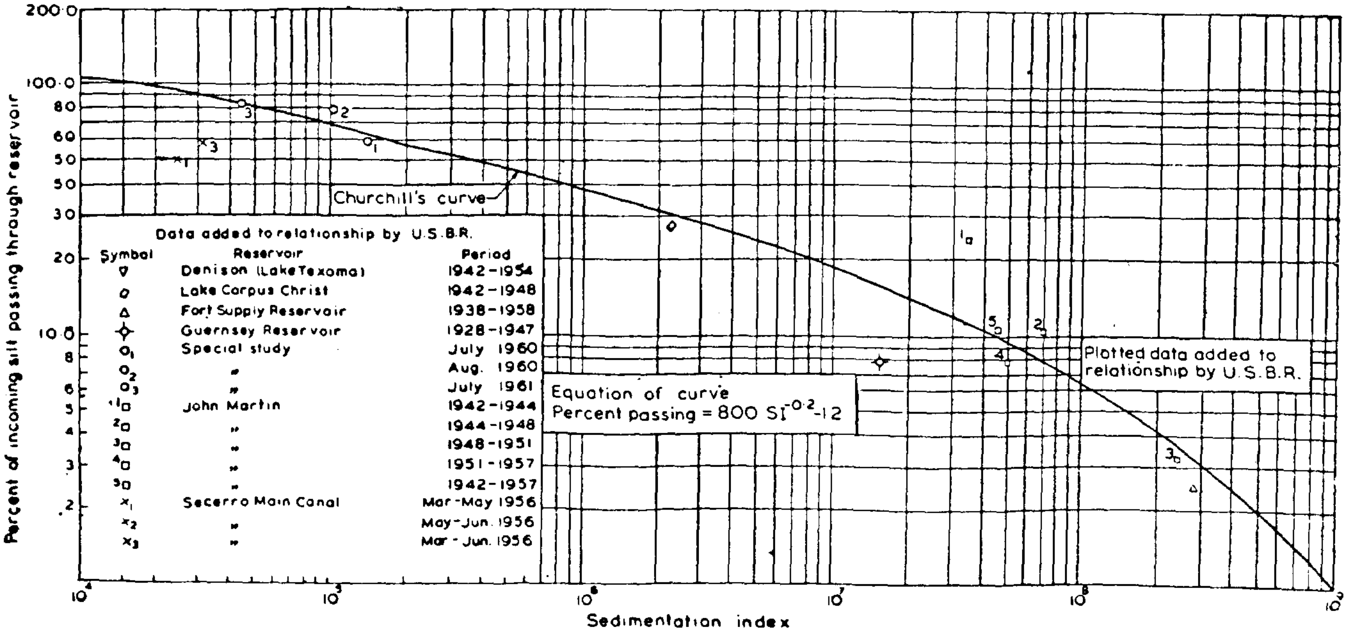

Figure F-3. Trap Efficiency Curve by Churchill [13]

F-4. Example Application.

a. Pertinent Data:

(1) Reservoir: J. Percy Priest Reservoir, Stones River, Tennessee

(2) Capacity: (Summer power and recreation pool elevation) 392,000 acre-ft

(3) Inflow rate: 1,070,400 acre-ft/year

(4) Watershed Area: 892 square miles

(5) Length: L = 41.8 miles (220,700 feet)

b. Brown's Method

Assume K = 0.1

C/W = 392,000/892
= 439.5

E = 100 [1 - 1/(1 + (0.1)(439.5))]
= 100 [1-0.022]
= 97.8%

c. Brune's Method

Assume median curve C/I = 392,000/1,070,400
= 0.366

E = 100 x 0.97**[0.19**Log(0.366)]
= 100 x 0.97**[2.066]
= 93.9%

d. Churchill's Method

C = 392,000 acre-ft x 43,560 cu ft/acre-ft
= 1.708 * 10**10 cu ft

I = 1,070,400 acre-ft/year * 43,560 cu ft/acre-ft
= 4.66266 * 10**10 cu ft/year

converting to cubic feet per second

= 4.66266 * 10**10 cu ft/year x 1 year/3.1536 x 10**7 sec
= 1478.52 cu ft/sec

C/I = [1.708 * 10**10] / 1,478.52
= 1.1549 * 10**7

S.I. = [(C/I)**2] / L
= [(1.1549 * 10**7)**2] / 220,700
= 6.044 * 10**8

From Figure F-3 Percent of "silt" passing = 1.4%

E = 100 - 1.4
= 98.6%

or from the equation shown on Figure F-3:

```
Percent of "silt" passing = [800(SI)**-0.2] - 12.0
                          = [800(6.044 * 10**8)**-0.2] - 12.0
                          = 2.0%

                        E = 100 - 2.0
                          = 98.0%
```