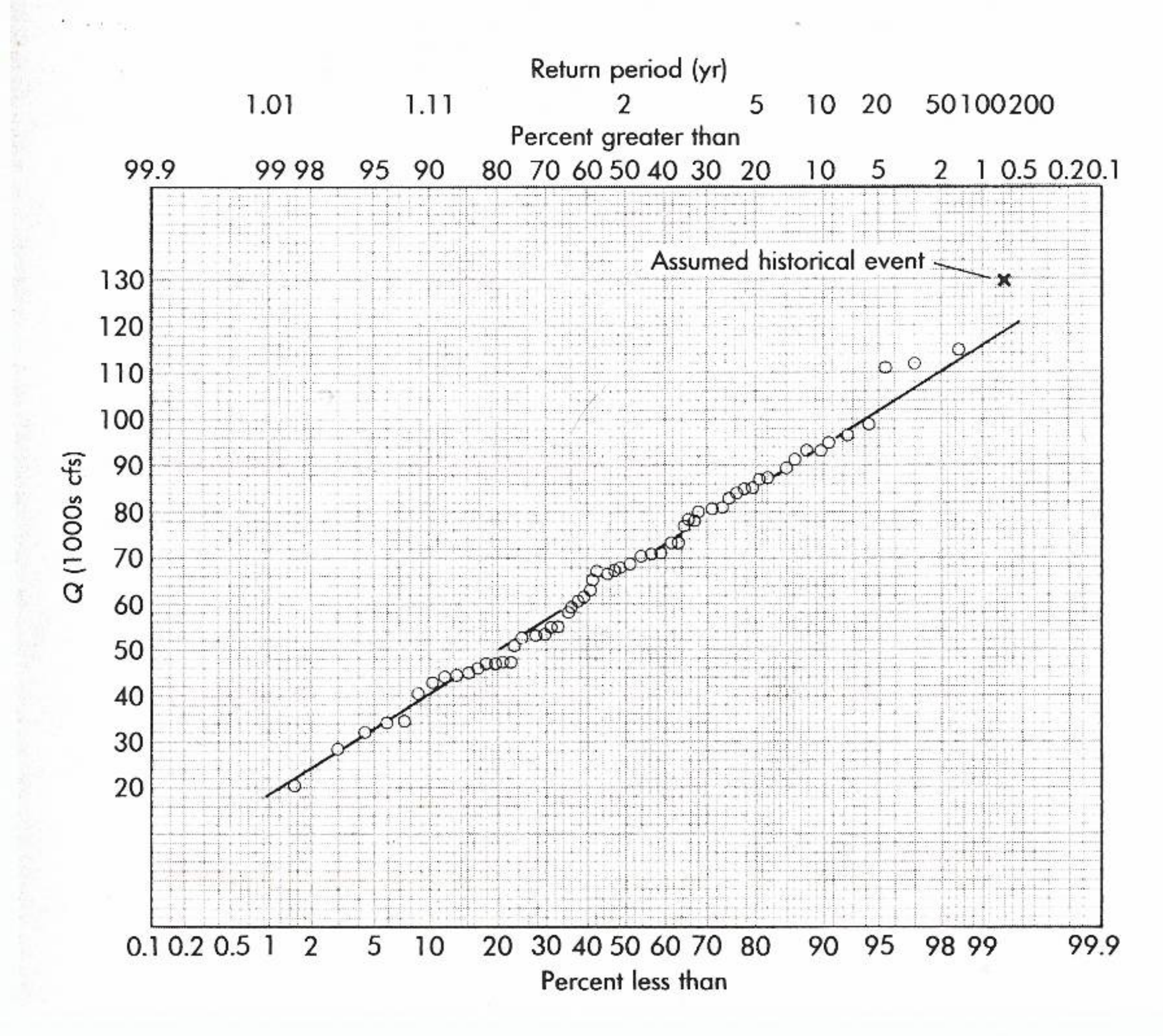
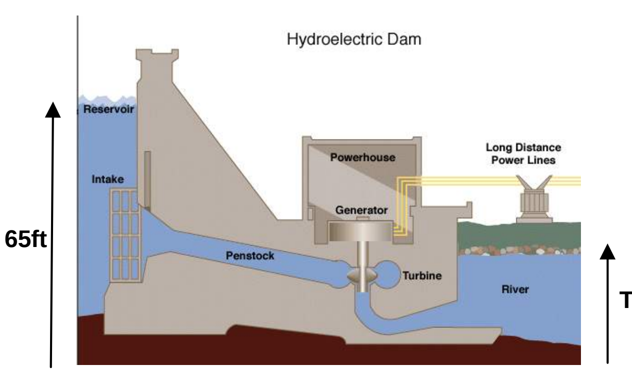
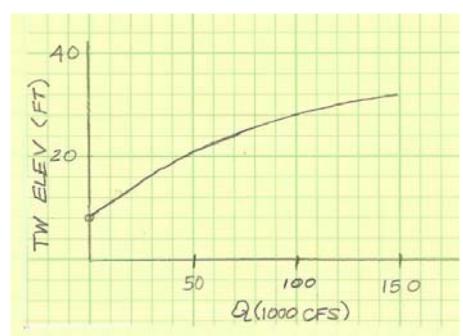
PROBLEM 1

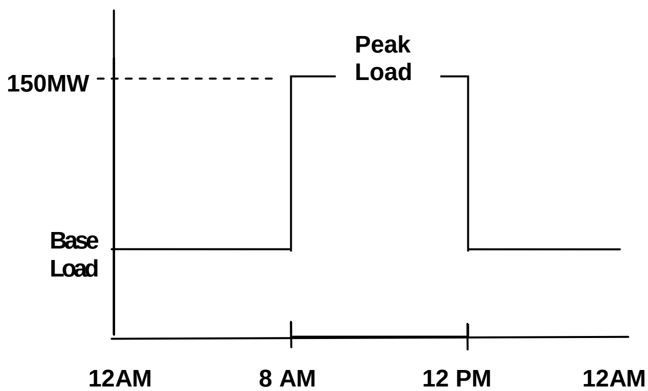
A dam with a run-of-river hydroelectric plant is planned for the Big River. (Run-of-river projects maintain a fairly constant pool elevation and pass the inflows through the power plant.) The historical stream flows at the dam site are shown here. It is proposed to have a dam with typical water surface elevation at elevation 65.0 ft. The head loss through the power plant is estimated to be 0.0001Q (in units of feet). The powerplant efficiency is 0.70. The tailwater elevation as a function of Q is shown in the rating curve below. Determine the firm energy and secondary energy that can be expected annually. Show all work.







PROBLEM 2
Assuming the power plant in Problem 1 will be designed to meet a peak industrial load of 150MW for 8 hours per day with firm energy, what base load will be met? Show all your calculations and assumptions.



PROBLEM 3
The Dendy and Bolton formula (see below) provides an estimate of sediment yield for basins up to 30,000 sq miles in area. Use this formula to find the annual yield of a river basin that is 425 sq km in area. What is the annual volume of sediment yield, assuming the sediment has average specific weight of 13kN/m^3?

Sediment Yield versus Drainage Area. Dendy and Bolton studied sedimentation data from about 1500 reservoirs, ponds, and sediment detention basins. In developing their formulas, they used data from about 800 of these reservoirs with drainage areas greater than or equal to 1 mi^2. The smaller watersheds—those of drainage area less than 1 mi^2—were excluded because of their large variability of sediment yield, reflecting the diverse effects of soils, local terrain, vegetation, land use, and agricultural practices.

For drainage areas between 1 and 30,000 mi^2, Dendy and Bolton found that the annual sediment yield per unit area was inversely related to the 0.16 power of the drainage area:

$$\frac{S}{S_R} = \left(\frac{A}{A_R}\right)^{-0.16} \qquad (15\text{-}10)$$

in which S = sediment yield in tons per square mile per year; S_R = reference sediment yield corresponding to a 1-mi^2 drainage area, equal to 1645 tons per year; A = drainage area in square miles; and A_R = reference drainage area (1 mi^2).

PROBLEM 4 – for 5838 Credit only
A reservoir with storage capacity of 30 hm^3 will be developed at the bottom of the basin in Problem 3. The mean annual runoff at the site is 345mm over the basin. Using the sediment yield found in Problem 3, and assuming a fine-grained sediment,

a) How long will it take for the reservoir to lose 80% of its storage volume?
b) How long will it take for the reservoir to fill up with sediment?

(Use the technique provided in Example 15-10 from Ponce on the following pages.)

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Sediment deposition occurs in the vicinity of reservoirs, typically as shown in Fig. 15-16 [20]. First, deposition of the coarser-size fractions takes place near the entrance to the reservoir. As water continues to flow into the reservoir and over the dam, the delta continues to grow in the direction of the dam until it eventually fills the entire reservoir volume. The process is quite slow but relentless. Typically, reservoirs may take 50 to 100 y to fill, and in some instances, up to 500 y or more.

The rate of sediment deposition in reservoirs is a matter of considerable economic and practical interest. Since reservoirs are key features of hydroelectric and water-resource development projects, the question of the design life of a reservoir is appropriate, given that most reservoirs will eventually fill with sediment. In an extreme example, the filling can occur in a single storm event, as in the case of a small sediment-retention basin located in a semiarid or arid region. On the other hand, the reservoir can take hundreds of years to fill, as in the case of a large reservoir located in a predominantly humid or subhumid environment.

Reservoir Trap Efficiency

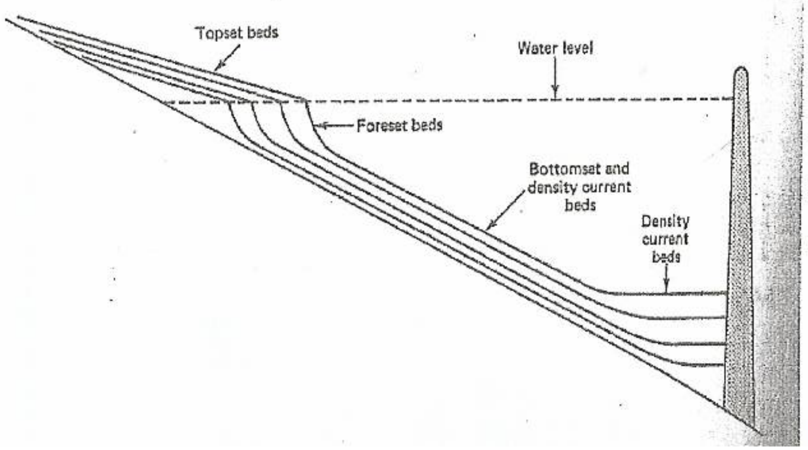
The difference between incoming and outgoing sediment is the sediment deposited in the reservoir. The incoming sediment can be quantified by the sediment yield, i.e., the total sediment load entering the reservoir. The outgoing sediment can be quantified by the *trap efficiency*. Trap efficiency refers to the ability of the reservoir to entrap sediment being transported by the flowing water. It is defined as the ratio of trapped sediment to incoming sediment, in percentage, and is a function of (1) the ratio of reservoir volume to mean annual runoff volume and (2) the sediment characteristics.

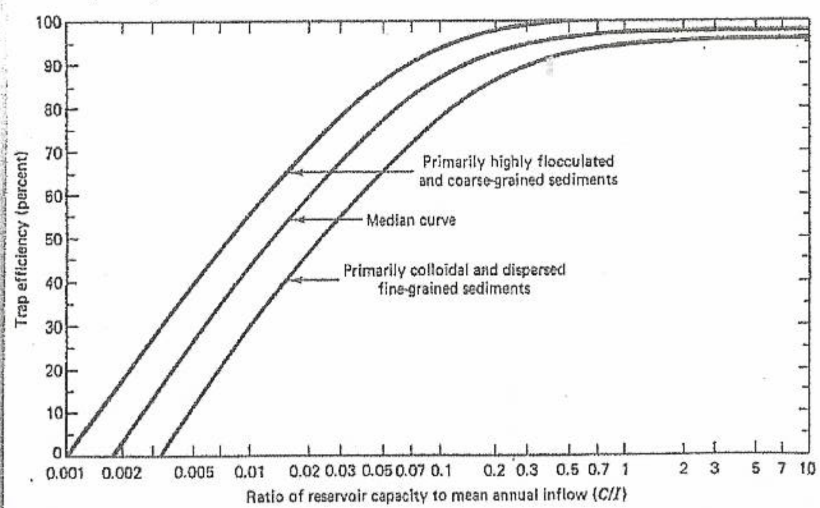
The following procedure is used to determine trap efficiency [41]:

1. Determine the reservoir capacity C in cubic hectometers or acre-feet.
2. Determine the mean annual (runoff volume) inflow I to the reservoir, in cubic hectometers or acre-feet.
3. Use Fig. 15-17 to determine the percentage trap efficiency as a function of the ratio C/I for any of three sediment characteristics. Estimate the texture of the incoming sediment by a study of sediment sources and/or sediment transport by size fractions. The upper curve of Fig. 15-17 is applicable to coarse sands or flocculated sediments; the middle curve, to sediments consisting of a wide range of particle sizes; and the lower curve, to fine silts and clays.

Reservoir Design Life

The design life of a reservoir is the period required for the reservoir to fulfill its intended purpose. For instance, structures designed by the Soil Conservation Service for watershed protection and flood prevention programs have a design life of 50 to 100 y. Due to reservoir sedimentation, provisions are made to guarantee the full-design reservoir water-storage capacity for the planned design life. This may entail either (1) cleaning out reservoir sediment deposits at predetermined intervals during the life of the structure or, as is more often the case, (2) providing a reservoir storage capacity large enough to store all the accumulated sediment deposits without encroachment on the designed water-storage volume. Typically, calculations of sediment-filling rates and sediment accumulation are part of the design of reservoir-storage projects.





Distribution of Sediment Deposits

The distribution of sediment deposits may be such as to materially affect the operation and maintenance of the dam and reservoir. The amount and types of sediment deposits vary with the nature of the sediment itself, the shape of the reservoir, the topography of the reservoir floor, the nature of the approach channel, detention time, and purpose of the reservoir. The coarser sediment sizes are the first to deposit in the vicinity of the reservoir entrance. Finer sediment sizes are able to travel longer distances inside the reservoir and deposit at locations close to the dam. However, very fine sediments are usually uniformly distributed in the reservoir bed.

Sediment-retention, or Debris, Basins

Sediment-retention basins, or debris basins, are small reservoirs located in upland areas with the specific purpose of trapping sediment and debris before they are able to reach the main fluvial network system. *Debris* is a general term used to describe the assortment of cobbles, boulders, branches, and other vegetative material that may clog channels and hydraulic structures, causing them to reach a critical design condition prematurely and often resulting in structural failure.

Debris basins are placed upstream of channels or reservoirs with the specific purpose of temporary detainment of debris. Debris basins are usually small and designed to be cleaned out from time to time. Some basins are sized to fill up during one or two major storms. Others may have a 50- or 100-y design life. Project costs and site conditions determine the size of debris basins.

Sediment-yield determinations for debris basin design should include both short-term and long-term analyses. The long-term sediment yield is determined from the appropriate sediment rating curve. For infrequent storms, however, sediment concentrations may exceed long-term averages by a factor of 2 or 3 [40].

Example 15-10.

A planned reservoir has a total capacity of 10 hm^3 and a contributing catchment area of 250 km^2. Mean annual runoff at the site is 400 mm, annual sediment yield is 1000 metric tons/km^2, and the specific weight of sediment deposits is estimated at 12,000 N/m^3. A sediment source study has confirmed that the sediments are primarily fine-grained. Calculate the time that it will take for the reservoir to fill up with sediments.

The calculations are shown in Table 15-9. Because of decreased reservoir capacity as it fills with sediment, an interval of storage equal to $\Delta V = 2$ hm^3 is chosen for this example. Column 2 shows the loss of reservoir capacity, and Col. 3 shows the accumulated sediment deposits. The mean annual inflow to the reservoir is 400 mm $\times$ 250 km^2 = 100 hm^3. Column 4 shows the capacity-inflow ratios at the end of each interval, and Col. 5 shows the average capacity-inflow ratios per interval. Column 6 shows the trap efficiencies T_i obtained from Fig. 15-17 using the curve for fine-grained sediments (lower curve). The annual sediment inflow I_s is:

$$I_s = \frac{1000 \text{ ton/km}^2\text{/y} \times 1000 \text{ kg/ton} \times 250 \text{ km}^2 \times 9.81 \text{ N/kg}}{12{,}000 \text{ N/m}^3 \times 10^6 \text{ m}^3\text{/hm}^3} \qquad (15\text{-}25)$$

$$I_s = 0.204 \text{ hm}^3\text{/y}$$

TABLE 15-9 SEDIMENT ACCUMULATION IN RESERVOIRS: EXAMPLE 15-10

(1) Interval i	(2) Reservoir capacity C (hm^3)	(3) Accumulated volume (hm^3)	(4) C/I ratio	(5) Average C/I in interval	(6) Trap efficiency T_i (%)	(7) Number of years to fill (y)
0	10	0	0.10			
1	8	2	0.08	0.09	77	13
2	6	4	0.06	0.07	72	14
3	4	6	0.04	0.05	66	15
4	2	8	0.02	0.03	55	18
5	0	10	0.00	0.01	30	33
Total						93

The number of years to fill each ΔV interval is $\Delta V/[I_s(T_i/100)]$, shown in Col. 7. The sum of Col. 7 is the total number of years required to fill up the reservoir: 93 y.

15.5 SEDIMENT MEASUREMENT TECHNIQUES

The measurement of fluvial sediments is often necessary to complement sediment yield and sediment transport studies. The accuracy of the measurement, however, is dependent not only on the equipment and techniques but also on the application of basic principles of sediment transport.

As sediment enters a stream or river, it separates itself into bed-material load and wash load. In turn, the bed-material load is transported as either bed load or suspended load. The suspended bed-material load plus the wash load constitutes the total suspended-sediment load of the stream or river.

The term *sampled suspended-sediment discharge* is used to describe the fraction of suspended-sediment load that can be sampled with available equipment. Generally, it excludes the *unsampled suspended-sediment discharge*, i.e., the fraction of suspended-sediment load that is carried too close to the stream bed to be effectively sampled. The suspended-sediment discharge is the sum of sampled and unsampled suspended-sediment discharges.

Sediment-sampling Equipment

Sediment-sampling equipment can be classified as the following:

1. Suspended-sediment samplers, which measure suspended-sediment concentration
2. Bed-load samplers, which measure bed load
3. Bed-material samplers, which sample the sediment in the top layer of the stream bed