METU
NORTHERN CYPRUS CAMPUS

CVE 471
WATER RESOURCES ENGINEERING

RESERVOIRS

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Overview

- **Introduction**
- Characteristics of Reservoirs
- Determination of Reservoir Capacity
  - Mass Curve Analysis
    - Determination of reservoir capacity for a known yield
    - Determination of yield from a known reservoir capacity
  - Sequent Peak Analysis
  - Operation Study
  - Other Approaches in Capacity Determination
- Reservoir Sedimentation

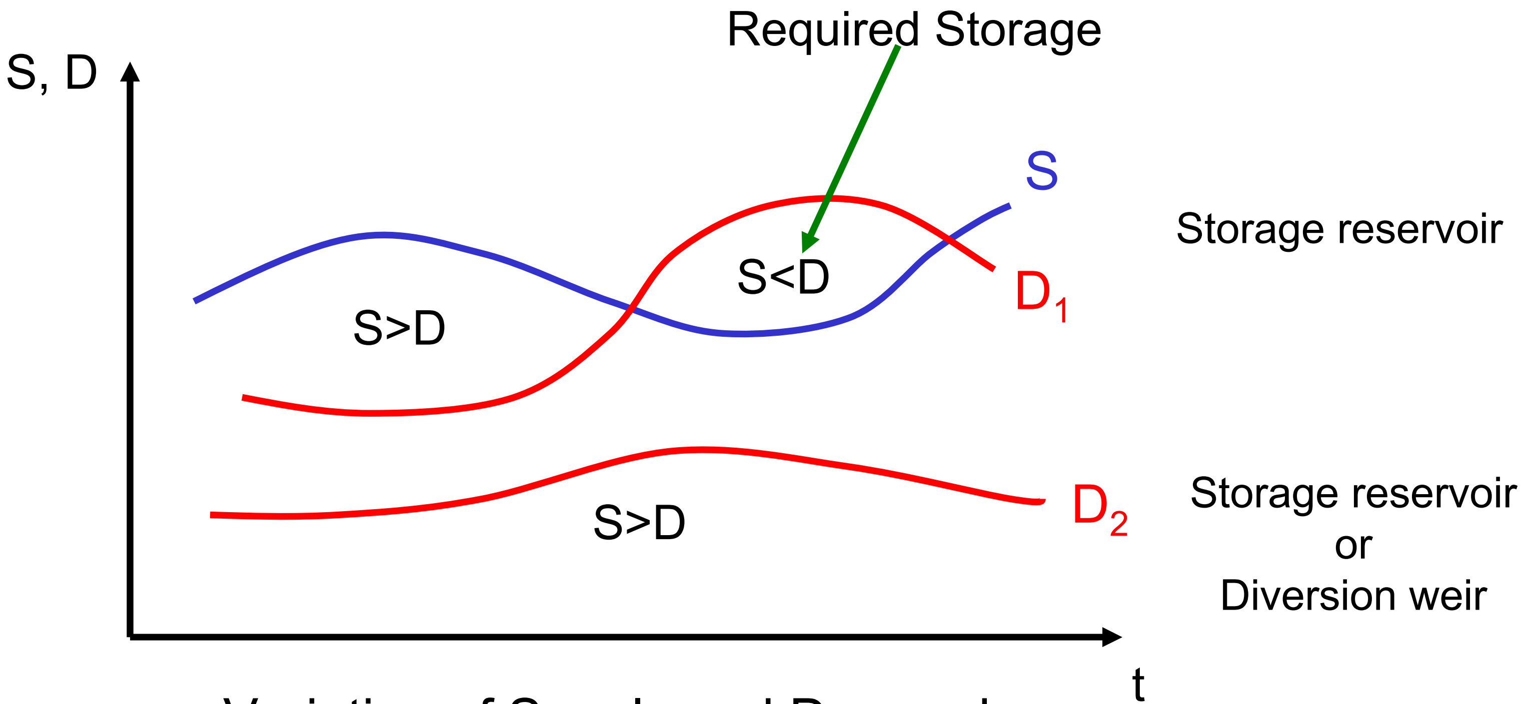
Introduction

- Reservoirs are structures that store water.
- In general, we observe high flow in winter and low flow in summer, and very high values in spring months or snowmelt seasons in Northern Hemisphere.
- On the other hand, the water demand is high in summer and low in winter.
- Therefore, the regulation of the streamflow is required to meet the demands.
- This regulation is possible by constructing reservoirs in the stream.

Introduction

(continued)

- When the total supply of water (ΣS) is sufficient to meet the total demand (ΣD) during a specified period of time, the water storage is required when S<D.



Variation of Supply and Demand

Introduction

(continued)

- There are number of purposes of constructing reservoirs
  - Irrigation,
  - Sediment accumulation,
  - Transportation,
  - Electricity generation,
  - Water supply (municipal and industrial)
  - Flood control, and
  - Recreational.
- They are also used to supply emergency water like fire fighting or stabilize pressures in the network.

Introduction

(continued)

- Reservoirs can be divided into two main categories according to their storage capacities:
  - Storage (conservation) reservoirs
  - Distribution (service) reservoirs

- Formation of a big reservoir behind a dam may have various environmental aspects.
  - For example:
    - For the construction of Keban Dam in Turkey,
      - ≈30,000 people were dislodged, and
      - 300 km road,
      - 48 km railway, and
      - A large area were expropriated.

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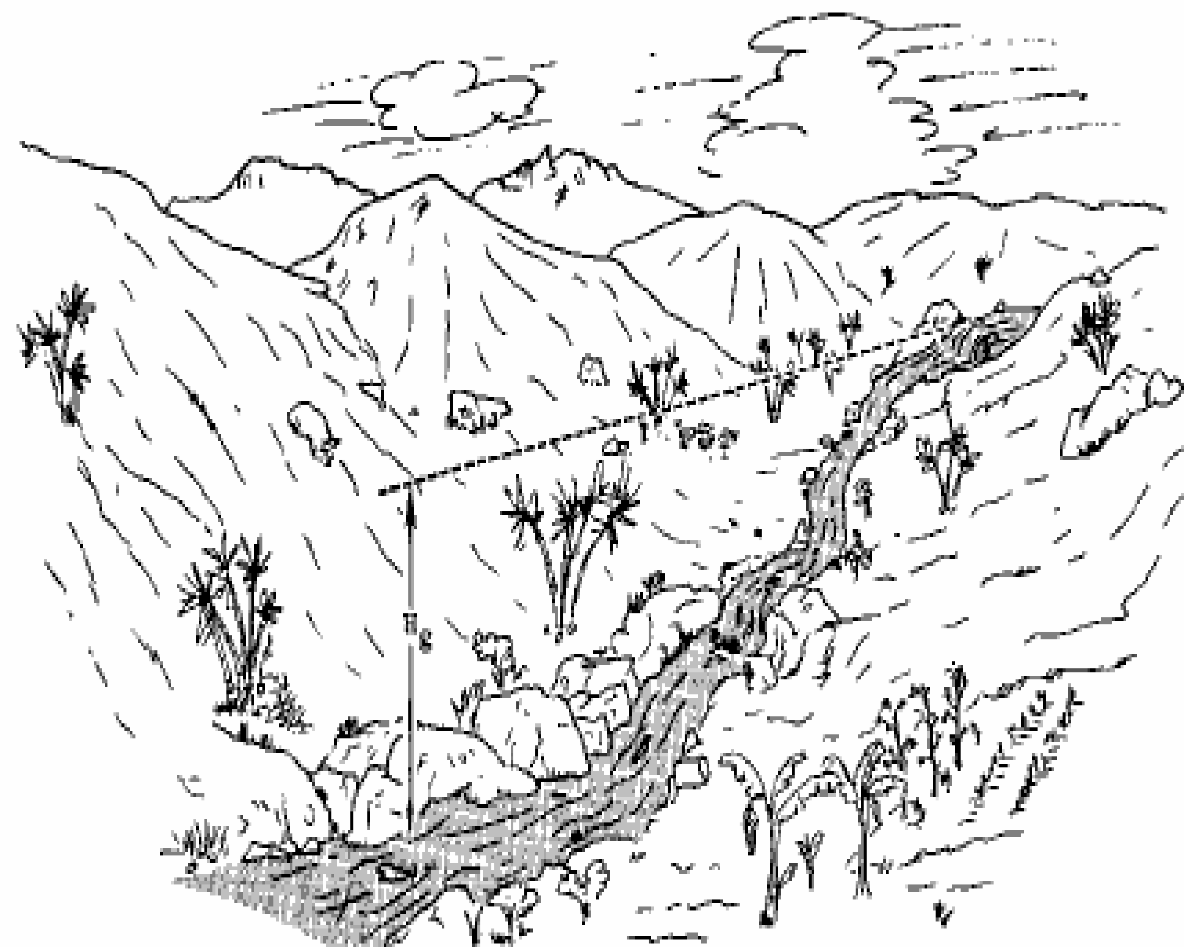
Characteristics of Reservoirs



Potential for a Hydropower Reservoir

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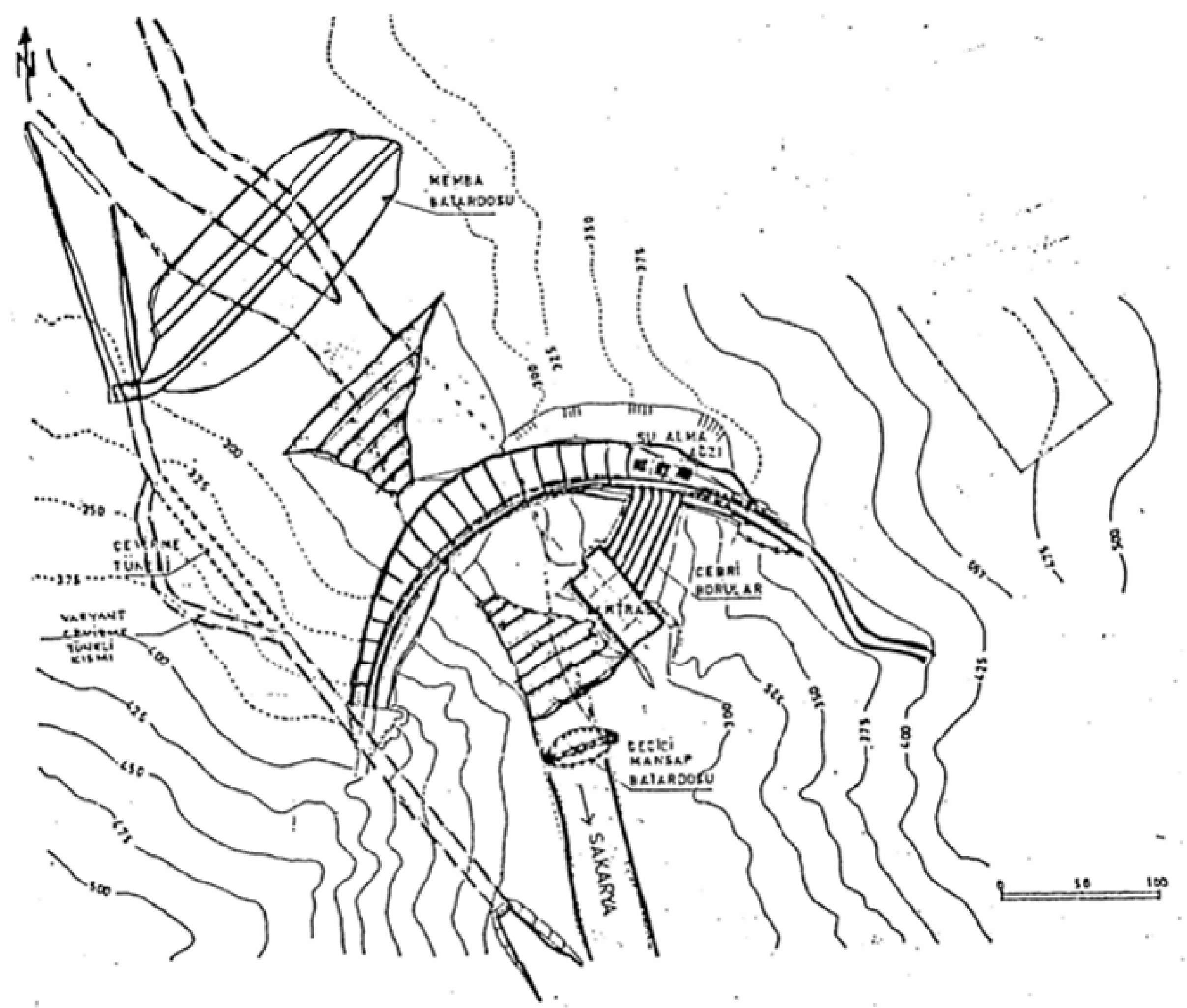
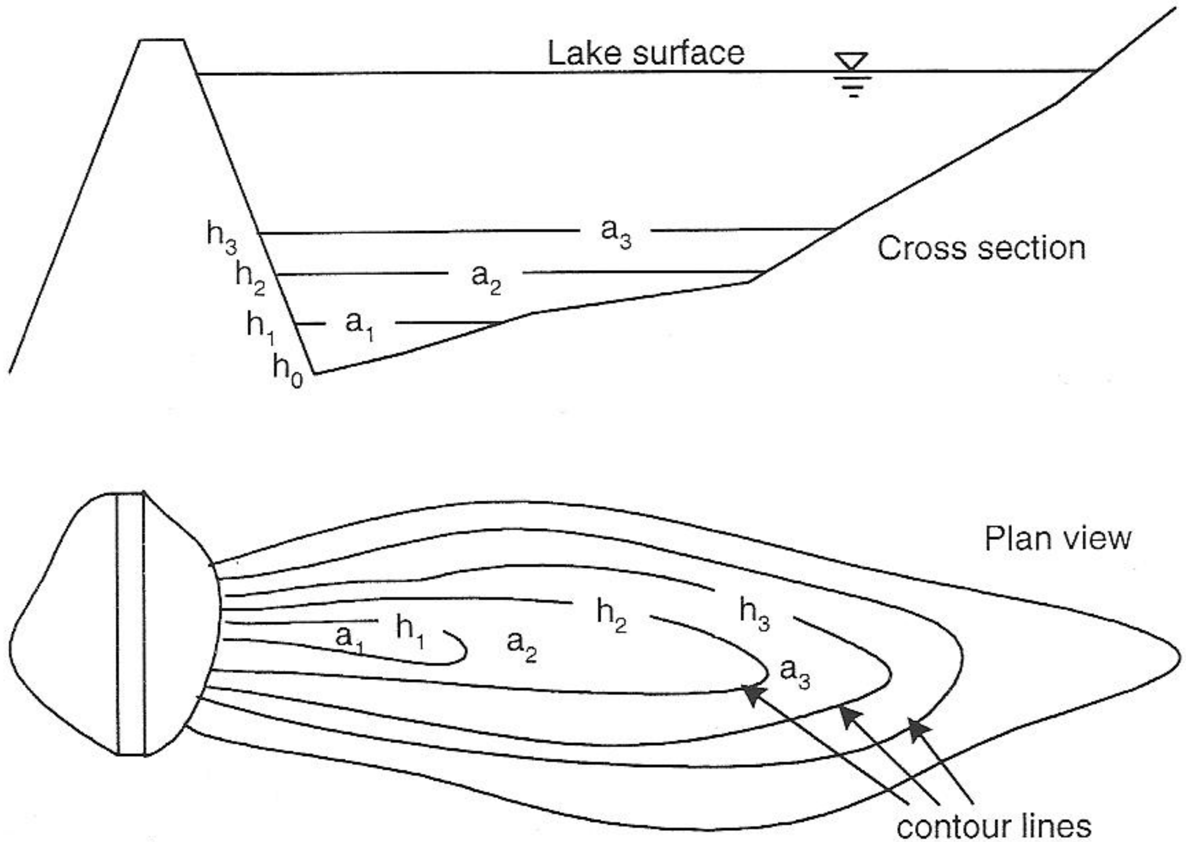
Characteristics of Reservoirs *(continued)*



Characteristics of Reservoirs *(continued)*



Characteristics of Reservoirs *(continued)*

- The capacity of the reservoir is very important since the main function of the reservoir is the storage of the water.

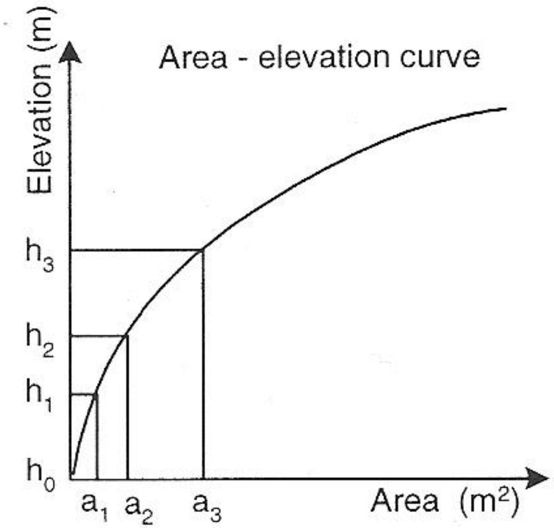
- The desired yield, *which is the amount of water delivered from a reservoir to meet downstream requirements*, must be available most of the time.

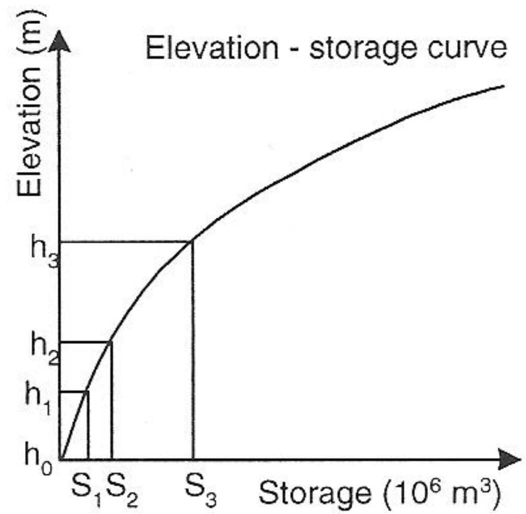
- For an ideal reservoir site:
  - Sufficient impervious and sound formation (bed and side)
  - Deep and narrow valley (less evaporation, low cost of expropriation)

Characteristics of Reservoirs *(continued)*

- After the determination of location of a reservoir, a special topographic map (1:5000 scaled) of the reservoir area is obtained with suitable contour intervals and
  - Elevation - Area Curve, and
  - Elevation – Storage Curve are obtained.

Characteristics of Reservoirs *(continued)*



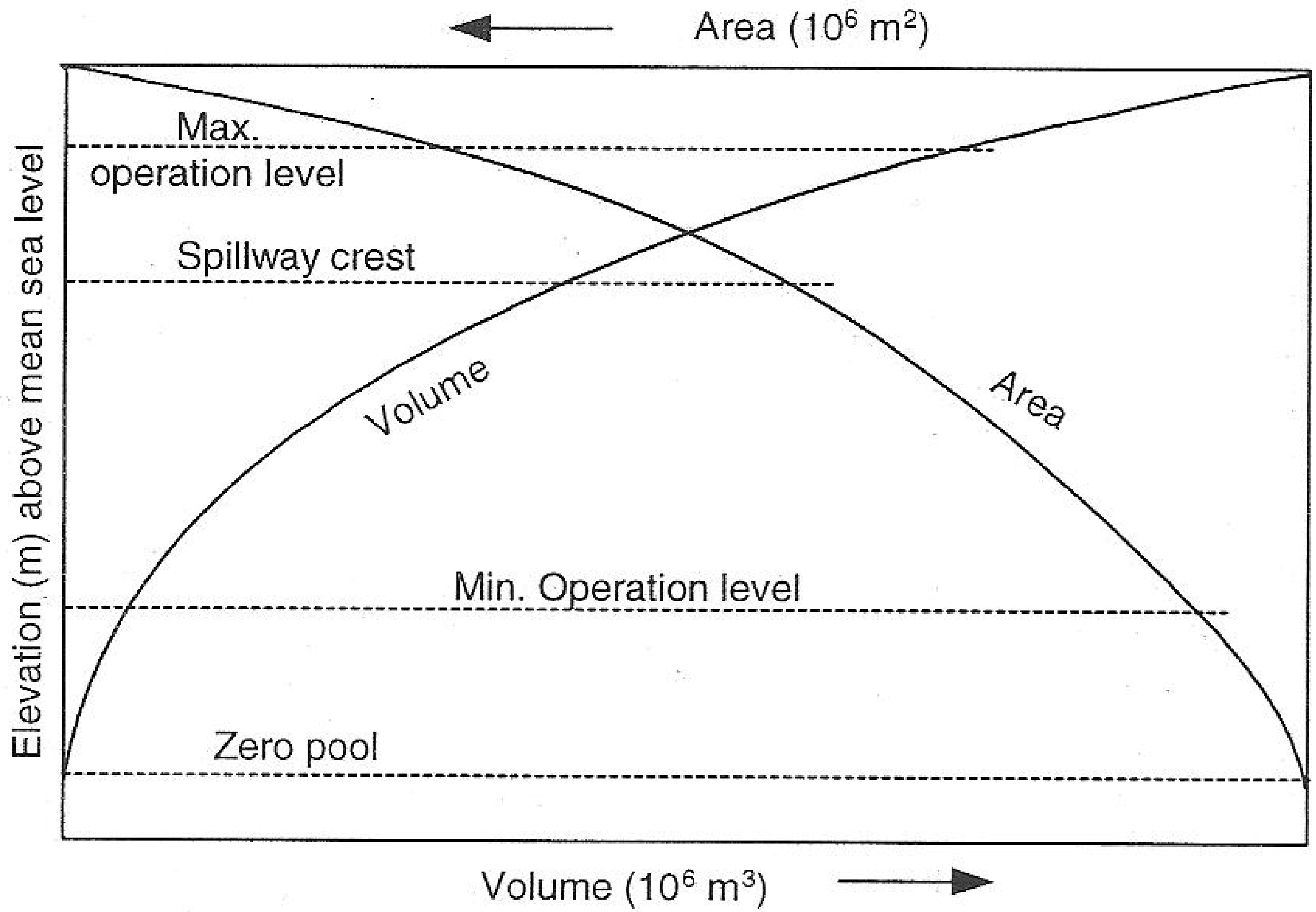


$$V_1 = \frac{a_1 (h_1 - h_0)}{2} \qquad S_1 = V_1$$

$$V_2 = \frac{a_1 + a_2}{2}(h_2 - h_1) \qquad S_2 = V_1 + V_2$$

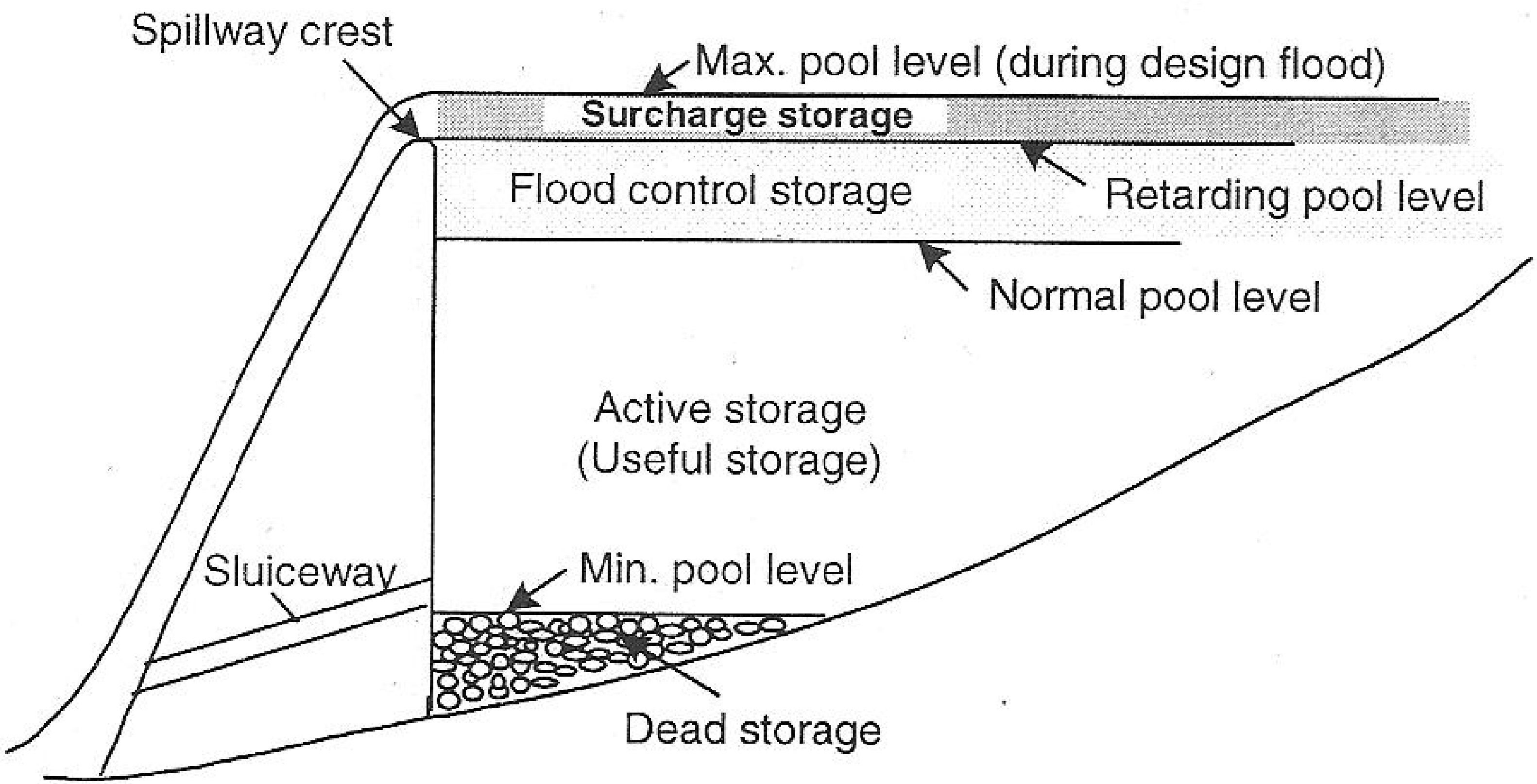
$$V_3 = \frac{a_2 + a_3}{2}(h_3 - h_2) \qquad S_3 = V_1 + V_2 + V_3$$

Characteristics of Reservoirs *(continued)*



Elevation – Area – Volume Curves for a reservoir

Characteristics of Reservoirs *(continued)*



Storage characteristics of a reservoir

Characteristics of Reservoirs *(continued)*

Hydropower Reservoir

Overview

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Determination of Reservoirs Capacity

- The **yield** of a reservoir is defined as the quantity of water, which is supplied for a certain duration.
- The duration may change with the purpose of the reservoir.
  - A few years → Large reservoirs
  - Week
  - Day
  - Hour
- The yield is a function of
  - the inflow, and
  - the capacity of the reservoir.

Determination of Reservoirs Capacity

(continued)

- Safe Yield (Firm Yield): The amount of water that is supplied for a critical period. It is a guarantied amount during this critical period.
- Critical Period: The duration of lowest flow observed in the records of the stream.
- Depending upon the length of the flow critical period may change so the safe yield.
- Yield is not calculated certainly. The probability must be used.
- During the periods of high flow there will be extra available water, more than the safe yield which is called secondary yield.

Determination of Reservoirs Capacity

(continued)

- Average Yield: The arithmetic average of the safe and secondary yields over a long period.
- There is a risk involved for a reservoir.
- The amount of risk depends on the purpose of the reservoir.
- Target Yield: The yield determined based on the estimated demands for a reservoir.

Determination of Reservoirs Capacity

(continued)

- For the determination of reservoir capacity, the critical period must be determined first.
- A long period of observed flow is required.
- When short period of observed flows or no observations area available stochastic methods are used to generate synthetic flows that has the same statistical properties such as mean, variance, correlations etc.

Determination of Reservoirs Capacity

(continued)

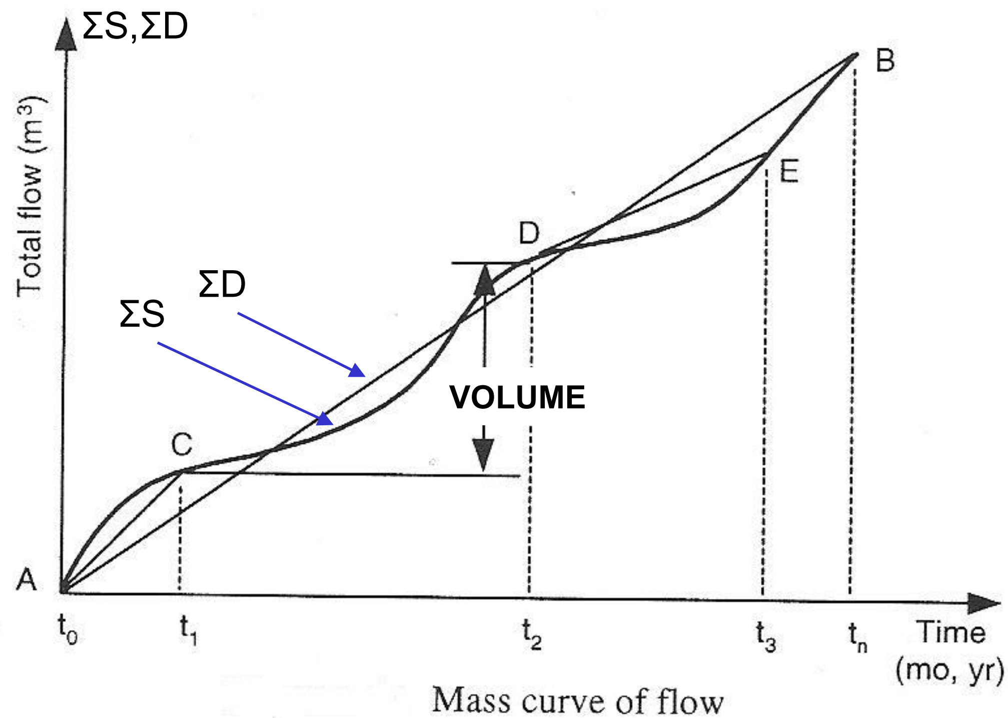
- There are four different methods to determine the capacity if a reservoir.
  - Mass Curve (Ripple diagram) Method,
  - Sequent Peak Algorithm,
  - Operation Study, and
  - Other Approaches (Stochastic Methods and Optimization Analysis etc…).

Determination of Reservoirs Capacity

(continued)

1. Mass Curve Analysis (Ripple Diagram Method, 1883)

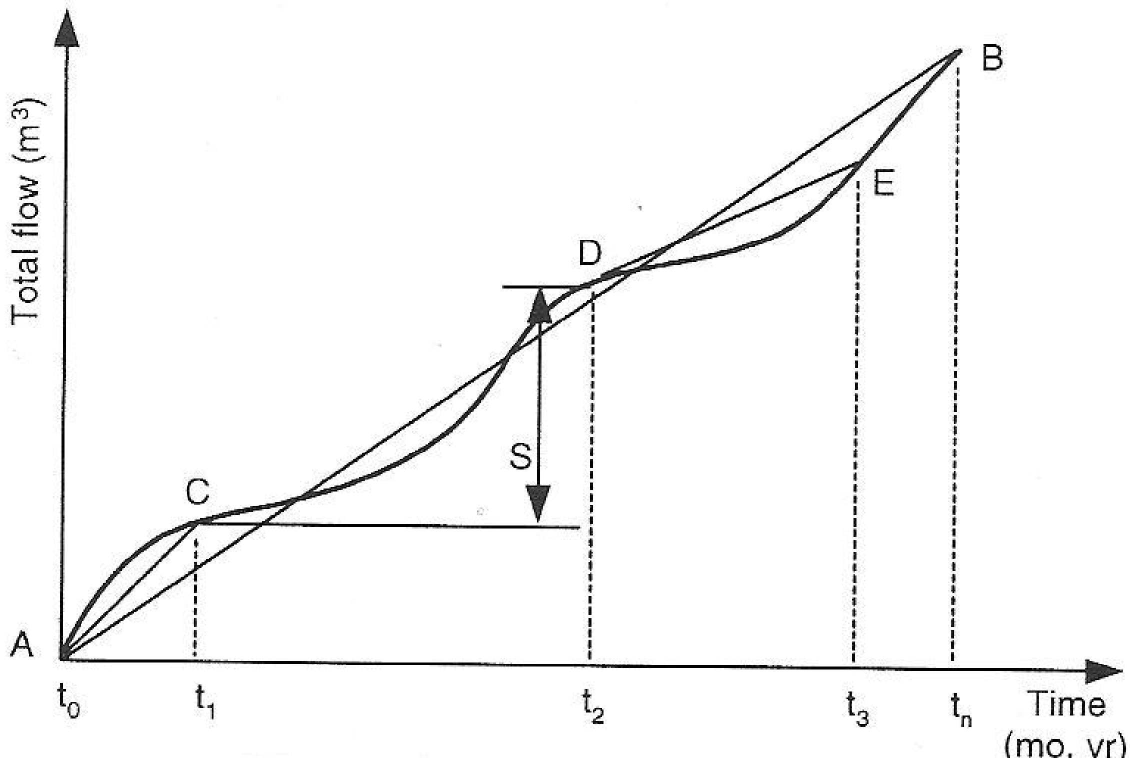
- One of the most widely used methods.
- Assumptions:
  - Demand is constant, and,
  - the year repeats itself continuously.



Determination of Reservoirs Capacity

(continued)

1. Mass Curve Analysis (Ripple Diagram Method, 1883)



Mass curve of flow

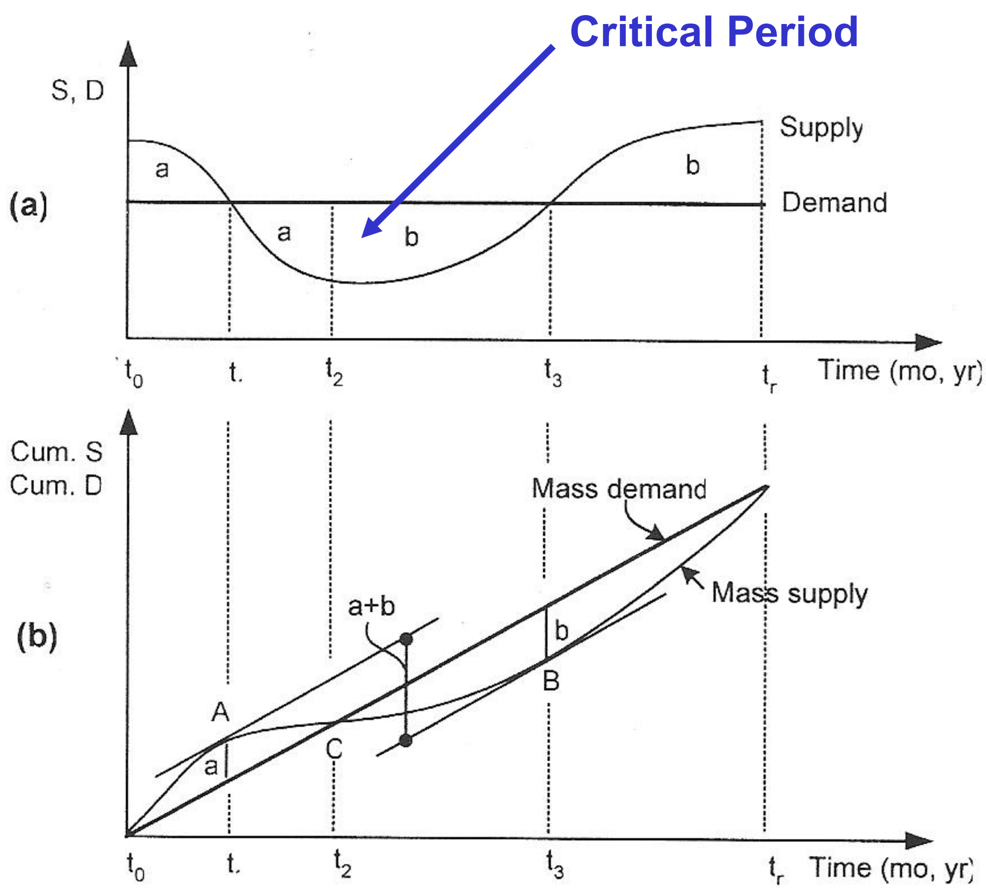
If the flow is the daily or monthly discharge then the area under the curve up to a certain time will be the volume of runoff for that period.

The slope of the mass curve at a certain time gives the discharge at that time on the hydrograph

Determination of Reservoirs Capacity

(continued)

1. Mass Curve Analysis (Ripple Diagram Method, 1883)



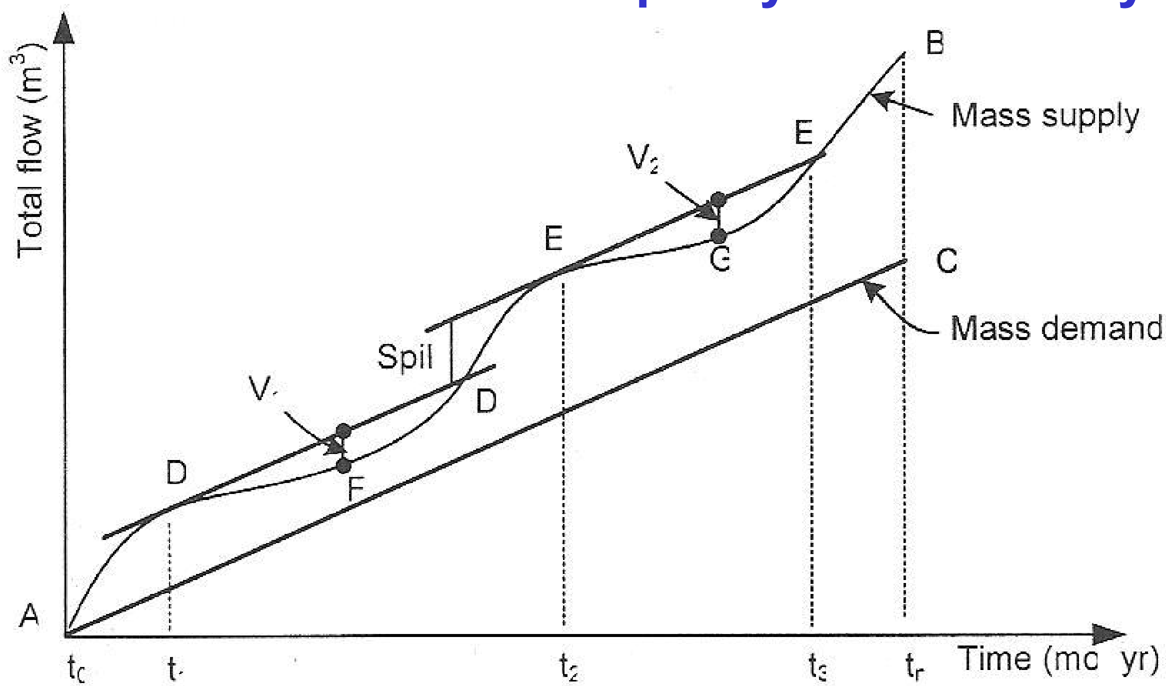
Required storage capacity of the reservoir is the vertical difference a+b

Determination of Reservoirs Capacity

(continued)

1. Mass Curve Analysis (Ripple Diagram Method, 1883)

a. Determination of capacity for a known yield



The reservoir would be full at points D, D’, E, and E’.

The reservoir would be empty at points F and G.

1. The tangents, which are parallel to the demand line, are plotted at the high points (D and E).

2. The maximum departures from the tangents to the following low points of the mass curve (F and G) determine the necessary storage amounts V_1 and V_2.

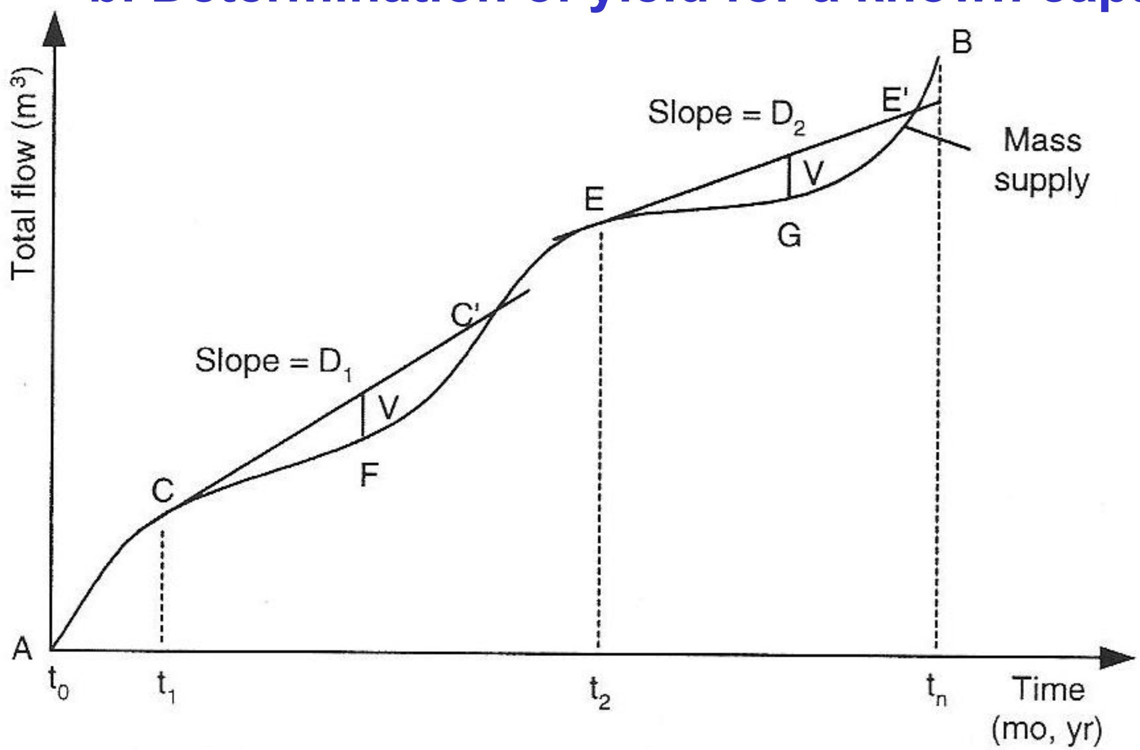
3. The largest one of the volumes will give the required capacity of the reservoir.

Determination of Reservoirs Capacity

(continued)

1. Mass Curve Analysis (Ripple Diagram Method, 1883)

b. Determination of yield for a known capacity



1. The value V of known reservoir capacity is placed vertically in all the low points in the mass curve and tangents are drawn to the previous high points.

2. The slope of these tangents (D_1 and D_2) indicate the yields that can be supplied for those critical periods with this given capacity.

3. The smallest one of the yields can be supplied all the time.

The plotted tangents must cut the mass curve when extended forward, as it is the case here with points C' and E'. Otherwise, the reservoir will not refill.

Determination of Reservoirs Capacity

(continued)

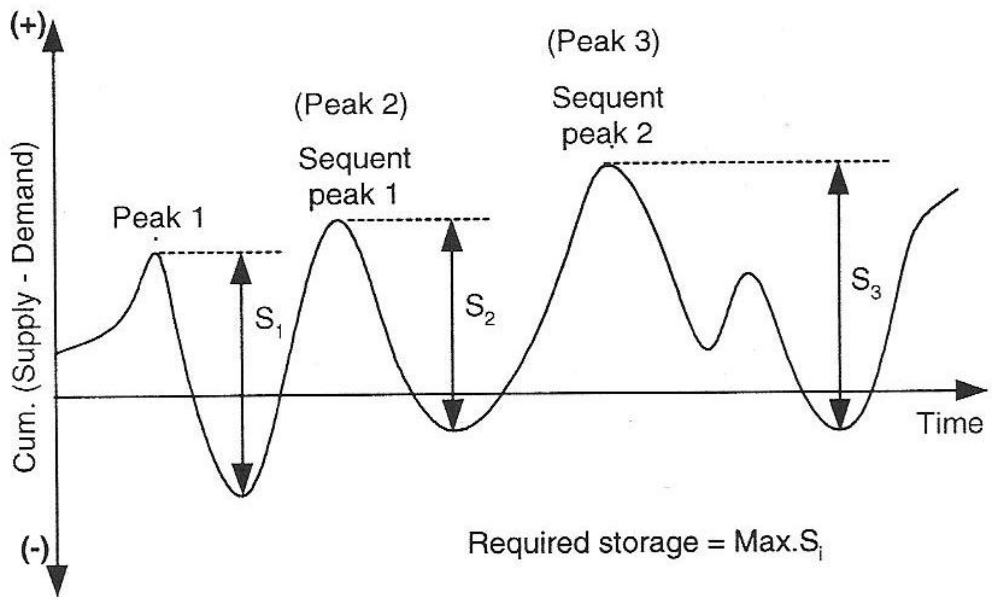
- The mass curve gives results if $\Sigma D < \Sigma S$ during the period of record.
- The graphical approach is quite satisfactory if the reservoir releases are constant during the period of analysis.
- When reservoir releases vary, the sequent-peak analysis is recommended.

Determination of Reservoirs Capacity

(continued)

2. Sequent Peak Analysis

Sequent Peak Analysis is more suitable when the data of long observation periods or long generated data are used, or when the demand is not constant.



1. Differences between inflows (S) and demands (D) are calculated and their summations obtained.

2. Σ(S-D) values are plotted against time as shown in the figure.

3. On this plot the first peak value and next larger peak (sequent peak) are determined.

4. The storage required between these two points is the difference between the first peak and the lowest point in this period.

5. This process is repeated for all the peaks in the record period as shown in the figure also. The maximum of the storage values is the required capacity.

Determination of Reservoirs Capacity

(continued)

2. Sequent Peak Analysis

- If the record period or generated data sequence is very long, the graphical solution may be time consuming.
- In that case and **analytical solution** procedure may be applied for the analysis and it can be solved easily using a computer.
- In this way, the required storage V_t at the end of a period t can be expressed as:

$$V_t = \begin{cases} D_t - S_t + V_{t-1} & \text{if positive} \\ 0 & \text{otherwise} \end{cases}$$

- At the beginning of the analysis, initially V_{t-1} is set to zero and calculations continue to find V_t values for **up to twice** the length of the record period.
- The maximum of all the calculated values of V_t is the required storage capacity.

Determination of Reservoirs Capacity

(continued)

3. Operation Study

- The reservoir storage is considered as adequate when the reservoir can supply all types of demands under possible losses like seepage and evaporation.
- In order to increase the operational performance of a reservoir, the evaporation and seepage must be controlled.
- The operation of a storage reservoir is also governed by the inflow.
- Rule curves indicating temporal storage requirements according to local conditions and project demands need to be used for effective operation purposes.

Determination of Reservoirs Capacity

(continued)

3. Operation Study

- Rules:
  - During normal periods of river flow, the reservoir will be maintained at the normal pool level.
  - If extremely high flows are expected, the normal pool level can be drawn to such an elevation that the maximum expected flood flow will be sufficient to restore the active storage to its maximum level.
  - In the case of higher flows induced by snowmelt, there is often enough time to empty the full content of the active pool prior to the arrival of the flood flows.

Determination of Reservoirs Capacity

(continued)

3. Operation Study

- The operation study is based on the solution of the continuity equation.

$$\frac{dV}{dt} = I - Q$$

where dV: differential storage during time dt

I: instantaneous total inflow

Q: instantaneous total outflow

- An operation study may be carried out only for a period of extremely low flows (critical period) or entire period of record.

Determination of Reservoirs Capacity

(continued)

3. Operation Study

- Since the information concerned the time variation of inflow and outflow is normally limited, then long term (e.g. one month) averaged quantities of inflow and outflow are considered in practice:

$$\frac{\Delta V}{\Delta t} = \bar{I} - \bar{Q}$$

where ΔV: the change in storage during time interval Δt.

$\bar{I}$: the average inflow (runoff, precipitation etc…) during Δt

$\bar{Q}$: the average outflow (evaporation, seepage, controlled outflows, mandatory releases, uncontrolled spills etc…) during Δt.

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Reservoir Sedimentation

- River carry some suspended sediment and move the larger solids along the stream bed (bed load).
- Suspended sediment and bed load are deposited as a delta at the head of the reservoir.
- Reservoir sedimentation directly affects the lifetime of a dam.
- However, mechanics of reservoir sedimentation is highly complicated.
- Therefore, in practice, sediment load measurement are carried out in streams and calibration curve (stream discharge, Q – suspened load, Q_s) is developed.
- The United States Bureau of Reclamation (USBR) recommends a sampling period of at least 5 years.

Reservoir Sedimentation

(continued)

- By examining the basin data of 16 different dams in Turkey, Göğüş and Yalçınkaya (1992) recommended the following best-fit equation for the annual sediment yield having a correlation coefficient of 0.89:

$$Y = 1906.26\, A_d^{0.953}$$

where Y: the mean annual sediment yield (m^3).

A_d : the drainage area (km^2).

Reservoir Sedimentation

(continued)

- Trap Efficiency: The percentage of the inflowing sediment which is retained in a reservoir.
- Trap efficiency is a function of the ratio of the reservoir capacity to total inflow.
- The trap efficiency of a reservoir decreases with age as the reservoir capacity is reduced by sediment accumulation.
- Actually, it is very difficult to predict the sediment accumulation
  - almost zero accumulation during low flows
  - extremely large accumulation during floods

Reservoir Sedimentation

(continued)

- In order to increase the lifetime of a reservoir, the rate and nature of sediment inflow to a reservoir can be controlled to a certain extend.

- This may be accomplished by:
  - using upstream sedimentation basins,
  - providing vegetative screens,
  - soil conservation methods, such as terraces, strip cropping, etc.
  - use of upstream by-pass channels,
  - design sluice gates at various levels to discharge suspended sediment,

- Irrespective of how well the above measures are taken, all reservoirs are eventually filled with sediment. However, the filling period may be extended.