Engineering Hydrology

Week-12

CHAPTER- 6 RESERVOIR CAPACITY DETERMINATION

Sisay Demeku Derib (PhD, PE)
Sisay.demeku@aastu.edu.et
Addis Ababa Science and Technology University (AASTU),
Department of Civil Engineering
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Lecture contents of the last weeks (Week- 10 &-11)

CHAPTER-5 STOCHASTIC HYDROLOGY

5.1 Introduction.

5.2 Time Series

5.3 Analysis of Hydrologic Time Series

5.4 Time Series Synthesis

5.5 Some Stochastic Models

Home assignment:

I hope you are sure you area able to exercise on:

- Analysis of hydrologic time series
- Compare some stochastic models

Lecture contents of the week (Week-12)

CHAPTE- 6 RESERVOIR CAPACITY DETERMINATION

6.1 Mass Curve (Ripple's) Method:

6.2 Design Reservoir Capacity and Sediment Inflow

6.3 Sediment Load

Lecture Learning Outcomes

Course Learning Outcomes: After completion of this Lecture, you will be able to:

CLO-1: Apply measurement techniques of the components of the hydrologic cycle, water balance and filling of missed data;

CLO-2: Examine rainfall-runoff relationship and hydrograph;

CLO-3: Examine the probability of occurrence;

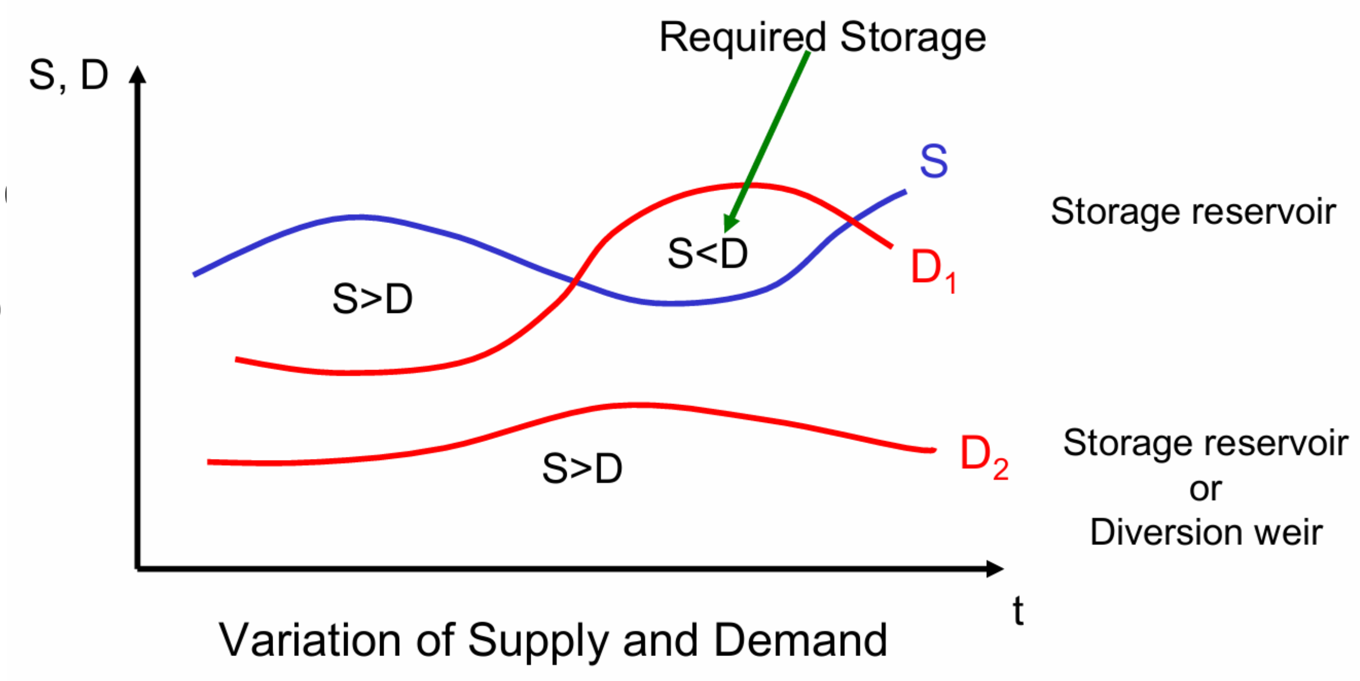
CLO-4: Analyze the water movement in to, over, and through the soil surface;

CLO-5: Design capacity of reservoir;

CLO-6: Design runoff volume and time of distribution of the runoff hydrograph from urbanization effect.

Reservoirs

- Are structures that store water
- Used to balance supply and deman
- When the total supply of water (ΣS) sufficient to meet the total demand (ΣD) during a specified period of time, the water storage is required when S<D.



Storage requirement: S-supplu and D-demand
Source: Bertuğ Akıntuğ (Undated): PPT of Middle East Technical University

Reservoirs

- 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.

Reservoirs

Reservoir capacity determination

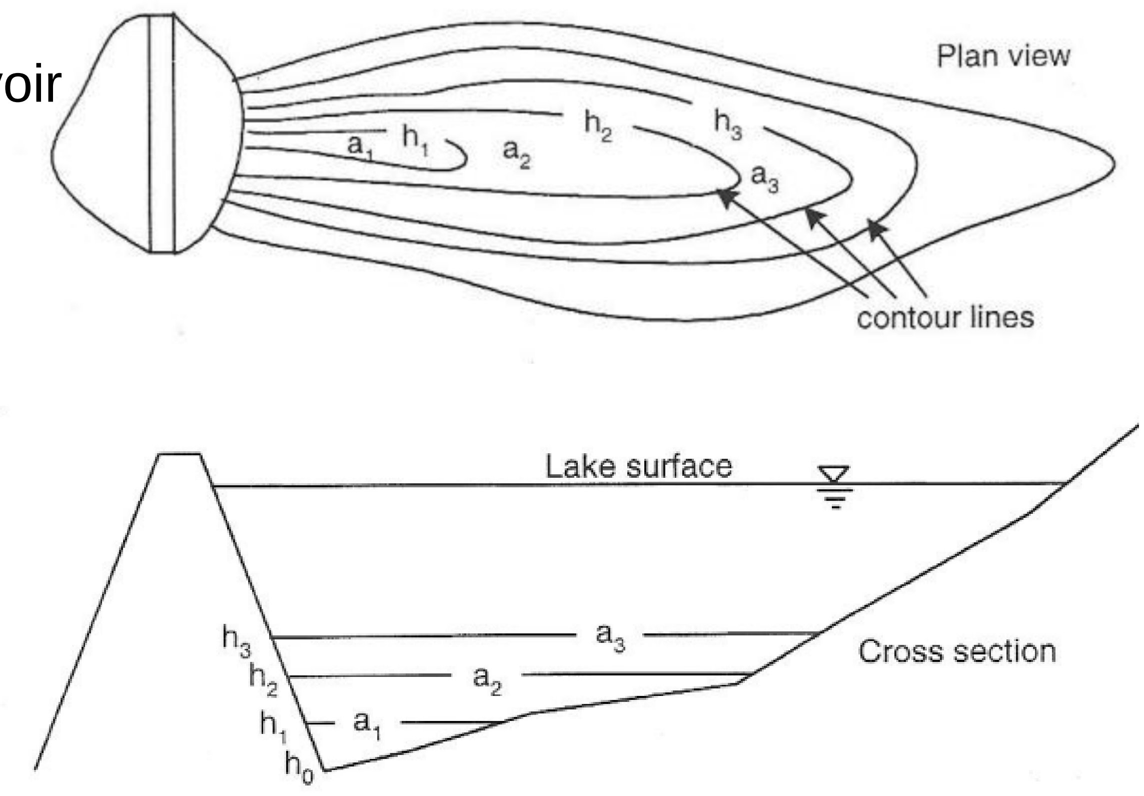
- It involves calculating the amount of water a reservoir can hold to meet a specified demand or yield, considering factors like inflow and demand.

A reservoirs has **two categories**:

- Storage (conservation) [i.e., GERD dam]
- Flood control reservoir
- Distribution (service) [for emergencies and fire fighting]
- OR natural and man-made

Physical **characteristics of reservoirs**

- Primary function is to store
- Most important characteristic: “Storage **Capacity**"



Plan and cross-sections view
Source: Bertuğ Akıntuğ (Undated): PPT of Middle East Technical University

Storage (conservation) reservoir

1. Storage (conservation) Reservoir

- Stores water during high flow of the rainy season to use during low flow of dry season.
- Used mainly for irrigation, hydropower, domestic and industrial supply.
- However, it can be used for multipurpose of single purpose.

2. Flood control reservoir

- Used to reduce the damage of flood
- Stores flood temporarily and release it slowly
- Also called “flood prevention/protection/mitigation reservoir”
- It requires spillways and sluice gates for controlled release.
- They are categorized as retarding reservoirs and detention basins.

Storage (conservation) reservoir

3. Distribution reservoir

- Is used to meet water supply demand of a community.
- Water may be released much more than the inflow to the reservoir.
- Water is pumped to the reservoir during little or no demand for storage.
- Stored water is released and distributed to customers according to the rate of the demand.

Application of reservoir

- Power generation
- Irrigation
- Domestic and industrial water supply
- Fishing, boating, aquatic habitat,
- Control flood

Reservoirs

GERD: Ethiopia

Gibe-III Dame: Ethiopia
https://www.pietrangeli.com/wp-content/uploads/2021/12/398-DJI_0488.jpeg

Service reservoir: Addis Ababa

Reservoirs

- The reservoir capacity is a term used to represent the reservoir storage capacity.

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

- Its determination is performed using historical inflow records in the stream at the proposed dam site.

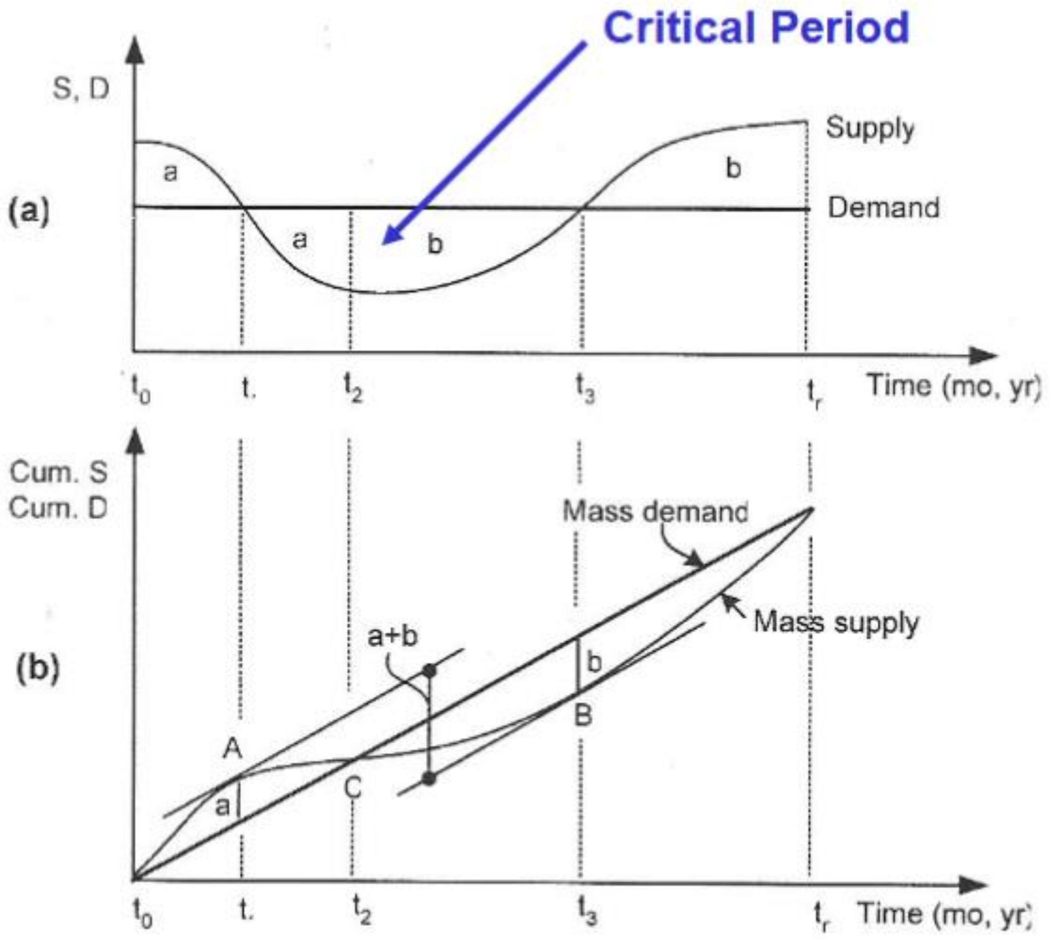
- The desired yield, which is the amount of water delivered from a reservoir to meet downstream requirements, must be available most of the time
- Ideal reservoir site:
  - Impervious and sound bed and side formation
  - Deep and narrow valley (less evaporation, low cost of expropriation)

Reservoirs capacity

- There are several methods to determine a reservoir storage capacity.
- The capacity of a reservoir is determined to meet the water demand.

Common methods to determine the capacity of a reservoir:

1. Mass curve (Ripple diagram) method,
2. Sequent peak algorithm,
3. Operation study, and
4. Other approaches (Stochastic methods and optimization analysis etc…).



Mass-Curve analysis

Source: Bertuğ Akıntuğ (Undated): PPT of Middle East Technical University

Mass curve (ripple's) method

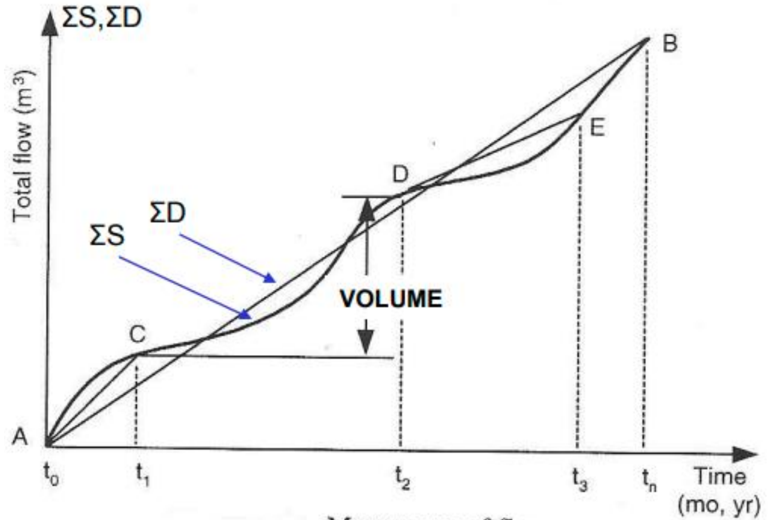
- It is the most widely used methods.
- **A mass curve** (or mass inflow curve) is a plot of **accumulated** flow in a stream against time.

Assumptions applied:

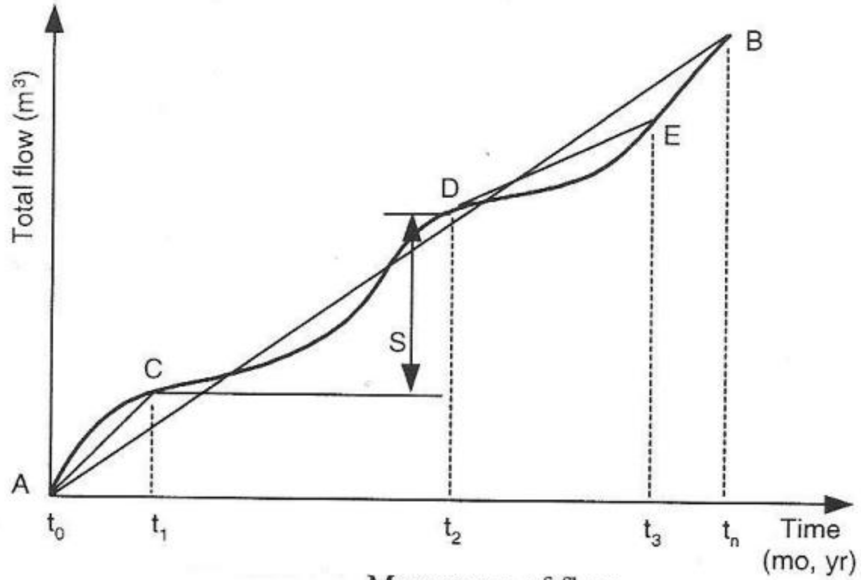
i. Demand is **constant**, and

ii. The year **repeats itself** continuously.

- **The area** under the curve up to a certain time (daily/monthly) will be **the volume** of runoff for that period.



Mass curve of flow



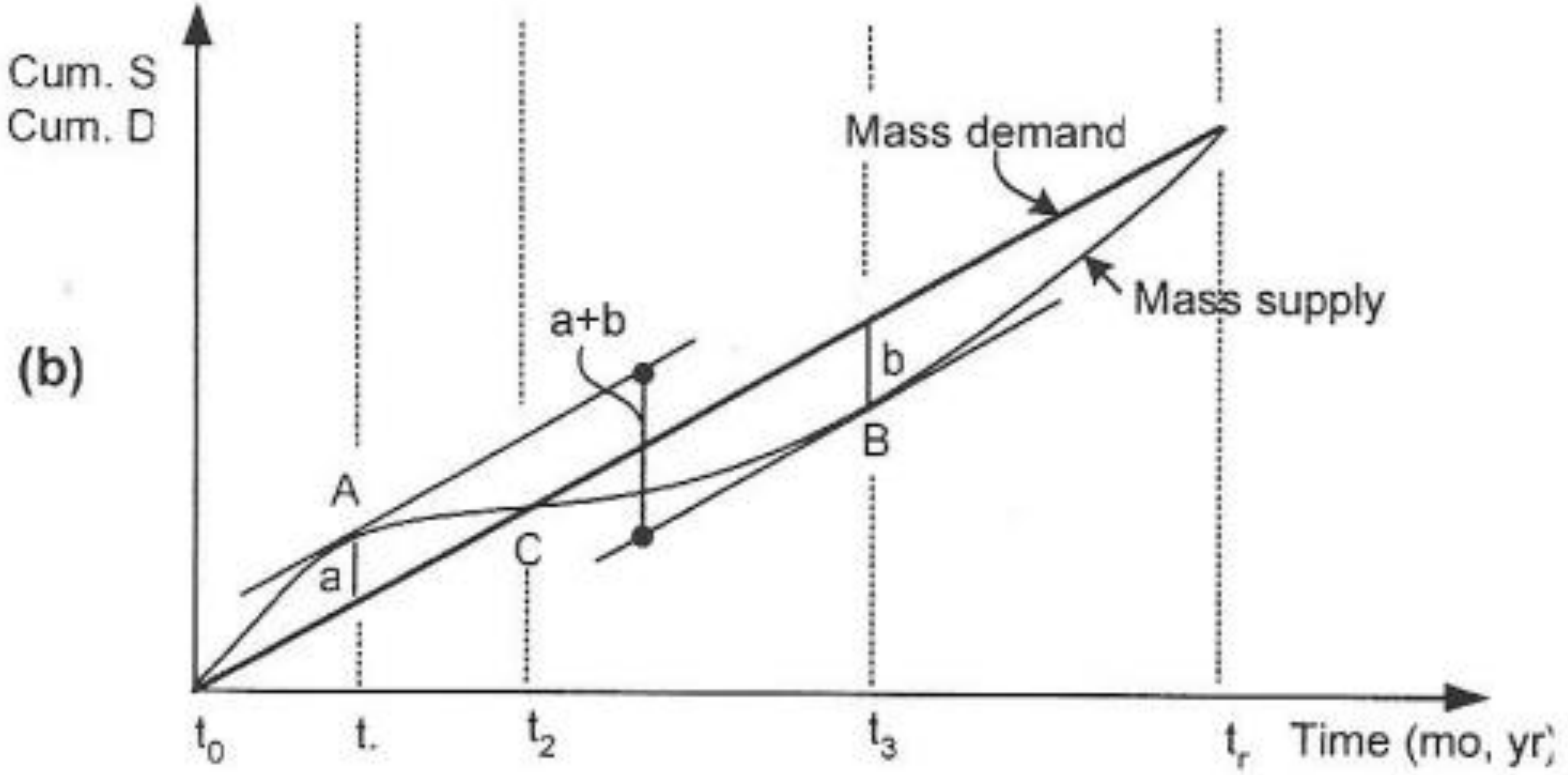
Mass curve of flow

Mass-Curve analysis

Source: Bertuğ Akıntuğ (Undated): PPT of Middle East Technical University

Mass curve (ripple's) method

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



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

Mass-Curve analysis

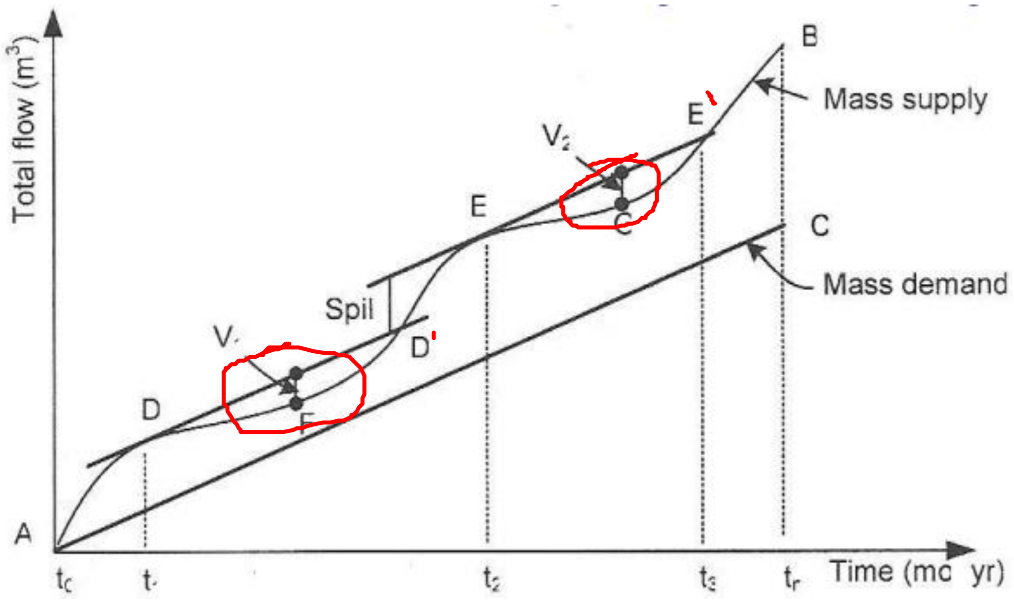
Source: Bertuğ Akıntuğ (Undated): PPT of Middle East Technical University

Mass curve (ripple's) method

a) Determination of capacity for a known yield

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.
4. The reservoir would be full at points D, D’, E, and E’.
5. The reservoir would be empty at points F and G.

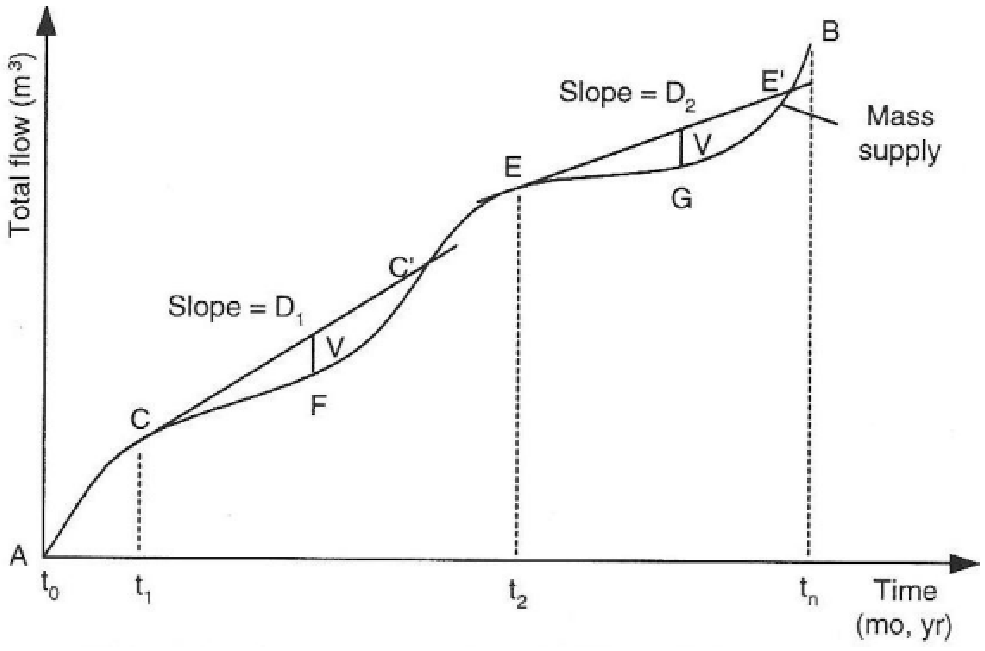


Mass-Curve analysis
Source: Bertuğ Akıntuğ (Undated): PPT of Middle East Technical University

Mass curve (ripple's) method

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.



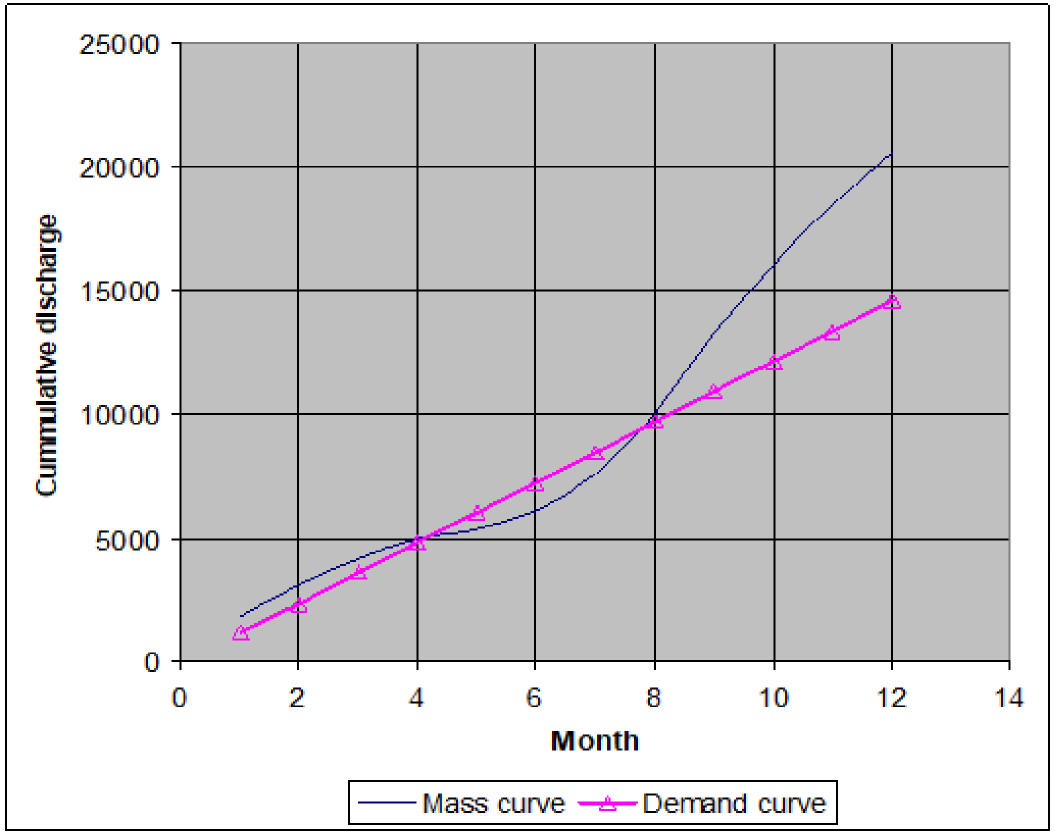
Mass-Curve analysis
Source: Bertuğ Akıntuğ (Undated): PPT of Middle East Technical University

3. 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**.

Reservoirs

- As indicated below, a **mass curve** can be prepared from the **flow hydrograph** of a stream for a large number of **consecutive previous years**

- If the demand is at a **constant rate** then the demand curve is a **straight line** having **its slope** equal to the **demand rate**.
- However, if the demand **is not constant** then the demand will be **curved** indicating a **variable rate** of demand.



Variable supply and constant demand mass curves
Source: Excel assignment in the class.

Sequent Peak Algorithm

- It overcomes some shortcomings associated with the **mass curve method**.
- This method is particularly suited for the analysis of large data with the help of a **computer**.
- Let I_t the **inflow to the reservoir in** the period t, $\mathbf{R_t}$ be the **release from the reservoir**, and
- S_t the storage at the beginning of the period t.
- The reservoir is assumed to be **empty in the beginning**.
- The mass curve of cumulative net flow volume (**Inflow - Outflow**) against chronological time is used.
- This curve will have peaks (**local maximums**) and troughs (**local minimums**).
- For any peak P_i the **next following** peak of magnitude greater than P_i is called a **sequent peak**.
- The computations are performed for twice the length of the inflow record by assuming that the inflows **repeat after the end of first cycle**.
- This assumption is made to take care of the case when the critical period falls at the end of the record.

Sequent Peak Algorithm

- This assumption is made to take care of the case when the critical period falls at the end of the record.

The variable S_t is calculated by the following equation:

$$S_t = \begin{cases} S_{t-1} + R_t - I_t & \text{if positive} \\ 0 & \text{if negative or zero} \end{cases}$$

The required storage capacity is equal to the maximum of S_t values.

Reservoirs and sediments

- A river entering a water reservoir will loose its capacity due to transport sediments.
- The water velocity decreases, together with the shear stress on the bed.
- The sediments will therefore deposit in the reservoir and decrease its volume.

- It is important to assess the magnitude of sediment deposition in the reservoir during dam design.

The assessments will be:

1. How much **sediments enter** the reservoir
2. What is the **trap efficiency** of the reservoir

Reservoirs and sediments

In general, there are **two approaches** to the sedimentation problem:

1. The reservoir is constructed **so large** that it will take **a very long time** to fill. The **economical value** of the project will thereby be maintained.

2. The reservoir is designed **relatively small** and the **dam gates** are constructed **relatively large**, so that it is possible to remove the sediments regularly by **flushing**.
   - The **gates are opened**, lowering the water level in the reservoir, which **increases the water velocity**.
   - The sediment **transport capacity is increased**, causing erosion of the deposits.

Reservoirs and sediments

- A **medium sized reservoir** will be the **least beneficial**. Then it will take relatively short time to fill the reservoir, and the size is so large that only a **small part of the sediments** are removed by **flushing**.

- The flushing has to be done while the water discharge **in to the reservoir** is relatively **high**.

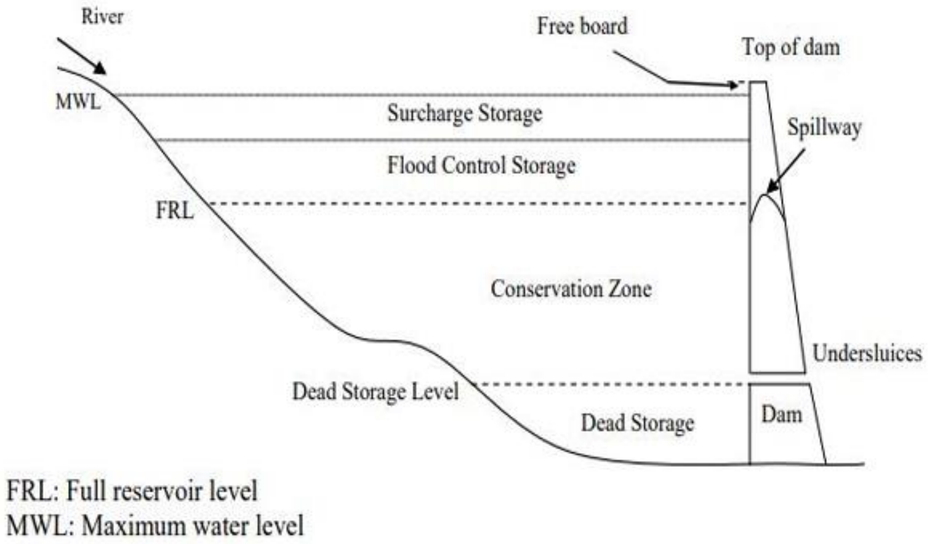
- The water will erode the deposits to a cross-stream magnitude similar to the normal width of the river.

- A **long and narrow reservoir** will therefore be more **effectively flushed** than a short and wide geometry.

- For the later, the sediment deposits may remain on the sides.

Reservoirs and sediments

- Another question is the **location of sediment deposits**. The Figure below shows a longitudinal profile of the reservoir.
- There is a **dead storage** below the lowest level the water can be withdrawn.
- This storage may be filled with sediments without affecting the operation of the reservoir.



Storage levels:
https://www.vssut.ac.in/lecture_notes/lecture1525502018.pdf

- Figure: Longitudinal profile of a reservoir MWL is the **maximum regulated water level**.
- The reservoir volume below **DSL is called the dead storage**, as this can be used.

Sediment Load Prediction

Rough estimates of sediment load may be taken from regional data.

- The mechanics of reservoir sedimentation is highly **complicated**.
- Sediment yield in the area is known from neighboring catchments.
- Assess the seriousness of the erosion in the present catchment and **estimate rough figures** of sediment yield.
- The **land use**, **slope** and **size** of the catchment are important factors.

Sediment Load Prediction

- For a more detailed assessment, measurements of the sediment concentration in the river have to be used.
- Therefore, sediment load measurement are carried out in streams and calibration curve (stream discharge, Q_w vs suspended load, Q_s) is developed.
- The United States Bureau of Reclamation (USBR) recommends a sampling period of at least **5 year**

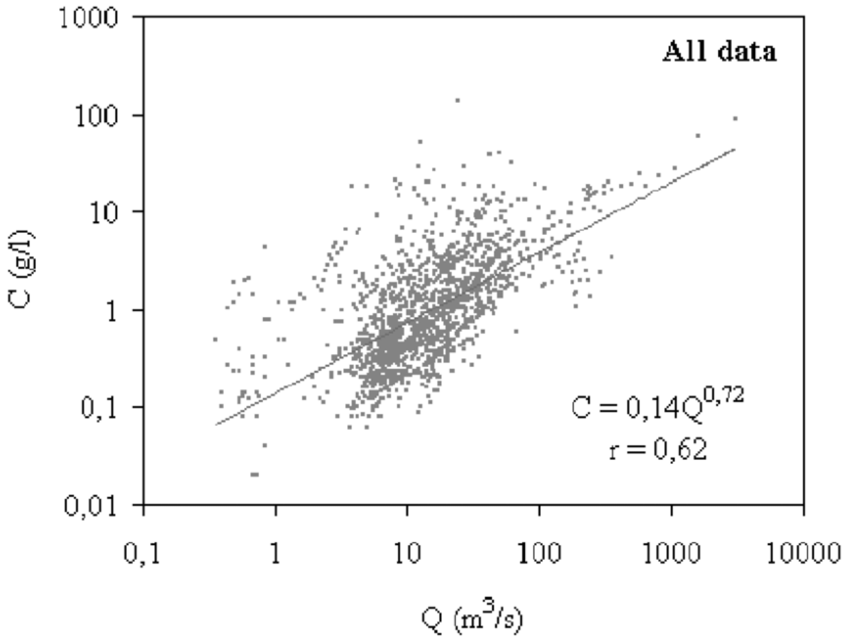
Sediment Load Prediction

- Sediment concentrations are measured using standard sampling techniques, and water discharges are recorded simultaneously.
- The measurements are taken at varying water discharges.
- The values of water discharge and sediment concentrations are plotted on a graph, and a rating curve is made. This is often on the form:

$$Q_s = {}_a Q_w^b$$

Where,

- Q_s is the sediment load,
- Q_w is the water discharge and
- a and b are constants, obtained by curve fitting



Source: Rating curve developed on all measured suspended sediment concentrations and water discharges

Examples

Example 1: Mean monthly river flow a given year is shown on the table below.

Calculate the minimum storage required to maintain a demand rate of 40 m^3/s

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean Flow (m^3/s)	60	45	35	25	15	22	50	80	105	90	80	70

Table 5.8 Calculation of Mass Curve—Example 5.9

Month	Mean flow (m^3/s)	Monthly flow volume (cumec-day)	Accumulated volume (cumec-day)
Jan	60	1860	1860
Feb	45	1260	3120
Mar	35	1085	4205
April	25	750	4955
May	15	465	5420
June	22	660	6080
July	50	1550	7630
Aug	80	2480	10,110
Sep	105	3150	13,260
Oct	90	2790	16,050
Nov	80	2400	18,450
Dec	70	2170	20,620

A mass curve of accumulated flow volume against time is plotted (Fig. 5.12). In this figure all the months are assumed to be of average duration of 30.4 days. A demand line

Given: Mean monthly river flow, Q (m^3/s)

Demand, D=40 m^3/s

Req.: Min. storage (m^3)

Soln.: Tabulate with cumulated supply, Q for the month ($m^3/s.d$). Draw tangent and identify the minimum departure from the supply.

Source: Textbook, (Ojha et al, 2008)

SOLUTION: From the given data the monthly flow volume and accumulated volumes and calculated as in Table 5.8. The actual number of days in the month are used in calculating of the monthly flow volume. Volumes are calculated in units of cumec. day ($= 8.64 \times 10^4$).

Reservoirs: Examples

with slope of 40 m^3/s is drawn tangential to the *hump* at the beginning of the curve; line *AB* in Fig. 5.12. A line parallel to this line is drawn tangential to the mass curve at the *valley* portion; line *A′B′*. The vertical distance S_1 between these parallel lines is the minimum storage required to maintain the demand. The value of S_1 is found to be 2100 cumec. Days = 181.4 million m^3.

Soln.:

$$V_{min} = 2100 m^3/s.day * 24hr/day * 60\text{min}/hr * 60\text{sec}/\text{min} = \mathbf{181.4\ m^3}$$

Source: Textbook, (Ojha et al, 2008)

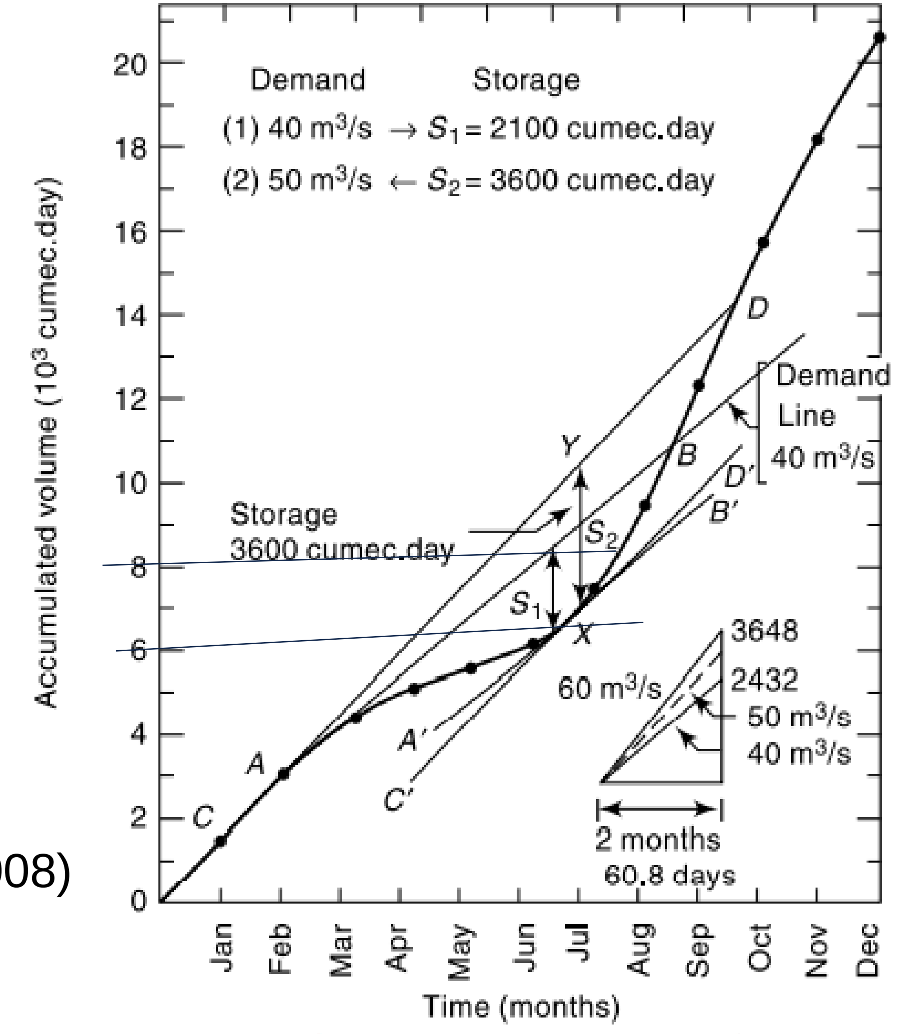


Fig. 5.12 Flow-Mass Curve—Example 5.9

Reservoirs: Examples

Example 2:

Let’s do example one without the application of the mass curve.

What is the maximum constant demand that can be sustained by the flow of the river given in example 1?

Given: Mean monthly river flow, Q (m^3/s)

Demand, D=40 m^3/s

Req.: Min. storage (m^3)

Soln.: Tabulate with cumulated supply, Q and demand, D, for the month ($m^3/s.d$). Draw or identify the minimum departure for demand

Table 5.9 Calculation of Storage—Example 5.9

Month	Mean inflow rate (m^3/s)	Inflow volume (cumec. day)	Demand rate (m^3/s)	Demand volume (cumec. day)	Departure [col. 3-col. 5)	Cum. excess demand volume (cumec. day)	Cum. excess inflow volume (cumec. day)
Jan	60	1860	40	1240	620		620
Feb	45	1260	40	1120	140		760
Mar	35	1085	40	1240	–155	–155	
Apr	25	750	40	1200	–450	–605	
May	15	465	40	1240	–775	–1380	
Jun	22	660	40	1200	–540	–1920	
July	50	1550	40	1240	310		310
Aug	80	2480	40	1240	1240		1550
Sept	105	3150	40	1200	1950		3500
Oct	90	2790	40	1240	1550		5050
Nov	80	2400	40	1200	1200		6250
Dec	70	2170	40	1240	930		7180
	Monthly mean =	**1718.3**					

Source: Textbook, (Ojha et al, 2008)

Reservoirs: Examples

Month	Volume in flow (cumec-day)	Volume demand (Cumec-day)	Departure (2)-(3) (cumec-day)	Cumulative Departure (cumec-day)	Storage (Cumec-day)
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Jan	1860	1240	620	620	
Feb	1260	1120	140	760	
Mar	1085	1240	-155	605	
Apr	750	1200	-450	155	
May	465	1240	-775	-620	
Jun	660	1240	-540	-1160	
Jul	1550	1240	310	-850	
Aug	2480	1240	1240	390	
Sept	3150	1200	1950	2340	
Oct	2790	1240	1550	3890	
Nov	2400	1200	1200	5090	
Dec	2170	1240	930	6020	

760-(-1160) =1920 cumec-day

Soln.: Tabulate with cumulated supply, Q and demand, D, for the month (m^3/s.d). Draw or identify the departure of maximum demand from maximum supply.

Reservoirs: Examples

Example 3: A reservoir is proposed using the following data.

- Water right to be released as environmental flow is 5 m^3/s.
- Average reservoir area is 20km^2.
- A runoff coefficient is assumed 0.5

Estimate the storage required to meet the demand and losses indicated on the table.

Source: Textbook, (Ojha et al, 2008)

Month	Mean flow (m^3/s)	Demand (million m^3)	Monthly evaporation (cm)	Monthly rainfall (cm)
Jan	25	22.0	12	2
Feb	20	23.0	13	2
Mar	. 15	24.0	17	1
April	10	26.0	18	1
May	4	26.0	20	1
June	9	26.0	16	13
July	100	16.0	12	24
Aug	108	16.0	12	19
Sept	80	16.0	12	19
Oct	40	16.0	12	1
Nov	30	16.0	11	6
Dec	30	22.0	17	2

Reservoirs: Examples

SOLUTION: Use actual number of days in a month for calculating the monthly flow and an average month of 30.4 days for prior right release.

Prior right release $= 5 \times 30.4 \times 8.64 \times 10^4 = 13.1\ \text{Mm}^3$ when $Q > 5.0\ \text{m}^3/\text{s}$.

$$\text{Evaporation volume} = \frac{E}{100} \times 20 \times 10^6 = 0.2\ E\ \text{Mm}^3$$

$$\text{Rainfall volume} = \frac{P}{100} \times (1 - 0.5) \times 20 = 0.1\ P\ \text{Mm}^3$$

Inflow volume: $I \times (\text{No. of days in the month}) \times 8.64 \times 10^4\ \text{m}^3$

the required storage capacity is $64.5\ \text{Mm}^3$.

Release:

$$ER = 5m^3/s * 30.4days/month * 24hrs/days * 60\min/hr * 60\sec/\min$$

$$= 5 * 30.4 * 8.64 * 10^4\ m^3/month$$

$$= 13.1Mm^3/month$$

The mass-curve method assumes a definite sequence of events and this is its major drawback. In practice, the runoff is subject to considerable time variations and definite sequential occurrences represent only an idealized situation. The mass-curve analysis is thus adequate for small projects or preliminary studies of large storage projects. The latter ones require sophisticated methods such as *time-series analysis* of data for the final design.

Reservoirs: Examples

Month	Inflow volume (Mm³)	Withdrawal				Total withdrawal (3+4+5+6) (Mm³)	Departure (Mm³)	Cum. Excess demand (Mm³)	Cum. Excess flow volume (Mm³)
		Demand (Mm³)	Prior rights (Mm³)	Evaporation (Mm³)	Rainfall (Mm³)				
1	2	3	4	5	6	7	8	9	10
Jan	67.0	22.0	13.1	2.4	–0.2	37.3	+29.7	—	29.7
Feb	48.4	23.0	13.1	2.6	–0.2	38.5	+9.9	—	39.6
Mar	40.2	24.0	13.1	3.4	–0.1	40.4	–0.2	–0.2	—
Apr	25.9	26.0	13.1	3.6	–0.1	42.6	–16.7	–16.9	—
May	10.7	26.0	10.7	4.0	–0.1	40.6	–29.9	–46.8	
June	23.3	26.0	13.1	3.2	–1.3	41.0	–17.7	–64.5	
July	267.8	16.0	13.1	2.4	–2.4	29.1	+238.7	—	238.7
Aug	289.3	16.0	13.1	2.4	–1.9	29.6	259.7		498.4
Sept	207.4	16.0	13.1	2.4	–1.9	29.6	177.8		676.2
Oct	107.1	16.0	13.1	2.4	–0.1	31.4	75.7		751.9
Nov	77.8	16.0	12.1	2.2	–0.6	30.7	47.1		799.0
Dec	80.4	22.0	13.1	3.4	–0.2	38.3	42.1		841.1

Rainfall is negative. Why?

It is against withdrawal.

Source: Textbook, (Ojha et al, 2008)

Reservoirs: Examples

Example 3: The following table gives:

- the monthly inflows during a critical **low water period** at a site of a proposed dam,
- the corresponding monthly **evaporation** and **precipitation** at a nearby station, and
- the estimated monthly **demand** of water.
- Prior water rights require a release of full natural flow or **6.5 hectare-metre per month**, whichever is less.
- Assume that **30 percent of the rainfall** on the land area to be flooded by the reservoir has reached the stream in the past.
- Take pan evaporation coefficient equal to **0.7**.

Using a net increased pool area of **520 hectares**, find the required **useful storage**.

Reservoirs: Examples

Month	Inflow at The proposed dam site (ha-m)	Pan Evaporation (mm)	Precipitation (mm)	Demand (ha-m)
January	0.0	25	0	5.5
February	0.0	32	0	5.5
March	2.7	35	0	10.5
April	6.0	62	15	13.0
May	6.7	110	20	15.5
June	138.3	132	90	15.5
July	210.2	117	208	8.0
August	80.8	91	60	8.0
September	34.2	78	45	9.5
October	8.8	54	0	13.0
November	3.0	37	0	15.5
December	0.0	23	0	15.5

Source: Textbook, (Ojha et al, 2008)

Reservoirs: Examples

Solution:

- **The first five columns** are same as given in the problem.
- **Column (6)** gives the downstream requirement on account of prior water right and the entries in this column are equal to the river flow or 6.5 hectare-metre whichever is less.
- **Column (7)** gives the quantity of water, E, which evaporates from whole of the water surface area of reservoir during each month which is computed by the following expression

$$R = \frac{\text{Reservoir area} \times \text{Pan evaporation} \times 0.7}{1000} = \frac{520 \times 0.7 \times \text{Column (3)}}{1000}$$

$$= 0.364 \times \text{Column (3) hectare-metre}$$

Reservoirs: Examples

- Column (8) gives the precipitation P in hectare-metre, falling over the reservoir area.
- Since 30% of the precipitation is assumed to have reached the stream it is included in the now given in Column (2) and hence only 70% of the precipitation falling on the reservoir area is considered which is given by the following expression-

$$P = \frac{\text{Reservoir area} \times \text{Precipitation} \times 0.70}{1000}$$

$$= \frac{520 \times \text{Column (4)} \times 0.70}{1000}$$

$$= 0.364 \times \text{Column (4) hectare-metre}$$

Reservoirs: Examples

Source: Textbook, (Ojha et al, 2008)

Month (1)	*Inflow (ha-m)* (2)	*Pan-Evaporation (mm)* (3)	*Precipitation (mm)* (4)	*Demand (ha-m)* (5)	*Downstream Requirement (ha-m)* (6)	*Evaporation E (ha-m)* (7)	*Precipitation P (ha-m)* (8)	*Adjusted Inflow I (ha-m)* (9)	*Required Storage S (ha-m)* (10)
January	0.0	25	0	5.5	0.0	9.10	0.00	–9.10	14.60
February	0.0	32	0	5.5	0.0	11.65	0.00	– 11.65	17.15
March	2.7	35	0	10.5	2.7	12.74	0.00	– 12.74	23.24
April	6.0	62	15	13.0	6.0	22.57	5.46	– 17.11	30.11
May	6.7	110	20	15.5	6.5	40.04	7.28	– 32.56	48.06
June	138.3	132	90	15.5	6.5	48.05	32.76	+ 116.51	Nil
July	210.2	117	208	8.0	6.5	42.59	75.71	+ 236.82	Nil
August	80.8	91	60	8.0	6.5	33.12	21.84	+ 63.02	Nil
September	34.2	78	45	9.5	6.5	28.39	16.38	+ 15.69	Nil
October	8.8	54	0	13.0	6.5	19.66	0.00	– 17.36	30.36
November	3.0	37	0	15.5	3.0	13.47	0.00	– 13.47	28.97
December	0.0	23	0	15.5	0.0	8.37	0.00	– 8.37	23.87
Total	490.7	796	438	135.0	50.7	289.75	159.43	309.68	216.36

Reservoirs: Examples

Column (9) gives the adjusted inflow I which is computed as follows**:**

$$I_{adj} = Column\ (2) — Column\ (6) — Column\ (7) + Column\ (8)$$
$$= I \quad - \quad ER \quad - \quad E \quad + \quad P.$$

Column (10) gives the quantity of water S required from storage to meet the required demand and it is computed as follows:

$$S = Demand — Adjusted\ inflow = Column\ (5) — Column\ (9)$$

column (10): Only the **positive values** of S are to be considered and entered **in column (10)** and where negative values are **obtained nil** should be entered in column (10).

- This is so because a **positive value** of S indicates that water is **required from the storage** since demand is more than the adjusted inflow,
- whereas a **negative value** of S indicates that **no water is required** from the storage since demand is less than the adjusted inflow.

The sum of the column (10) gives the **required useful storage**, the value of which in this case is found to be **216.36 hectare-metre**. What does hectare-metre mean?

It is given for your home study to change it in m^3 and other expressions.

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Thank you very much for your active attendance!!

Prepared By: Sisay Demeku Derib (PhD, Practicing Hydraulics Engineer, Assistant Prof.)
Affiliated to: Addis Ababa Science and Technology University –AASTU, Department of Civil Engineering
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