5. Reservoir

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5.1 Reservoir

Reservoir: During high flows, water flowing in a river has to be stored so that a uniform supply of water can be assured, for water resources utilisation like irrigation, water supply, power generation, etc. during periods of low flows of the river.

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

- Type of Reservoir

Storage or conservation reservoir

- Can retain excess supplies during period of peak flows and can release gradually during low flows

Flood control reservoir

- to minimize the flood peaks at the areas to be protected downstream.

Multipurpose reservoir

- designed to protect the downstream areas from floods and to conserve water for water supply, irrigation, industrial needs, hydroelectric purposes etc

Distribution reservoir

- Is a small storage reservoir constructed within a city water supply system

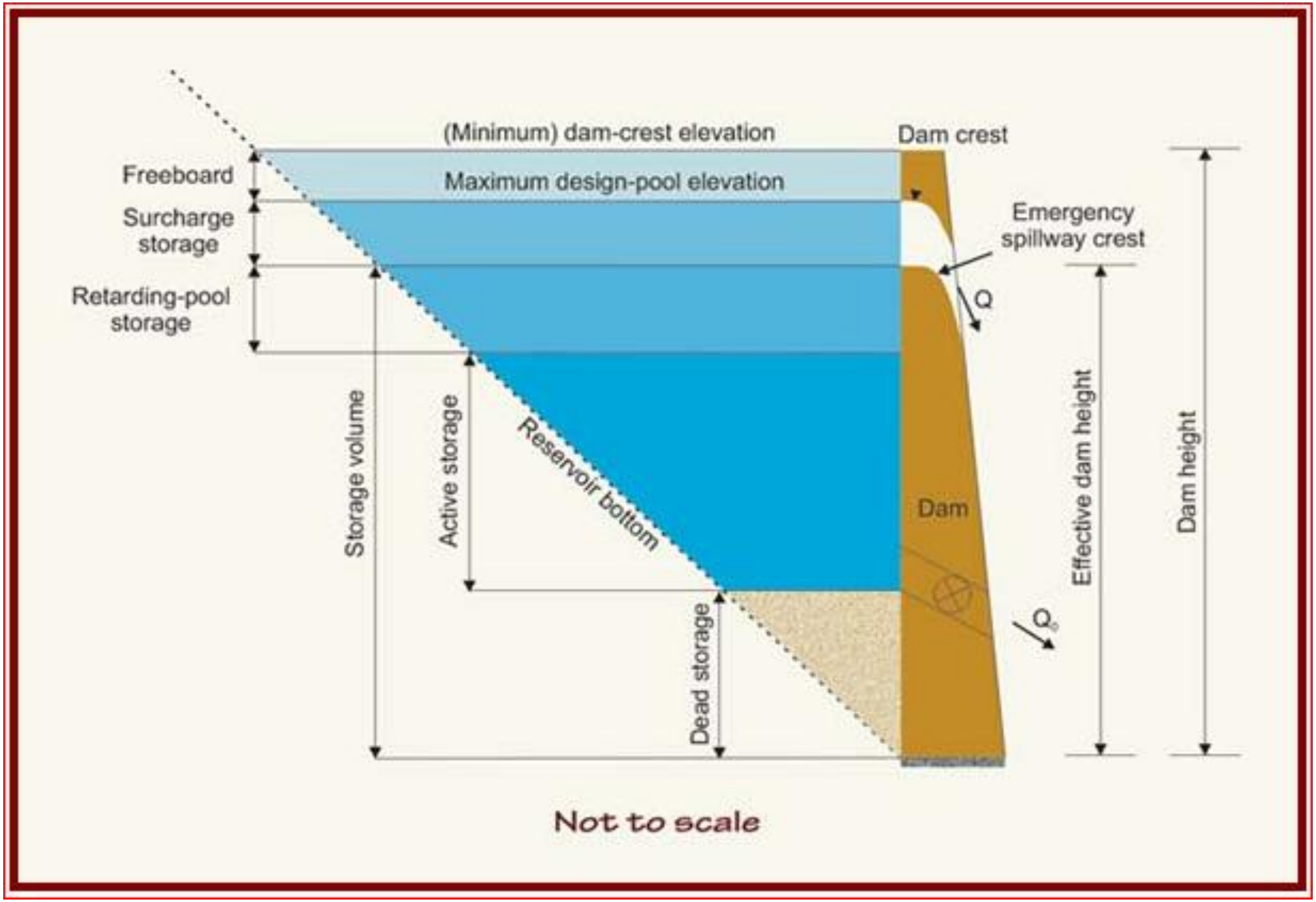
5.1.1 Storage Zone of Reservoir

- **Normal pool level:** It is the maximum elevation, to which the reservoir water surface will rise during normal operating condition.
- **Minimum pool level:** The lowest water surface elevation, which has to be kept under normal operating condition in a reservoir
- **Surcharge storage:** This is the storage between full reservoir level and maximum water level.
- **Dead storage** (low water level): It is the minimum reservoir level below which, water is not allowed to be drawn for conservation purposes.

Storage Zone of Reservoir

- **Live storage:** It is also known as the useful or conservation storage of a reservoir and it is the difference between the storages at full reservoir level and dead storage level
- **Bank storage:** It is the storage of water in the permeable reservoir banks.
- **Full reservoir level** (FRL): It is the level of spillway crest (for un gated spillway) or the top of spillway gate (for gated spillway) to which the reservoir is usually filled.
- **Maximum water level** (MWL): It is the new elevation to which, water in the reservoir rises when design flood impinges at full reservoir level.

Reservoir structure



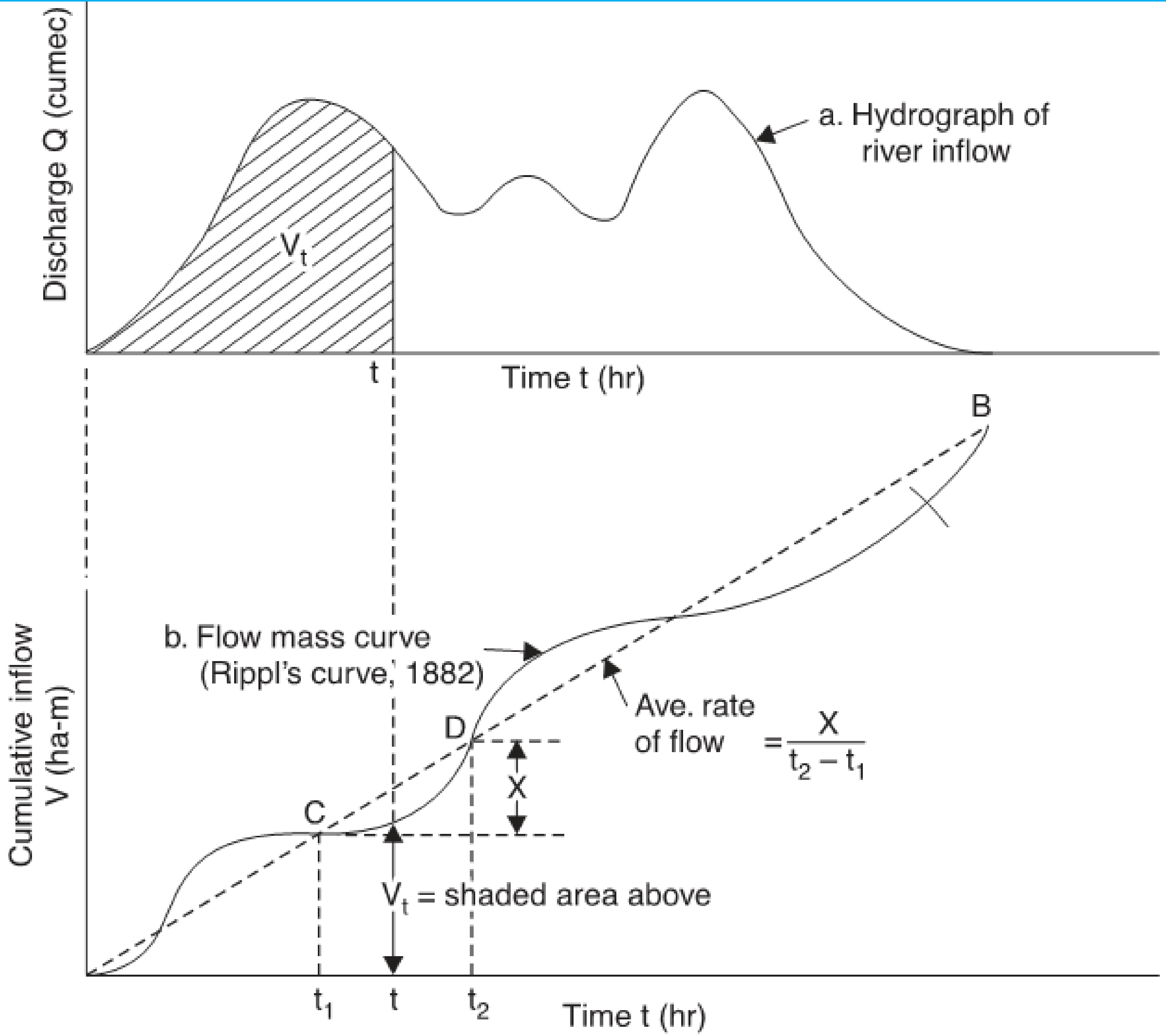
5.2 Methods to determine a reservoir storage capacity.

I. **Mass curve (Rippl's)**
II. **Sequent peak algorithm**
III. **Flow duration curve**

I. Mass curve (Rippl's) method:

- A mass curve (or mass inflow curve) is a plot of accumulated flow in a stream against time. It rises continuously as it shows accumulated flows.
- The slope of the curve at any point indicates the **rate of inflow** at that particular time.
- Required rates of draw off from the reservoir are marked by drawing tangents, having slopes equal to the demand rates, at the highest points of the mass curve
- 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**.

I. Mass curve method



I. Mass curve method

- The maximum departure between the **demand line** and the **mass curve** represents the **storage capacity** of the reservoir required to meet the demand.
- A demand line must intersect the mass curve when extended forward, otherwise the reservoir is not going to refill.

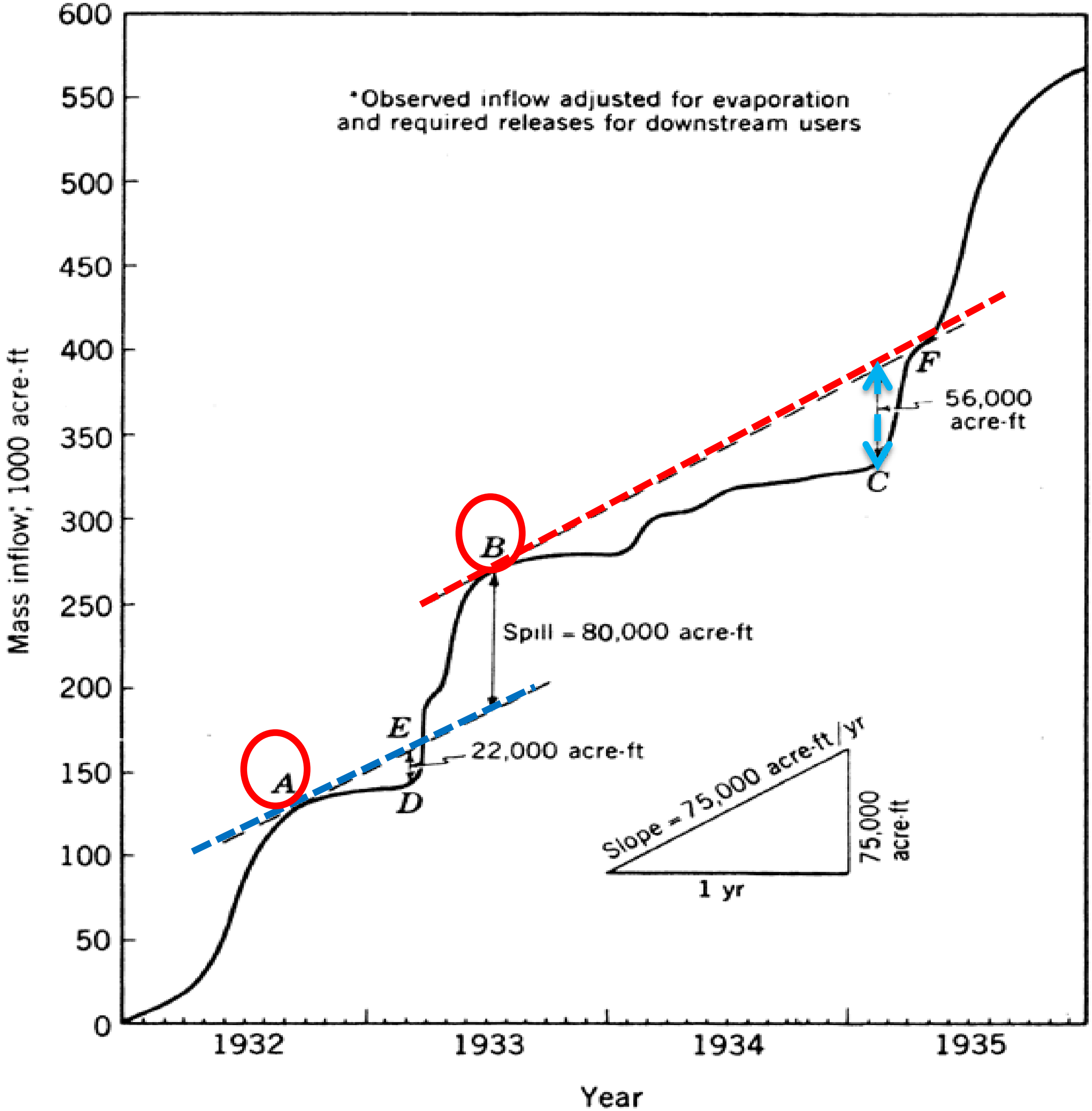
Assumptions

- The reservoir is full at time zero.
- In using historical flow data it is implicitly assumed that future flow sequence will not contain a more severe drought than the historical flow sequence.

Attributes

- The procedure is simple and it is widely understood
- It takes into account seasonality

I. Mass curve method



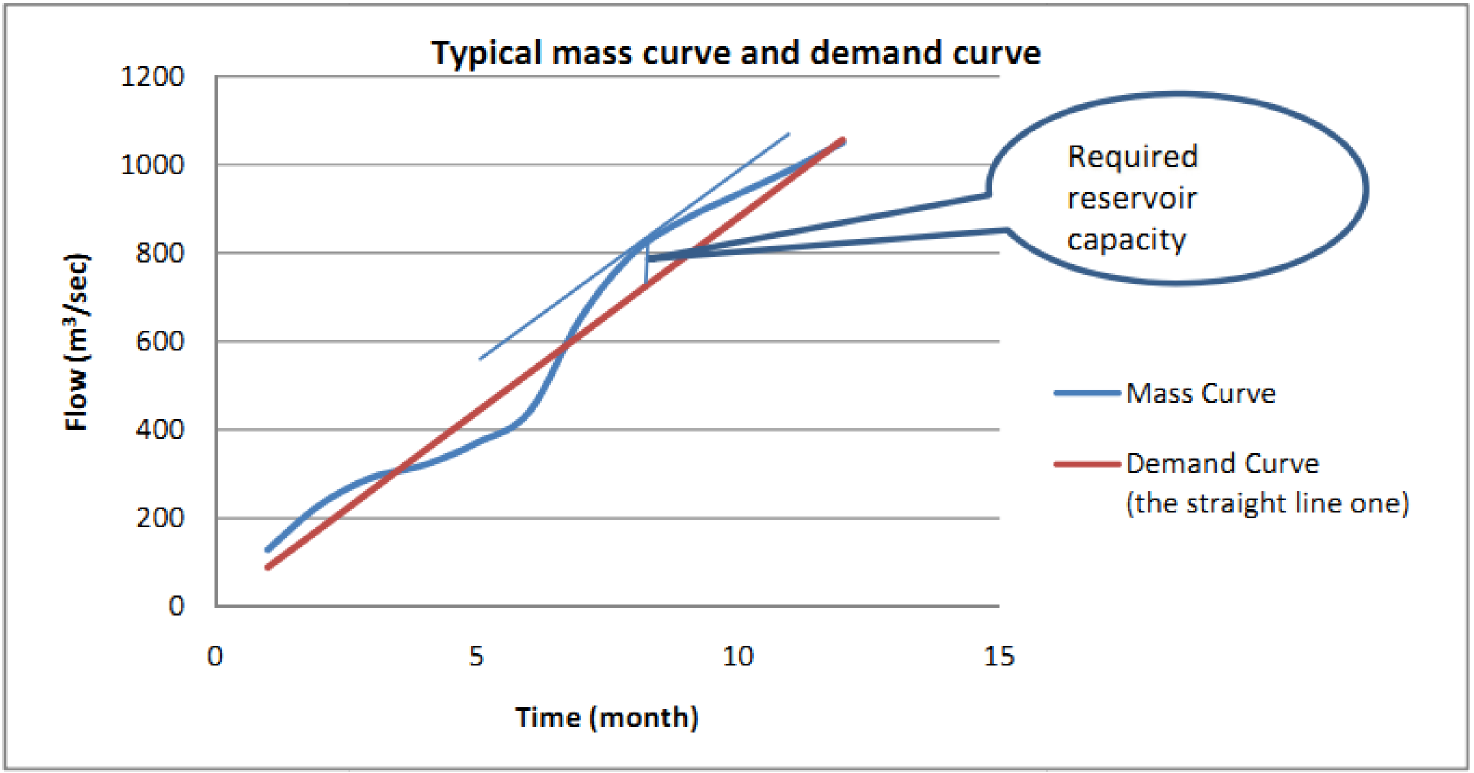
Mass curve procedure

- The reservoir capacity required for a specified yield or demand may be determined by using mass curve and demand curve using the following steps

1. A mass curve is prepared from the flow hydrograph for a number of consecutive years selected from the available stream flow record such that it includes the most critical or the driest period.
2. Corresponding to the given rate of demand, a demand curve is prepared.
3. Lines are drawn parallel to the demand curve and tangential to the high points of the mass curve

3. The maximum vertical intercepts between the tangential lines drawn in step 3 and the mass curves are measured

4. The largest of the maximum vertical intercepts determined in step 4 represents the reservoir capacity required to satisfy the given demand.



II. Sequent peak algorithm

Given an **N** year record of streamflow at site of proposed dam and demand, it is required to find a reservoir of minimum capacity such that the design demand can always be satisfied if the flows and demands are repeated in acyclic progression of cycles of **N** periods each.

Steps

I. Calculate (Flow-Demand) for all **i = 1, 2, …… , 2N** and hence the net cumulative flow $\sum_{i=1}^{t}(\boldsymbol{Flow} - \boldsymbol{Demand})$ *for* all **i = 1, 2, …… , 2N**

II. Locate the first peak, $\mathbf{H_1}$ in the column of cumulative net inflows

III. Locate the sequent peak, $\mathbf{H_2}$, which is the next peak of greater magnitude than the first.

IV. B/n this pair of peaks find the lowest trough $\mathbf{T_1}$ and calculate $\mathbf{H_1 - T_1}$.

V. Starting with $\mathbf{H_2}$, find the next sequent peak, $\mathbf{H_3}$, that has a magnitude greater than $\mathbf{H_2}$.

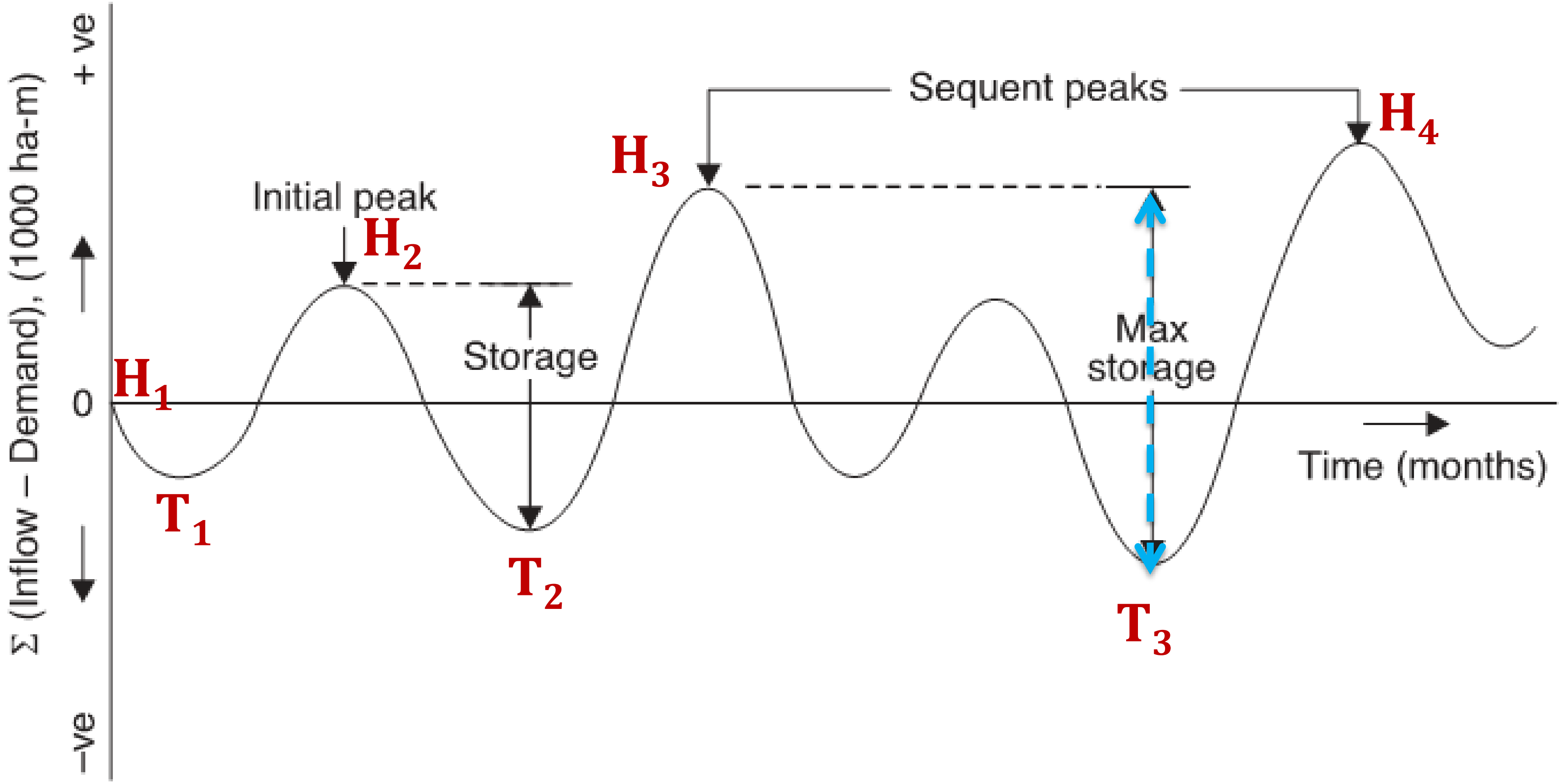
VI. Find the lowest trough, $\mathbf{T_2}$, b/n $\mathbf{H_2}$ and $\mathbf{H_3}$ and calculate $\mathbf{H_2 - T_2}$.

VII. Starting with $\mathbf{H_3}$, find $\mathbf{H_4}$ and $\mathbf{T_3}$ as above; calculate $\mathbf{H_3} - \mathbf{T_3}$.

VIII. Continue until all **k** sequent peaks in the series of the **2N** periods have been found.

IX. The required capacity is $\mathbf{C = max\ (H_k - T_k)}$

II. Sequent peak algorithm



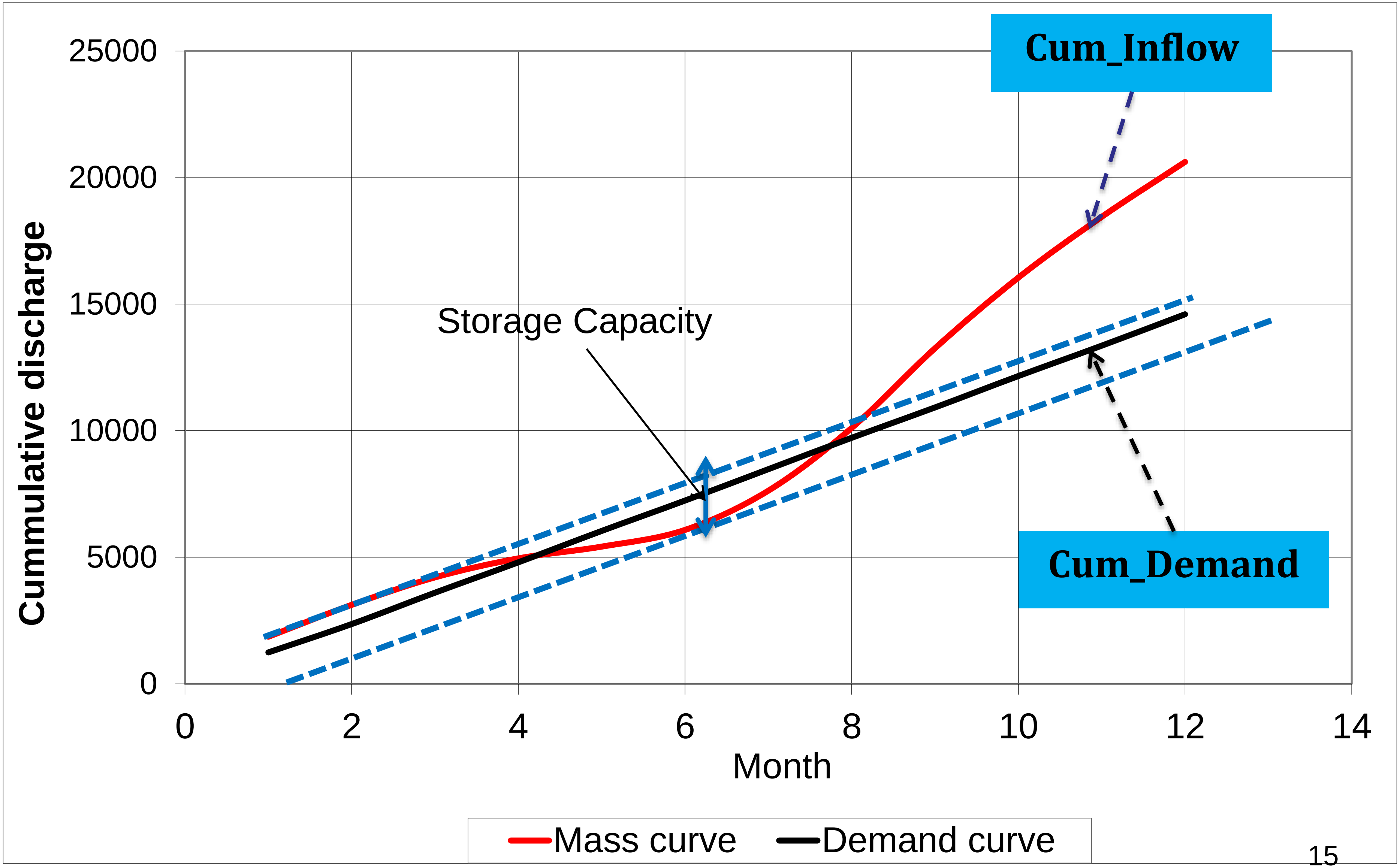
Example 1 Reservoir Capacity

The following table gives the mean monthly flows in a river during certain year. Calculate the minimum storage required for maintaining a demand rate of 40m3/s: (a) using graphical solution (b) using tabular solution.

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Mean flow M3/s	60	45	35	25	15	22	50	80	105	90	80	70

Month	Mean flow m3/s	Monthly flow (m3/s).day	Accum flow (m3/s). Day	Demand m3/s	Demand (m3/s). Day	Accum demand (m3/s). Day
Jan (31)	60	1860	1860	40	1240	1240
Feb (28)	45	1260	3120	40	1120	2360
Mar(31)	35	1085	4205	40	1240	3600
Apr(30)	25	750	4955	40	1200	4800
May(31)	15	465	5420	40	1240	6040
Jun(30)	22	660	6080	40	1200	7240
July(31)	50	1550	7630	40	1240	8480
Aug(31)	80	2480	10110	40	1240	9720
Sep(30)	105	3150	13260	40	1200	10920
Oct(31)	90	2790	16050	40	1240	12160
Nov(30)	80	2400	18450	40	1200	13360
Dec(31)	70	2170	20620	40	1240	14600

Example 1: Mass curve



Example 1: Sequent peak algorithm

1 Month	2 Monthly flow (m3/s).day	3 Demand (m3/s). Day	4 = (2 - 3) Departure (m3/s).day	5 Cum departure (m3/s) .day
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	1200	-540	-1160
July	1550	1240	310	-850
Aug	2480	1240	1240	390
Sep	3150	1200	1950	2340
Oct	2790	1240	1550	3890
Nov	2400	1200	1200	5090
Dec	2170	1240	930	6020
Jan	1860	1240	620	6640
Feb	1260	1120	140	6780

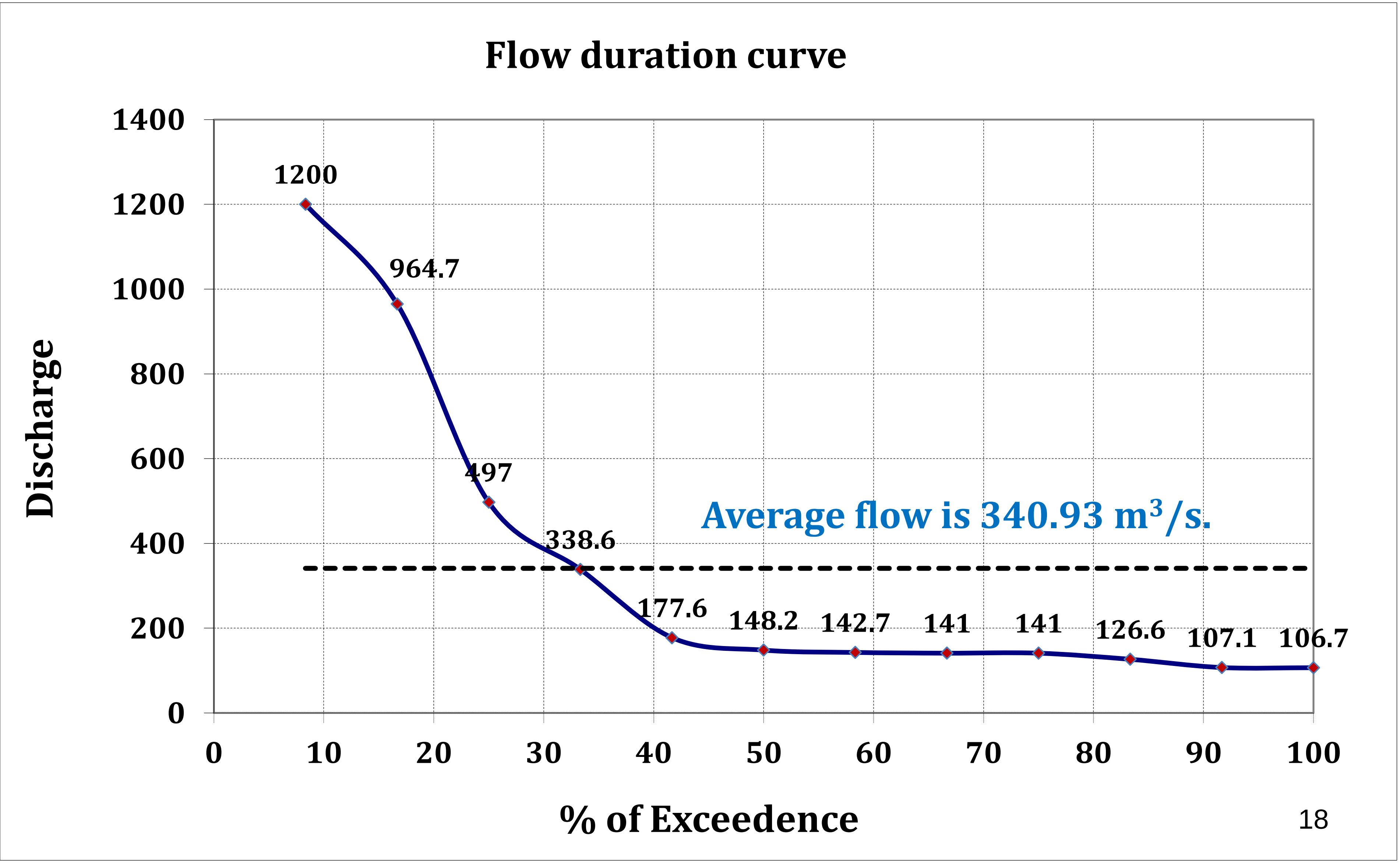
(H-T)=
760-(-1160)=
1920 Cumec-day

III. Flow duration curve method

Example 2: Reservoir Capacity determination by the use of **flow duration curve**. Determine the reservoir capacity required if a hydropower plant is designed to operate at an average flow. (p=m/n)

Month	Discharge (m3/s)	Rank	Discharge	% exceeded	Constant flow
Jan	106.7	1	1200	8.33	340.93
Feb	107.1	2	964.7	16.67	340.93
Mar	148.2	3	497	25.00	340.93
Apr	497	4	338.6	33.33	340.93
May	1200	5	177.6	41.67	340.93
Jun	964.7	6	148.2	50.00	340.93
Jul	338.6	7	142.7	58.33	340.93
Aug	177.6	8	141	66.67	340.93
Sep	141	9	141	75.00	340.93
Oct	141	10	126.6	83.33	340.93
Nov	142.7	11	107.1	91.67	340.93
Dec	126.6	12	106.7	100	340.93
Average flow			**340.93**		

III. Flow duration curve method



Average flow is 340.93 m^3/s.

III. Flow duration curve method

1	2	3	(3-1)	Area	No. days
Discharge	**% exceeded**	**Constant flow**			
1200	8.33	340.93	0	0	31
964.7	16.67	340.93	0	0	28
497	25.00	340.93	0	0	31
338.6	33.33	340.93	2.33	6.90	30
177.6	41.67	340.93	163.33	14.84	31
148.2	50.00	340.93	192.73	16.29	30
142.7	58.33	340.93	198.23	16.59	31
141	66.67	340.93	199.93	16.66	31
141	75.00	340.93	199.93	17.26	30
126.6	83.33	340.93	214.33	18.67	31
107.1	91.67	340.93	233.83	19.50	30
106.7	100.00	340.93	234.23		31
340.93			Sum	126.72	30.417

Storage (Mm^3)	**332.83**

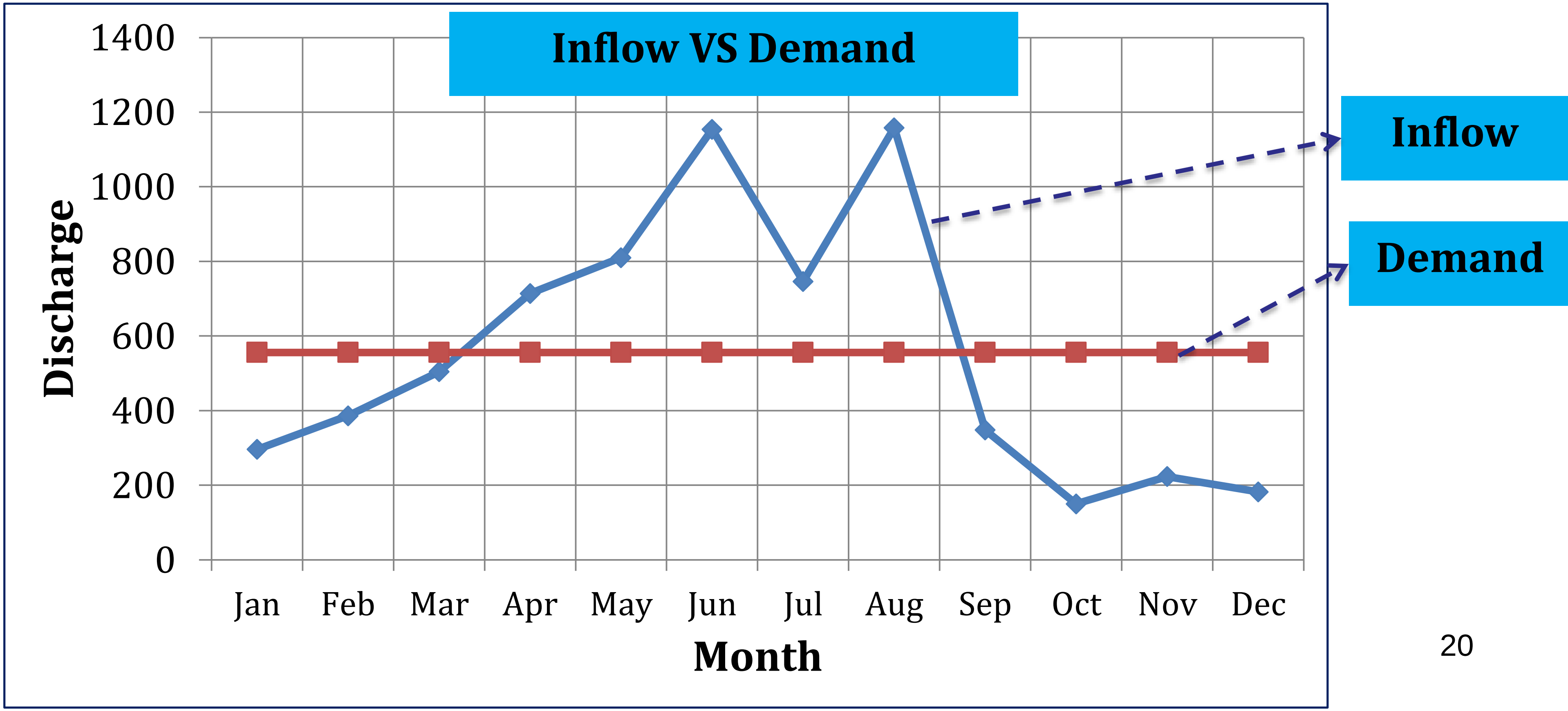
Area =((2.33+163.3)/2)*(41.67-33.33)*(1/100)

Storage = (126.72*30.4*24*60*60) / (1000000)

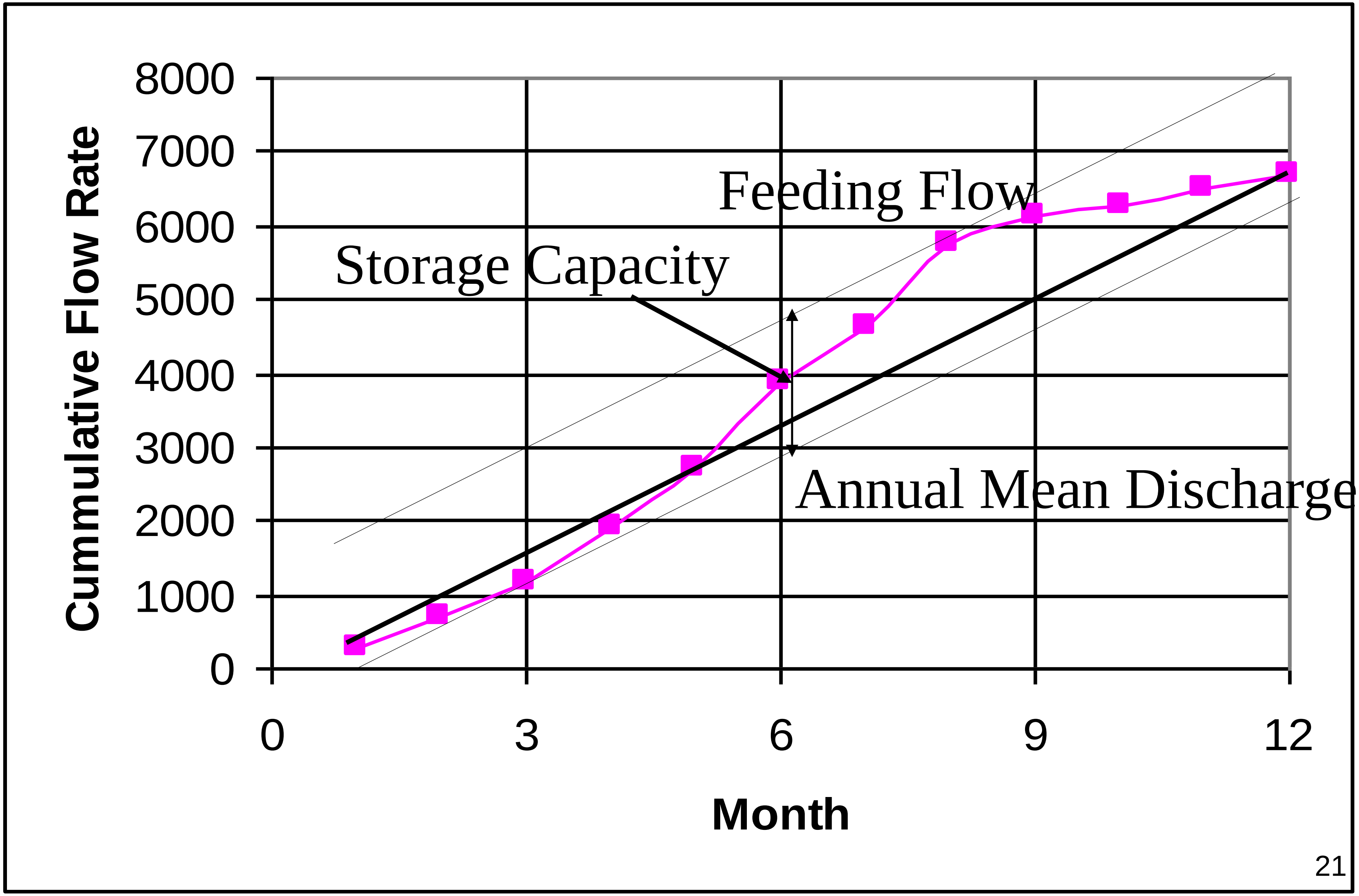
Example 3 Reservoir Capacity

The following table gives the mean monthly flows in a river during certain year. Calculate the minimum storage required for maintaining a demand rate of Mean flow (Average flow): **Mean flow = 555.9167**

Month	1	2	3	4	5	6	7	8	9	10	11	12
Discharge (MCM)	296	386	504	714	810	1154	746	1158	348	150	223	182



Example 3: Mass curve

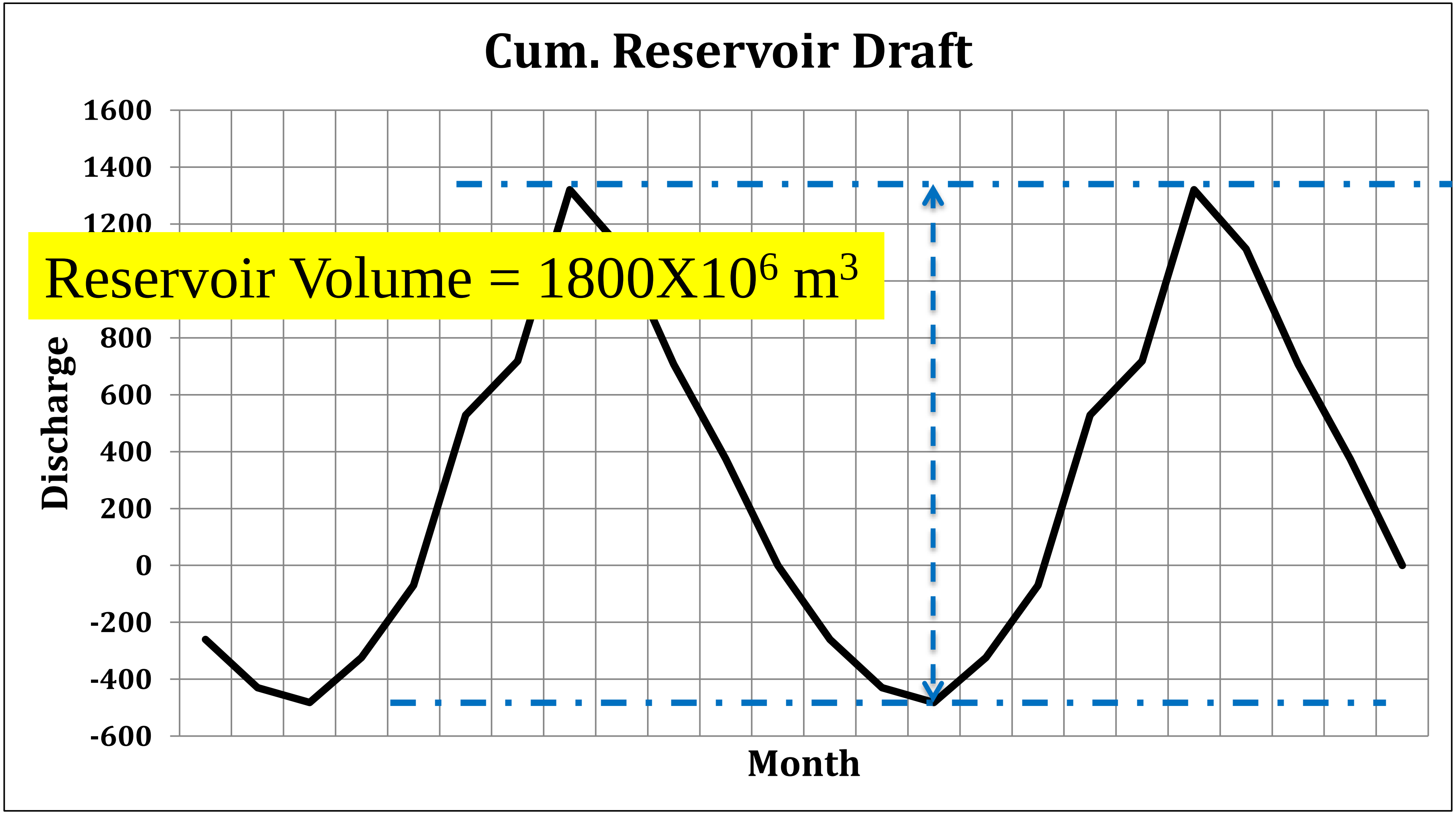


Example 3: Sequent peak algorithm

Month	Inflow Discharge	Inflow-Draft	Cum. Reservoir Draft
			0
1	296	-259.92	-259.9167
2	386	-169.92	-429.83
3	504	-51.92	**-481.75**
4	714	158.08	-323.67
5	810	254.08	-69.58
6	1154	598.08	528.50
7	746	190.08	718.58
8	1158	602.08	**1320.67**
9	348	-207.92	1112.75
10	150	-405.92	706.83
11	223	-332.92	373.92
12	182	-373.92	0.00
1	296	-259.92	-259.92
2	386	-169.92	-429.83
3	504	-51.92	**-481.75**
4	714	158.08	-323.67
5	810	254.08	-69.58
6	1154	598.08	528.50
7	746	190.08	718.58
8	1158	602.08	**1320.67**
9	348	-207.92	1112.75
10	150	-405.92	706.83
11	223	-332.92	373.92
12	182	-373.92	0.00

(H-T)= 1320.67-(-481.75)
=1802 Mm^3

Example 3: Sequent peak algorithm



Reservoir Volume = $1800X10^6$ m^3

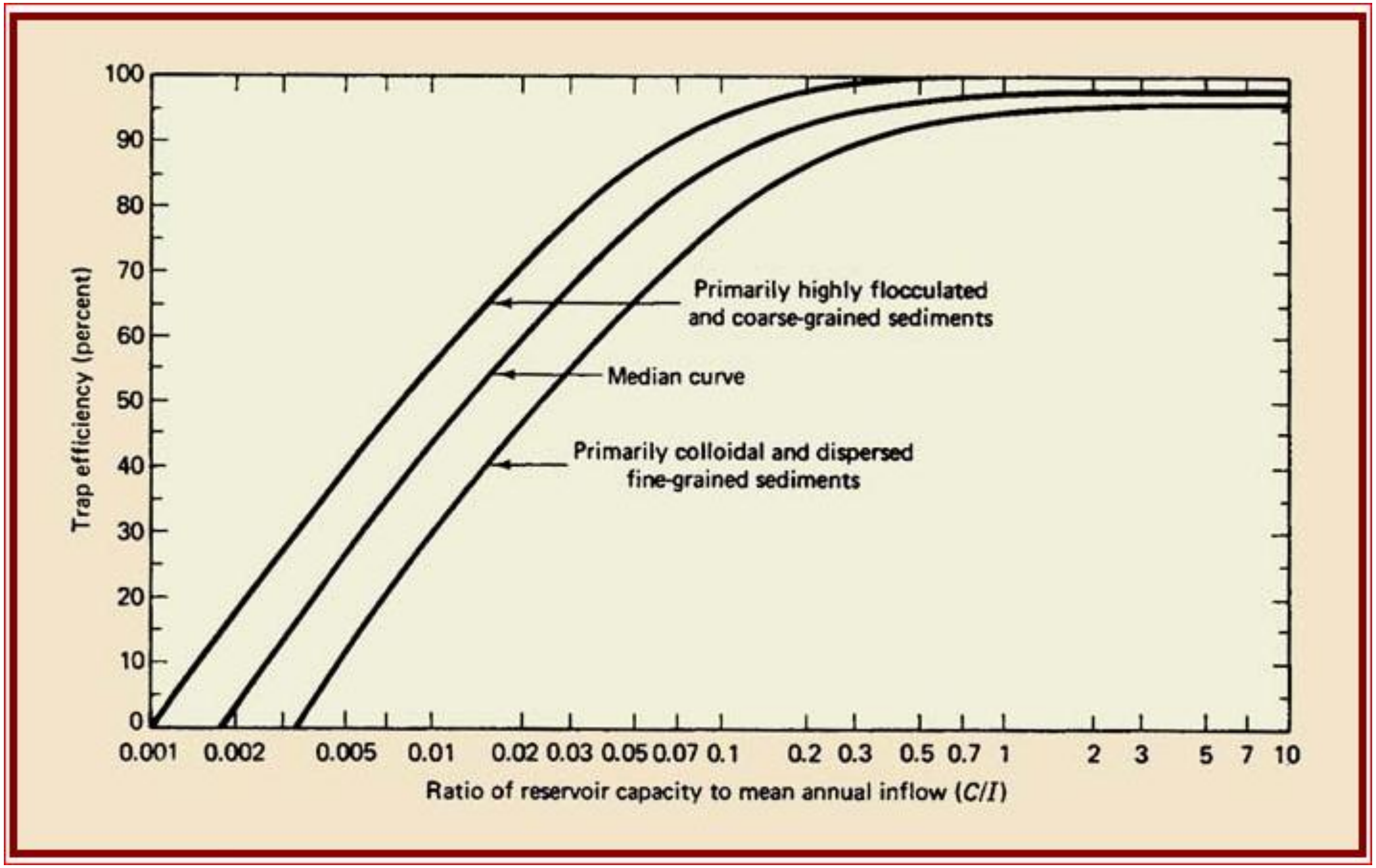
5.3. Reservoirs and sediments

- A river entering a water reservoir will loose its capacity to transport sediments. b/c water velocity decreases, together with the shear stress on the bed. The sediments will therefore deposit in the reservoir and decrease its volume.
- In the design of dam, it is important to assess the **magnitude of sediment deposition in the reservoi**r. The problem can be divided In two parts:

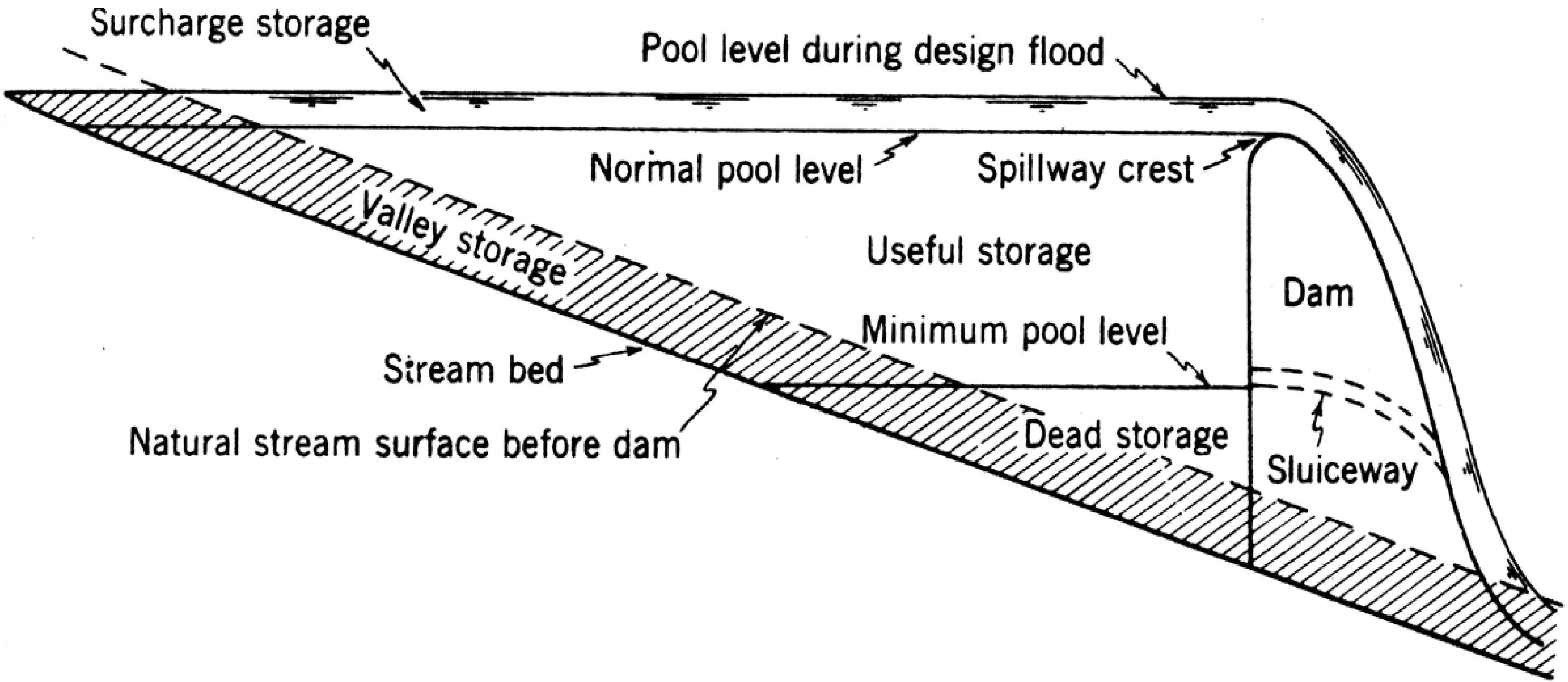
1. How much sediments enter the reservoir
2. What is the trap efficiency of the reservoir

- In a detailed study, the sediment **size distributions** also have to be determined for question 1.
- Question 2 may also involve **determining the location of the deposits** and **the concentration and grain size distribution** of the sediments entering the water intakes.

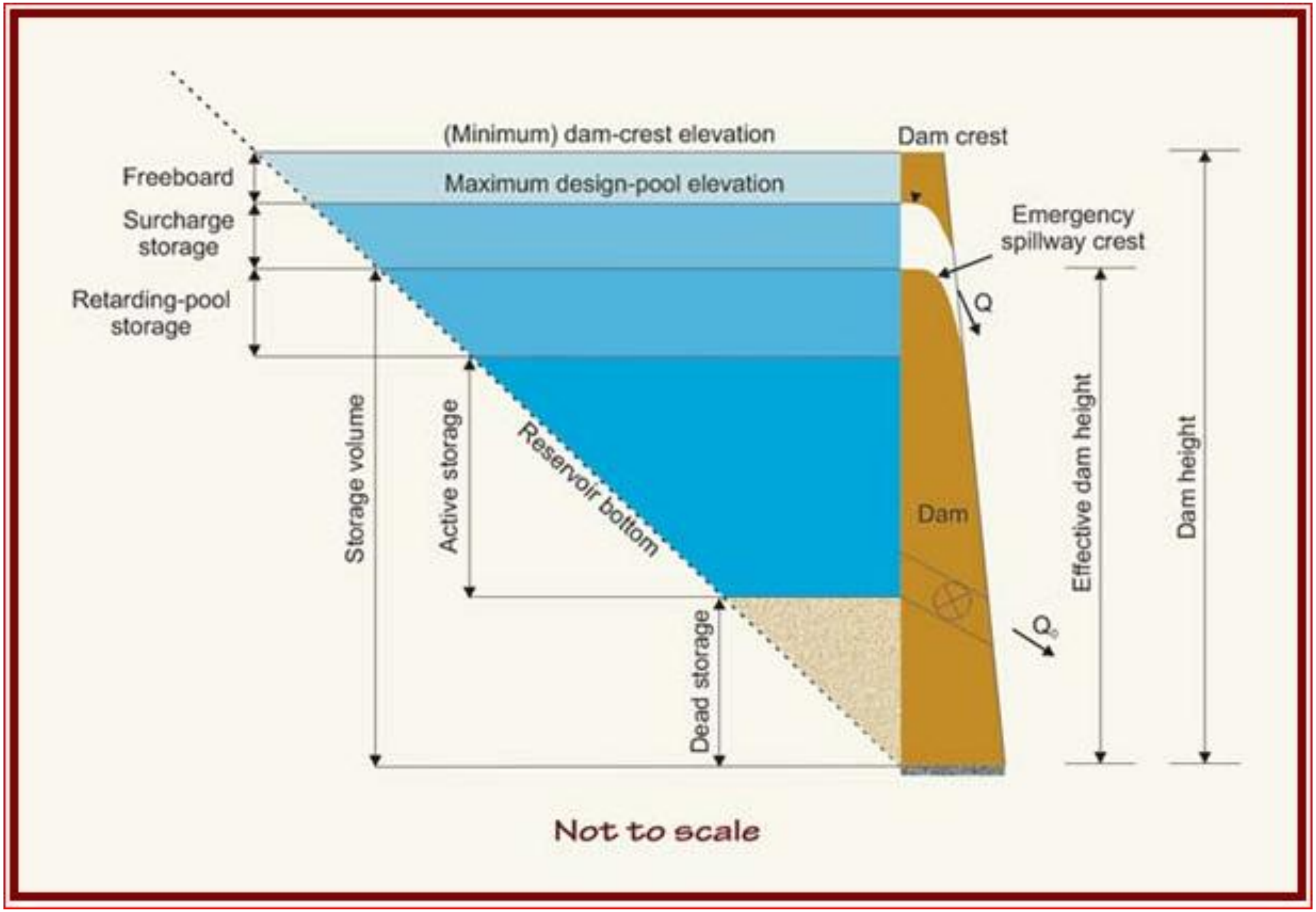
Trap efficiency



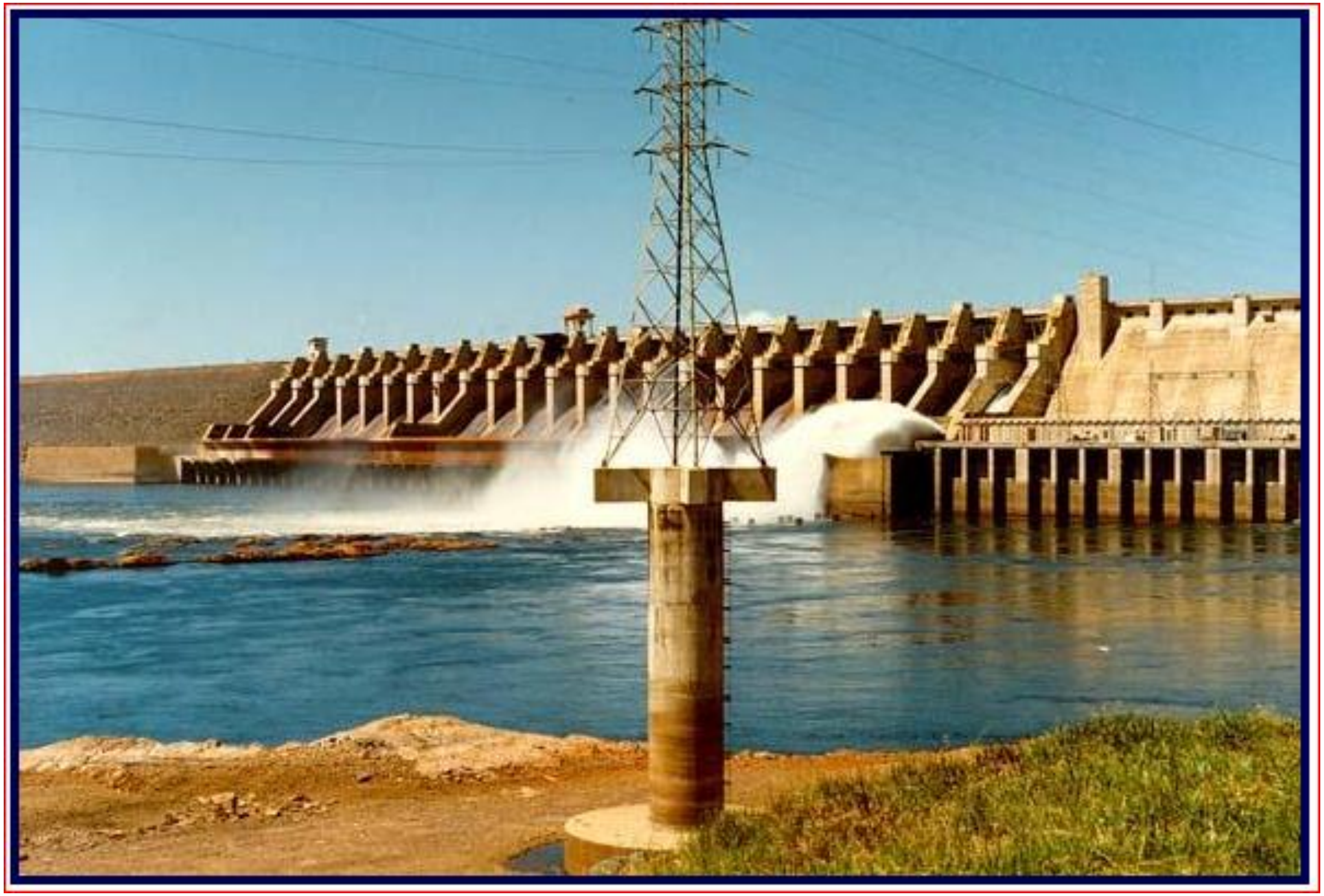
The structure of a reservoir



Reservoir structure



Spillway



Reservoirs and sediments

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

I. 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.

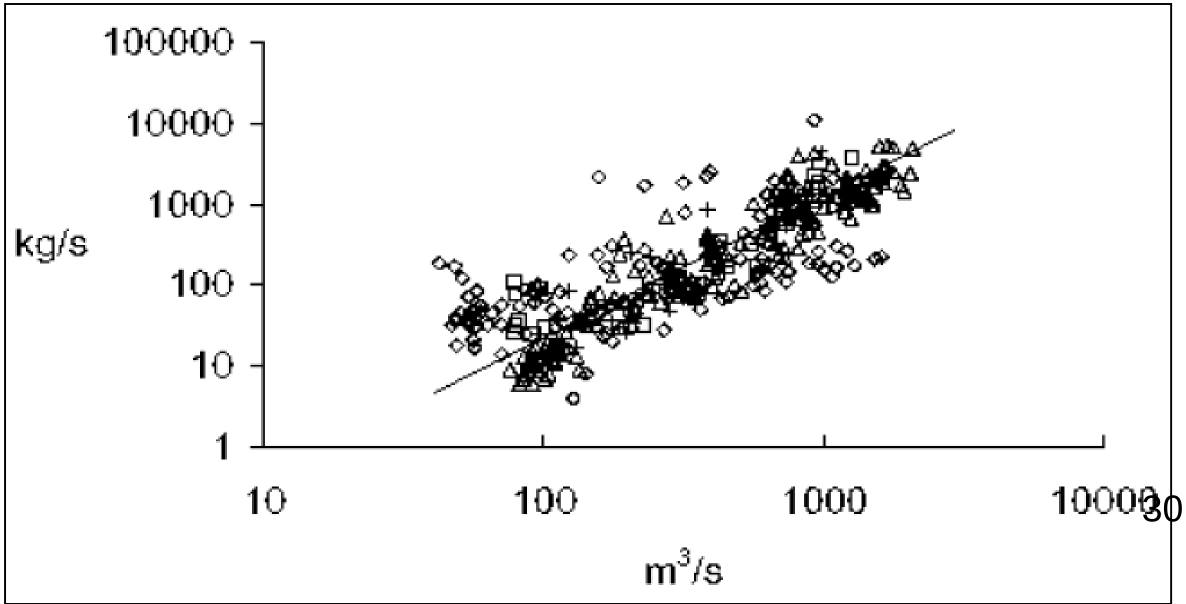
II. The reservoir is designed relatively small and the dam gates are constructed relatively large, so that it is possible to remove the sediments regularly by flushing. The gates are opened, lowering the water level in the reservoir, which increases the water velocity.

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

5.4. Sediment Load Prediction

- The land use, slope and size of the catchment are important factors for determination of sediment load.
- Sediment moves in the streams as suspended load (fine particles) and as bed load. 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:

$$Q_s = a\,Q_w^b$$



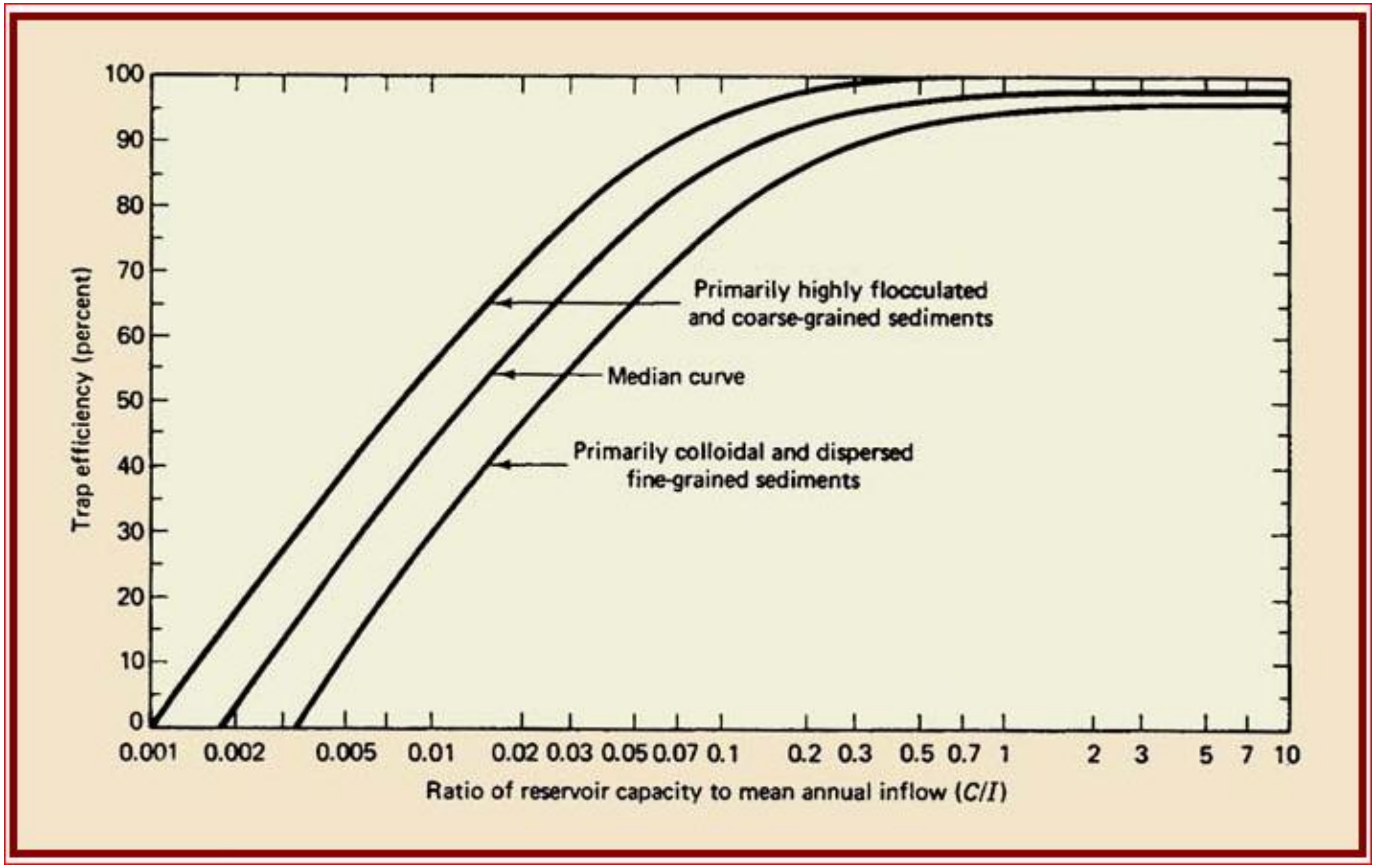
5.5 Reduction in reservoir capacity

- The useful life of a reservoir gets reduced due to sediment deposition causing a decrease in its storage capacity.
- The Percent of the inflowing sediment which is retained in a reservoir is called the **trap efficiency** and it is a function of the ratio of **reservoir capacity** to **total annual sediment inflow**
- The total sediment transport may be estimated by adding 10-22% to the suspended sediment transport to allow for the bed load contribution.

The rate at which the capacity of a reservoir is reduced by sediment deposition depends on

1. The rate of sediment inflow i.e sediment load
2. The percentage of the sediment inflow trapped in the reservoir, i.e. trap efficiency
3. The density of the deposited sediment.

Trap efficiency



Sediment Management

- Catchment Vegetation
- Construction of coffer dams/low height barriers
- Flushing and desilting of sediments
- Low level outlets / sediment sluicing

Catchment vegetation

Wooden barriers

Wooden barriers

Stepped watershed for sediment control

Flushing of sediments from reservoir

Sediment sluicing

Sediment sluicing

Thank You !!!