CE 703 – Water Resources Engineering

Credits : 4

Theory : 60 Marks

Sessional: 40 Marks

Water Resources Engineering

CE 703

Semester : VII

Credit: 4

Unit I

Water resources of India, global water resources, surface and ground water resources, multipurpose uses of water purposes served by water resources development projects, impact of climate change on water resources, single and multipurpose projects, consumptive, non-consumptive, and partial consumptive use, firm yield, secondary yield, estimation of reservoir yield and storage capacity of reservoirs.

Syllabus

Unit II

Sediment transport: Mechanism of sediment transport, sediment load, bed load, suspended load, reservoir sedimentation, trap efficiency, capacity-inflow ratio, measures for control of reservoir sedimentation, estimation of useful life of reservoir

Unit III

Floods and their management, Probable maximum flood, standard project flood, flood estimation techniques, classification of methods of flood control, flood plain management, flood damages, methods for estimation of flood damages, national policy on flood control

Syllabus

Unit IV

General arrangement of hydroelectric projects, hydropower development of India and the world, major hydroelectric projects in India, comparison with thermal and nuclear plants, environmental issues related to hydropower production, firm and secondary power, power duration curves, reliability of hydropower production, illustrative examples

UNIT V

River morphology; classification of rivers and river training works, methods of river training works, marginal embankments, guide bunds, groynes, cutoffs, bank pitching and launching aprons, design of guide bunds.

Reference Books

Irrigation Water Resources and Water Power Engineering, P. N. Modi

Water Resources Engineering, Larry W Mays

Water Resources Engineering, R. K. Linsley et al.

Water Resources Engineering, S K Garg

Irrigation Engineering, B C Punmia

Water Resources Engineering, Principles and Practices, Satya Narayana Murty Challa

Applied Hydrology, V. T. Chow et al.

Water Resources Engineering

Science which deals with the conception, planning, design, construction and operations of facilities and structures related to utilisation of the water available on the earth

Also deals with control of water and water quality management

Types of Water Resources Projects

Water resources projects for utilisation of water are those of irrigation, hydropower, water supply, navigation etc.

Projects to control water include those for flood control, land drainage, sewerage and highway culvert design

Projects for water quality management are required to maintain desired water quality for municipal supplies and irrigation, and for preserving the aesthetics of the river

Importance of Water

Water is an important constituent of the geo-system

It is the most abundant substance on earth

Oceans cover more than 70 percent of the earth's surface and contain roughly 1.35 x 10^9 km^3 of water

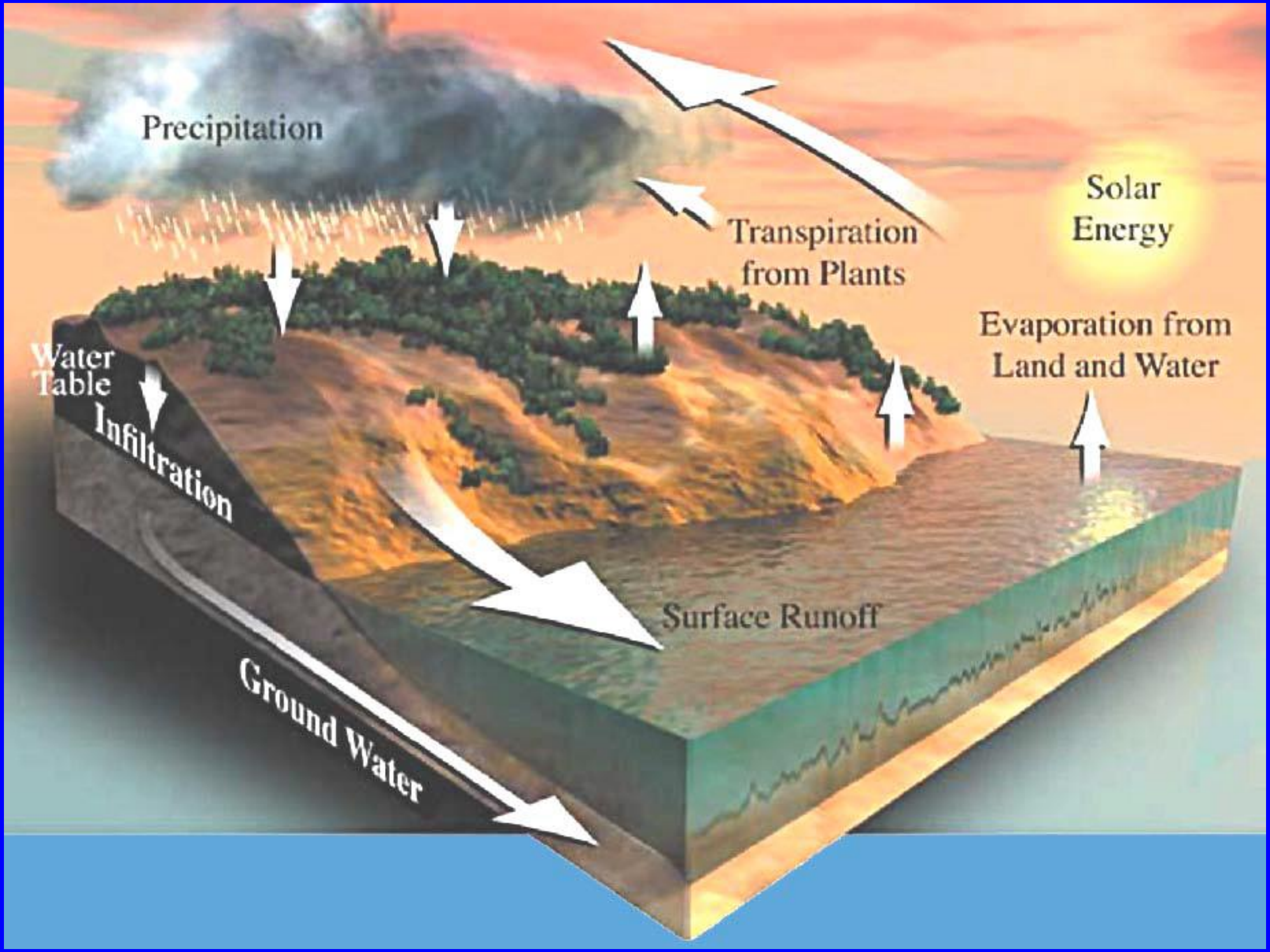
Human body itself is 65 percent water and everyday 5 percent of it must be replaced

Man can live without food for several weeks, but without water the longest he can live is about ten days

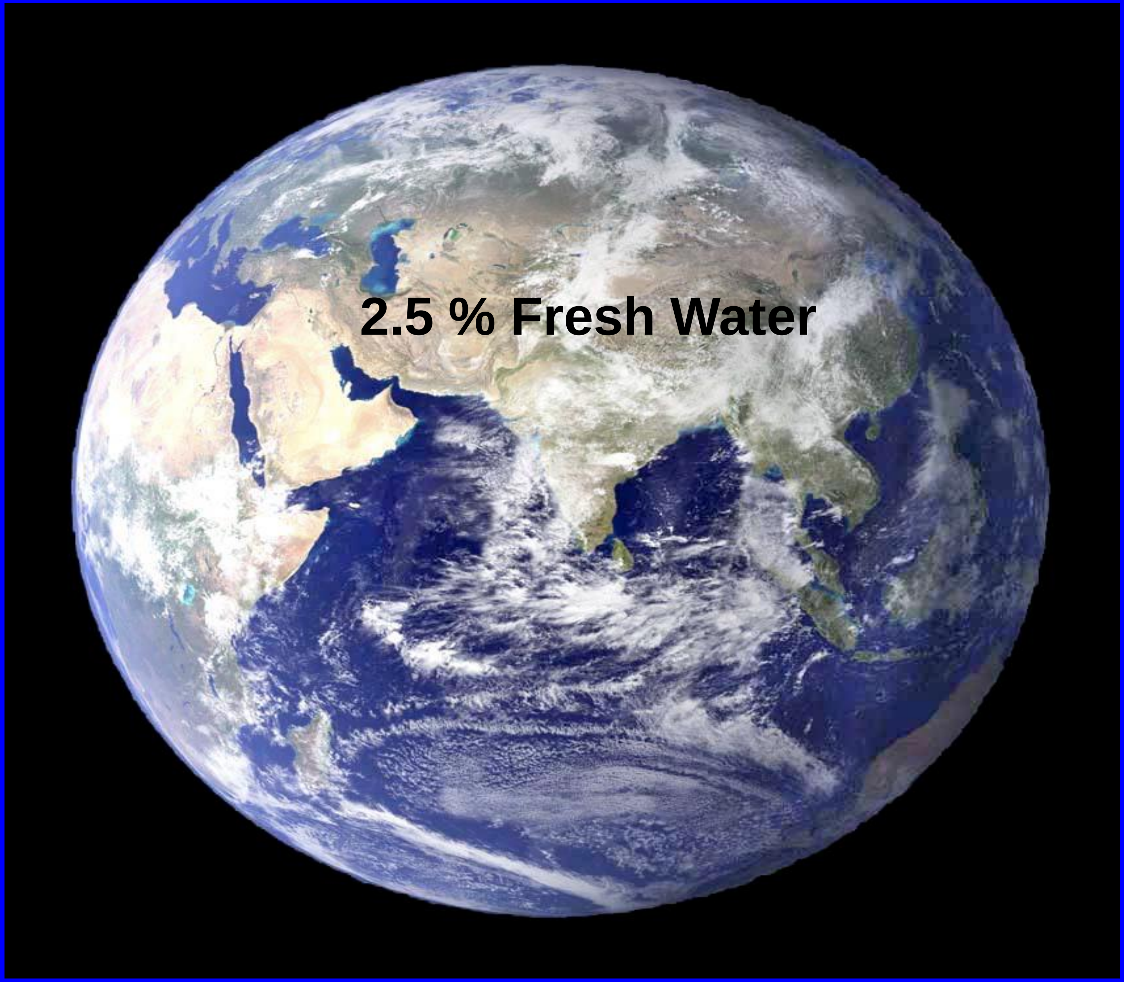
Water is not only vital for sustenance of life, but it is also essential for socio-economic development

Irrigation, industries, navigation – all require water

The Hydrological Cycle



Freshwater Availability

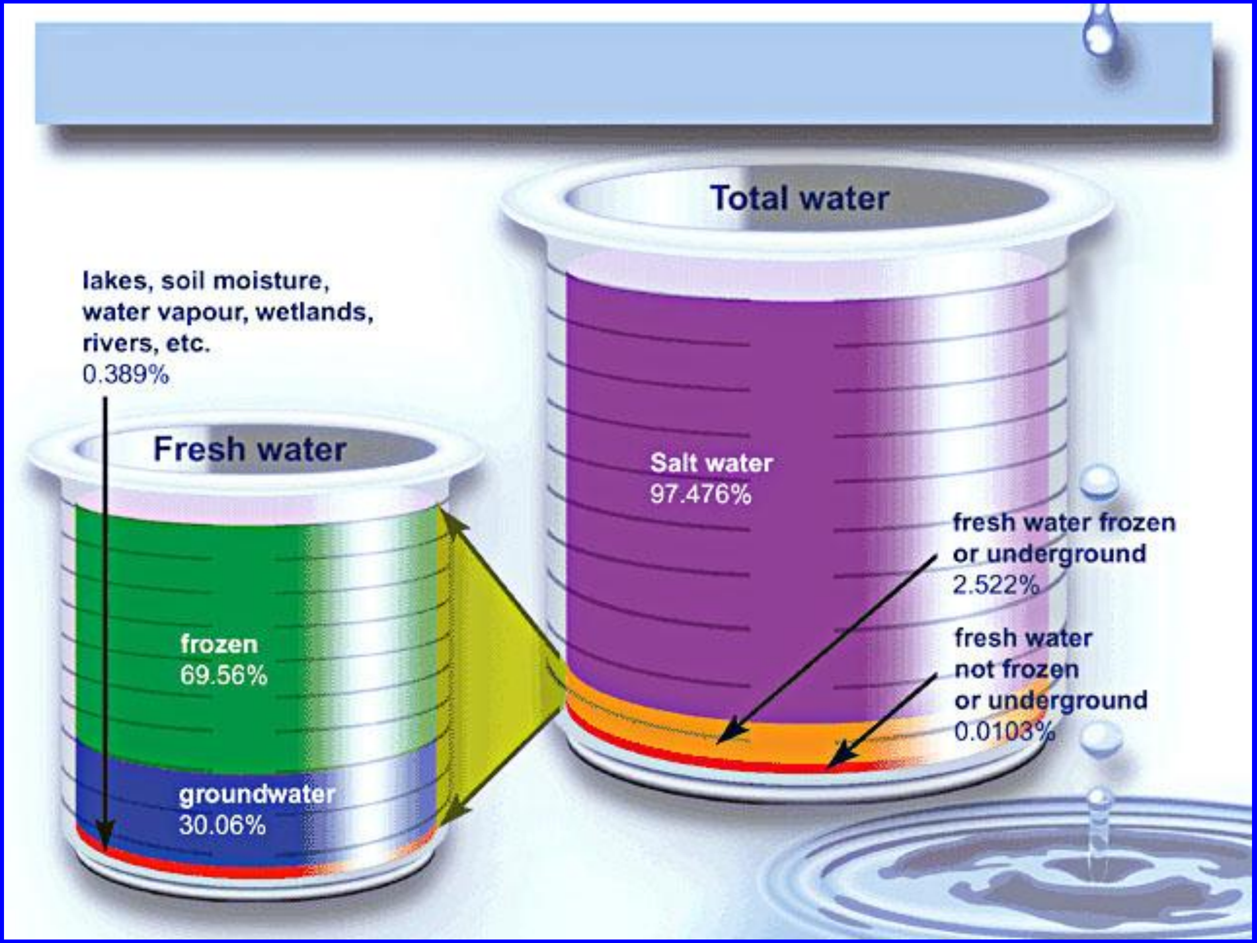


Freshwater Availability

Fresh water is stored in

- **Aquifers**
- **Surface water bodies**
- **atmosphere**

Fresh Water Availability



Water Resource Management

- Water Resources Management aims at optimizing the available natural water flows, including surface water and groundwater, to satisfy competing needs
- Adding uncertainty, climate change will increase the complexity of managing water resources
- In some parts of the world, there will be more available water but in other parts, including the developing world, there will be less than what is required to satisfy the basic needs

Potential Problems

Importance of Water Resource Projects

With higher rates of urbanization, increasing demand for drinking water will put stress on existing water sources

Feeding a planet of 8 billion by 2030 will require producing more food with less water and through improved water efficiency in agriculture

Energy demand will more than double in poor and emerging economies in the next 25 years and hydropower will need to be a key contributor to clean energy production

Floods and droughts will continue to threaten farmer livelihoods and lowland economies due to climate change

The Global Water Situation

- If these trends continue well into the future, doubling of the world's population would mean a six fold increase in the total global water requirements
- This would most likely be an unsustainable situation on a long-term basis

The Global Water Situation

- **Total Global water use has steadily increased throughout the recorded history, and the trends observed in the 20th century are no exception**
- **Total Global Water use is likely to have increased about tenfold from 1900 to 1999**
- **The total water use growth rate has been significantly higher than the population growth rate in the present century**

The Global Water Situation

- Globally, an estimated 2.6 billion people lack access to adequate sanitation, and current efforts to improve access are not adequate to meet the Millennium Development Goal (MDG) of halving the number of people without access to improved sanitation by 2015
- At the current rate of progress, the world will miss the MDG target by 13 percentage points and by 2015 there will be 2.7 billion people without access to basic sanitation. Even if we were able to meet the MDG target, there would still be 1.7 billion people without access to basic sanitation

Water Stress Criterion

Index of water per capita, (Schram, 1999)

▪ Renewable freshwater per capita (mcum/y)	Effects on country
> 1700	limited stress
1000 – 1700	water stressed
1000 – 500	water scarce
< 500	absolute scarcity

Schram.T.J. (1999). Evaluation of water scarcity in Africa.

http://www.ce.utexas.edu/stu/schramtj/scarcity/scarcity.html

Global Water Resources

▪ Total water on Earth :	1384 million cu. km
▪ Water in Oceans as saline water (97.4%):	1348 million cu. Km.
▪ Polar ice cap and glaciers (2.01 %)	27.82 million cu. Km
▪ Soil moisture and ground water (0.58%)	8.03 million cu. Km.
▪ Lakes and rivers (0.02 %)	0.277 million cu. Km
▪ Atmosphere (0.001%)	0.014 million cu. Km

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The World Water Resources

▪ Total water on Earth :	1384 million cu. km
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▪ Lakes and rivers (0.02 %)	0.277 million cu. Km
▪ Atmosphere (0.001%)	0.014 million cu. Km

The World Water Resources

- Total fresh water on the earth is 36 million cu.km which is about 2.5 percent of the total water on this planet. Out of this 77 percent is frozen and only 0.01 percent i.e. 0.36 million cu. Km is available in rivers and streams. The balance is accounted for by ground water, lakes and swamps and atmosphere

- Utilizable limit of water is further governed by three major considerations i.e. quality, location, and time of availability. Thus, the useable water constitutes infinitesimally small part of the total supply.

Population and Per Capita Water Availability

	Population (Millions)			Per capita freshwater availability (1000 m^3)		
	1994	2025	2050	1994	2025	2050
Bangladesh	117.8	196.1	238.5	20.0	12.2	9.88
Canada	29.1	38.3	39.9	99.69	75.74	72.7
China	1190.9	1526.1	1606.0	2.35	1.83	1.74
India	913.6	1392.1	1639.1	2.28	1.50	1.27
United Kingdom	58.1	61.5	61.6	2.07	1.95	1.95
United States	260.6	331.2	349.0	9.51	7.48	7.1

Water Resources of India

- **India has one of the most fertile river basins in the world. Physiographically, India can be divided into:**
- **The Northern Mountains:** Himalayan ranges are 2500 Km in length, 250-400 km in width with a mean elevation of 6000 m above msl. The region is underdeveloped. Only 17 percent of the ultimate potential of hydropower in northern region and 0.3 percent of north eastern region is developed.
- **The Great Plains:** These strech across hundreds of kilometres at the foot of the Himalayas. Extending over an area of about 6,52,000 sq. km the plains mostly consist of alluvial deposits and abundant ground and water resources. These are amongst the most fertile regions in the world.

Water Resources of India

- **The Central Highlands**
  - **The central highlands lie between the great plains of North India and the Plateaus of Deccan and constitute one sixth of the total area of India**
- **The Peninsular Plateau**
  - **It is the largest physiographic division of India. It constitutes the area, triangular in shape between the Bay of Bengal in the east and The Arabian sea in the west.**

Water Resources of India

- **The West Coast Belt**
  - **It extends over a distance of 1,000 km, from Cape Comorin (the southern most tip) northwards with an average width of 100 km to 130 km**
- **The Islands of India**
  - **They include Lakhwadeep in the Arabian sea and Andaman and Nicobar in the Bay of Bengal, among others.**

Water Resources of India – Rainfall Distribution

- Long-period average annual rainfall over India is about 117 cm
- Spatial and temporal distribution of this rainfall is, however, highly non-uniform
- Almost 75% of the long-term average annual rainfall occurs in four months, June–September (southwest monsoon season)
- The heaviest rains of the order of 200–400 cm or even more occur over northeast India and along the Western Ghats situated along the west coast of the peninsular India

Water Resources of India – Rainfall Distribution

- **Some regions in the extreme western part of the country, such as western Rajasthan, receive average annual rainfall of the order of about 15 cm or even less**

- **There are considerable intra-seasonal and inter-seasonal variations as well**

The year-to-year variability in monsoon rainfall leads to extreme hydrological events (large-scale droughts and floods) resulting in serious reduction in agricultural output and affecting the vast population and national economy

A normal monsoon with an evenly distributed rainfall throughout the country is rare

Water Resources of India

Annual precipitation	4000 BCM
Available water resources	1869
Utilizable	1122
Surface water (storage and diversion)	690
Groundwater (replenishable)	432
Present utilization	605
(Surface water 63%, groundwater 37%)	
Irrigation	501
Domestic	30
Industry, energy and other uses	74

Break-up of India's Surface Water Resources

Basin	Average annual runoff (million ha m)	Utilisable flow (million ha m)
Indus basin	7.7	4.93
Ganga basin	51.0	15.0
Brahamputra Basin	54.0	2.4
East Flowing Rivers	34.8	33.8
West Flowing Rivers	30.5	9.9
Total	178.0	66.03

Consumptive and Non-Consumptive Uses

Water use may be broadly considered under the three groups

Consumptive

Non Consumptive

Partial-consumptive

Consumptive Use

Irrigation is a real consumptive use due to evapotranspiration losses

Irrigation accounts for single largest use of water – nearly 90%

At present nearly 40% of irrigation water is used for rice cultivation

The quantity of water required per hectare of rice is sufficient for 3 to 4 hectares of other crops

Even a light water consuming crop like wheat needs as much as 1500 tonnes of water per tonne of wheat

Consumptive Use

Irrigation requires vast amounts of water. In a single growing season a plant may soak up as much as 20000 times its grain yield

Organized irrigation developed in Mesopotamia as early as 4000 B C and in the Nile Valley around 3400 B C

Indus basin system in India and Pakistan supply water to 9 million ha of land

Imperial valley system in the US irrigates more than 2 million ha of land

Consumptive Use

Agricultural Product (per ton)	Water Required (ton)
Wheat	1500
Maize/ Bajra	2000
Groundnut	3000
Sugarcane	4500
Rice	5000

Non Consumptive Use

Non-consumptive use normally do not require any reservation of water. With proper coordination, the water reserved for other purposes can meet the needs of the non-consumptive uses

Major non-consumptive uses

Hydropower Generation

Hydropower is renewable, resource saving and environmental friendly. Perennial and inexhaustible hydel power represents the cheapest source of energy

Non Consumptive Use

Unlike irrigation, no water is consumed in hydropower generation and it is considered incidental to the irrigation releases in a multipurpose project

However, at certain times releases may have to be made for hydropower generation even when irrigation demand is not there

With the use of sophisticated computer models for reservoir operations, the utilisation of water can be improved

Non Consumptive Use

Inland Navigation

Navigation is the cheapest means of transportation . Besides, it does not consume water.

Navigation is developed as an incidental benefit to irrigation on irrigation channels while navigation on rivers is dependent on river flows

Two important requirements of navigation are a minimum water depth of 3 m, and moderate velocity of flow to permit upstream travel

Partial Consumptive Use

Use of water for domestic and industrial purposes are partial consumptive as most of the water could be recycled or reuse after proper conditioning

Major partial consumptive uses are

- Domestic
- Fire Demand
- Industrial
- Thermal and Nuclear Power Generation

Partial Consumptive Use

Domestic

It is estimated that the water utilization for domestic purposes including livestock requirements in India is about 1.7 million hectare metre

The rate of demand for water supply depends upon population, climate, season, living conditions, quality, status of water pricing policies

Modern living standard has made it necessary to rely upon water supplies of far greater volume than required earlier

Partial Consumptive Use

Fire Demand

It is a function of population

The total amount of water used in fire extinguishing is negligible compared to total use but it shall be adequate in capacity and pressure and free from reasonable possibility of interruption

Generally, fire demand is taken as 1 lpcd

Partial Consumptive Use

Industrial Use

Industries are a heavy user of water . Industrial water use varies with the intended type of operation

The factors that affect industrial use are

1. Nature of the processes and equipment employed
2. Availability and cost of water
3. Difficulty in water disposal
4. Water conservation measures adopted
5. Recycling of water

Partial Consumptive Use

Thermal and Nuclear Power Generation

- **The principal use of water in the steam electric generation plant is for condenser cooling purposes.**
- **The steam after its use in turbines is passed through the condenser where it is cooled and condensed**
- **The only consumptive use is the evaporation loss**
- **With recirculation, the present cooling water requirement is 255 lites/KWh**
- **In the USA, water used for steam plants is estimated as 600-1000 tonnes for each tonne of coal burnt**
- **Nuclear power plants require 50 percent more water than fossil fuel plants**

Partial Consumptive Use

- Industries require huge amount of water - each automobile coming out of the assembly linerepresents an expenditure of at least 150,000 litres of water
- Every litre of gasoline represents 300 litres of water utilized in refining
- Each kilowatt hour of energy generated through thermal conversion requires 255 litres of water for condenser requirements

Reservoirs

Reservoirs are created by constructing a dam across the river which can retain water from periods of high flows for use during the period of low flows

Reservoirs are constructed to serve many purposes as indicated below

(i) Flood Control

(ii) Irrigation

(iii) Hydropower Development

(iv) Navigation

(v) Recreation

(vi) Water Supply

Reservoirs

Reservoir Storage Zones

Normal Pool Level:

Maximum elevation to which the water surface will rise in the reservoir during ordinary operating conditions. It is determined by the elevation of the spillway crest

Minimum Pool Level

Lowest elevation to which water is drawn from the reservoir under normal conditions. This may be fixed by the elevation of the lowest outlet in the dam or by the minimum head required for efficient functioning of the turbine

Maximum Pool Level

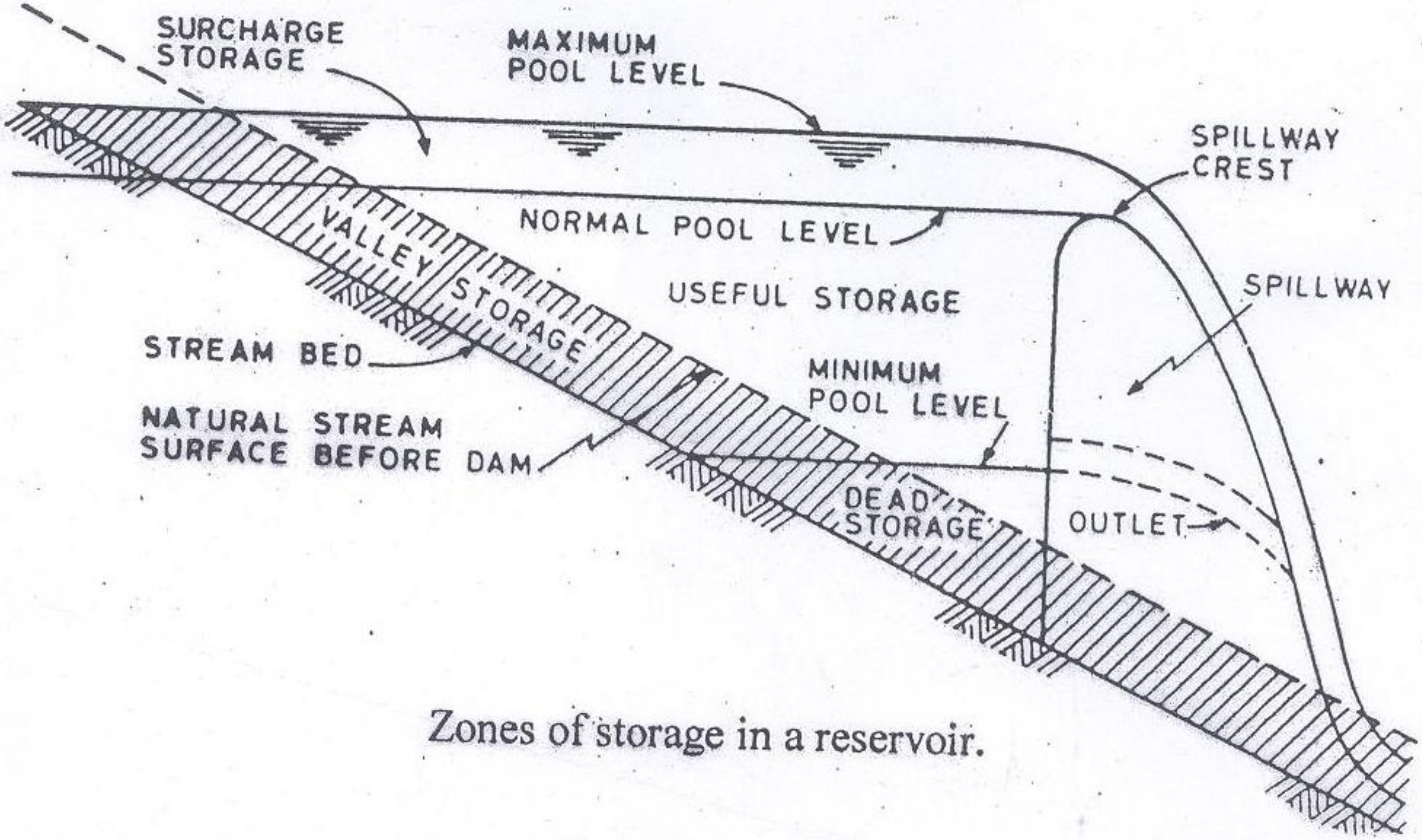
Maximum elevation to which the water surface will rise in the reservoir during the design flood.

Reservoirs

The various zones of storage in a reservoir are as follows

- **(a) Useful Storage**
- **(b) Dead Storage**
- **(c) Surcharge Storage**
- **(d) Bank Storage**
- **Useful Storage**

The volume of water stored between the normal pool level and the minimum pool level of a reservoir.



Zones of storage in a reservoir.

Reservoirs

- **Dead Storage**

  The volume of water held below the minimum pool level

- **Surcharge Storage**

  The volume of water stored between the normal pool level and the maximum pool level of a reservoir. This storage is an uncontrolled storage as it exists only while a flood is occurring and cannot be retained for later use

- **Bank Storage**

  The bank storage is the volume of water that is temporarily stored in the permeable banks of a reservoir when the reservoir fills and drains out as the water level in the reservoir is lowered

Reservoir Yield

- The most important aspect of reservoir design is an analysis of the relation between yield and capacity
- Yield is the amount of water which can be supplied from the reservoir in a specified interval of time
- The time interval may vary from a day for a small reservoir to a year or more for a large storage reservoir
- Yield depends upon the inflow and will vary from year to year.

Reservoir Yield

- Safe Yield is the maximum quantity of water which can be supplied during a critical or a worst period. The period of lowest natural flow on record for the stream is usually taken as the critical period.
- Secondary Yield is the quantity of water available in excess of safe yield during periods of high flows
- Inflow – Yield = Change in Storage

Reservoir Yield

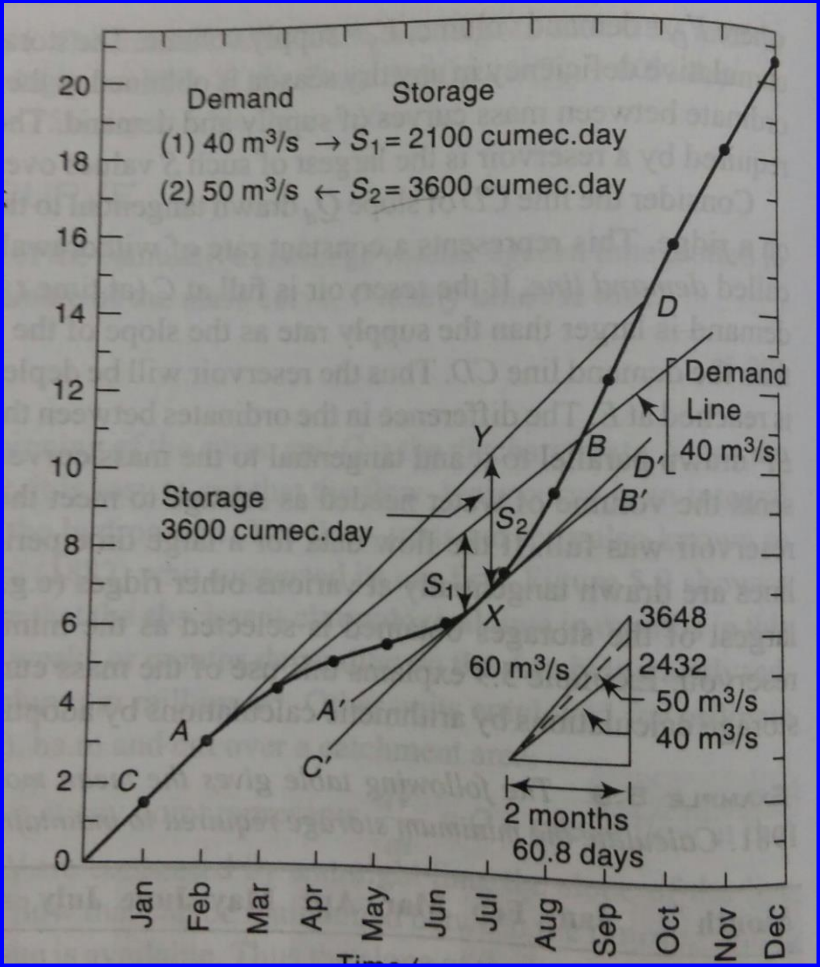
- The value of the yield adopted for the design of a reservoir is known as design yield which should be such that the demands of the consumers are met with and at the same time the storage is not unduly depleted
- A reservoir for domestic water supply must be planned on the basis of firm yield. On the other hand a reservoir for irrigation should be planned for design yield 20% higher than the firm yield

Mass Curve

- **A mass curve is a plot of accumulated flow in a stream against time. A mass curve can be prepared from the flow hydrograph of a stream for a large number of consecutive years.**

- **Figure below shows a typical hydrograph of a stream for six consecutive years. The area under the curve from the starting year (i.e. 1953) upto any time t_1 represents the total quantity of water that has flown through the stream from 1953 upto time t_1 and hence it is equal to the ordinate of the mass curve at time t_1. Ordinates at different times are thus obtained and plotted against time to obtain the mass curve. A mass curve continuously rises as it shows accumulated flows.**

Mass Curve



Demand
Storage
(1) 40 m³/s → S₁ = 2100 cumec.day
(2) 50 m³/s ← S₂ = 3600 cumec.day
Storage
3600 cumec.day
Demand
Line
40 m³/s
A
B
C
D
A′
B′
C′
D′
X
Y
S₁
S₂
60 m³/s
3648
2432
50 m³/s
40 m³/s
2 months
60.8 days
0
2
4
6
8
10
12
14
16
18
20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Demand Curve

- A demand curve is a plot between accumulated demand and time. If the demand is at a constant rate then the demand curve is a straight line with slope equal to the demand rate

Determination of reservoir capacity required for a specific yield or demand using mass curve

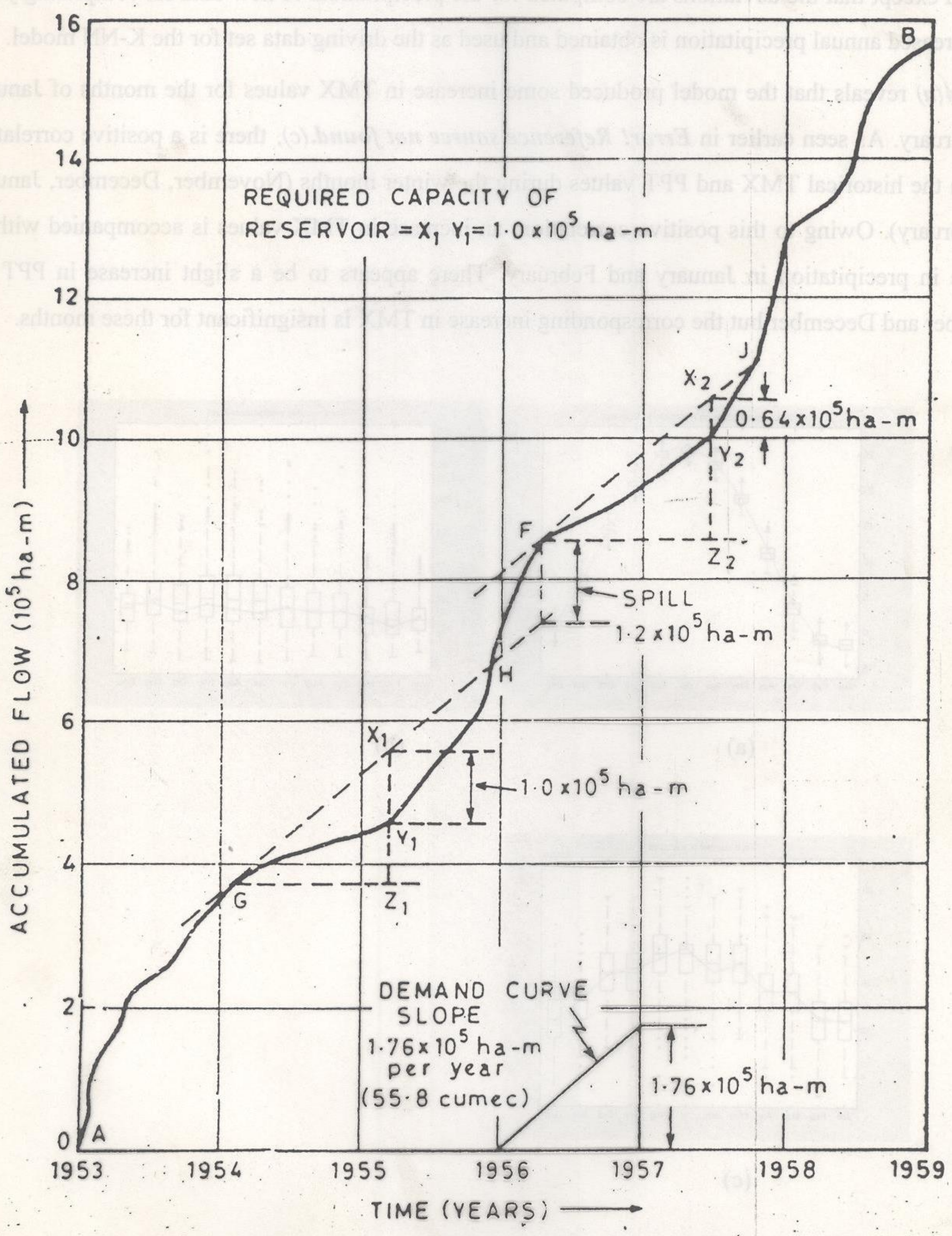
- The procedure for determining the reservoir capacity for a given yield or demand is as follows

1. Draw the mass curve from the flow hydrograph that includes the most critical driest period
2. Corresponding to a given rate of demand, a demand curve is prepared. If the demand is constant then it is a straight line
3. Tangents such as GH and FJ are drawn at the high points of the mass curve i.e. G and F

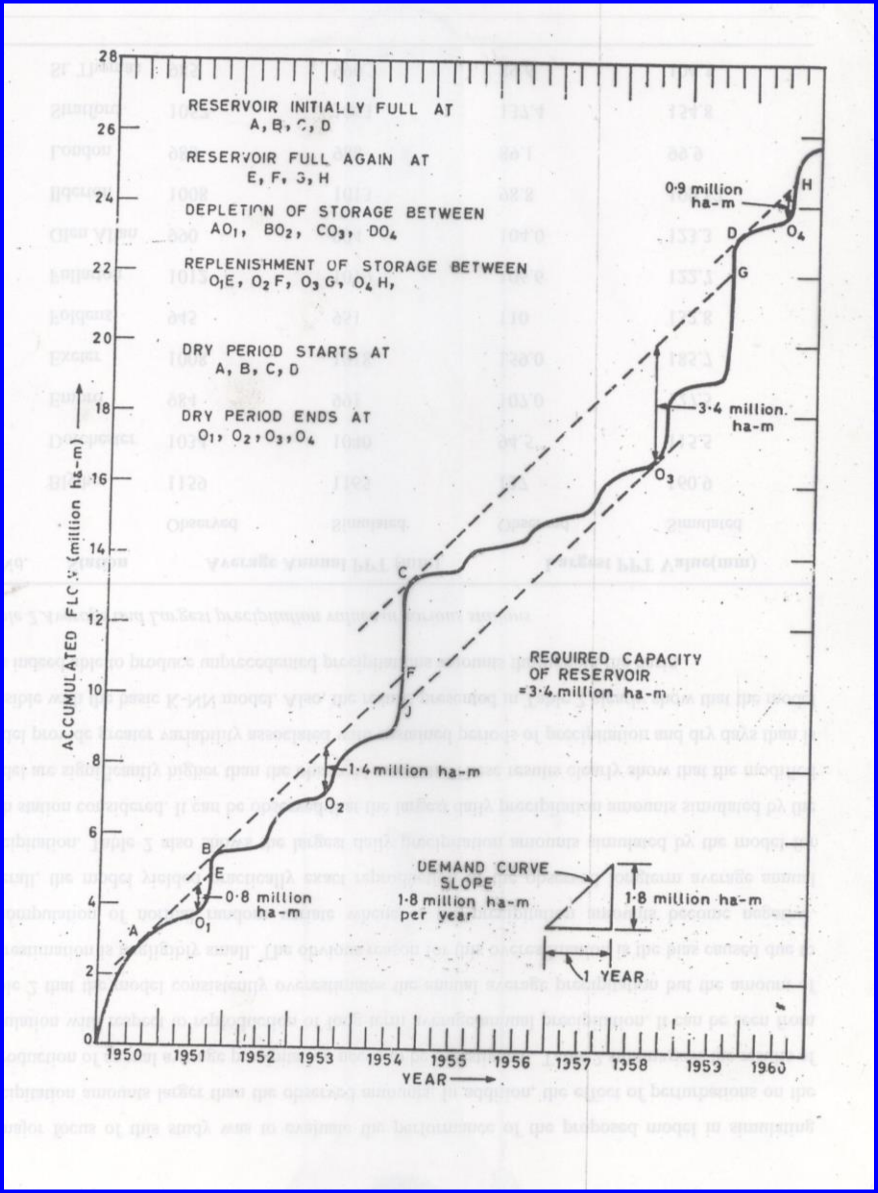
Determination of reservoir capacity for a specific yield or demand using mass curve

4. The maximum vertical intercepts X_1Y_1 and X_2Y_2 between the tangents and the mass curve are measured. The vertical intercepts represent the deficit between demand and the total flow. Hence, this amount is required to be provided from the reservoir storage. For example assuming the reservoir to be full at G, for a period corresponding to points G and Z_1, there is a total flow in the stream represented by Y_1Z_1 and there is a total demand represented by X_1Z_1, leaving a deficit of X_1Y_1 which must be met from the reservoir storage

5. The largest of the maximum vertical intercept represents the reservoir capacity required to satisfy the given demand



Determination of Reservoir Capacity


RESERVOIR INITIALLY FULL AT A, B, C, D
RESERVOIR FULL AGAIN AT E, F, G, H
DEPLETION OF STORAGE BETWEEN AO1, BO2, CO3, DO4
REPLENISHMENT OF STORAGE BETWEEN O1E, O2F, O3G, O4H,
DRY PERIOD STARTS AT A, B, C, D
DRY PERIOD ENDS AT O1, O2, O3, O4
ACCUMULATED FLOW (million ha-m)
YEAR
0·9 million ha-m
3·4 million. ha-m
1·4 million ha-m
0·8 million ha-m
REQUIRED CAPACITY OF RESERVOIR =3·4 million ha-m
DEMAND CURVE SLOPE 1·8 million ha-m per year
1·8 million ha-m
1 YEAR

Determination of spill from mass curve

The vertical distance between the successive tangential lines such as GH and FJ represents the quantity of water which would spill. This is because at H the demand curve intersects the mass curve and therefore the reservoir would remain full between H and F. However, if the demand curve do not intersect the mass curve, the reservoir will not be filled again.

From the Figure shown here, following results are obtained

The reservoir capacity X_1Y_1 = 1.0 x 10^5 ha-m

Determination of spill from mass curve

Assuming the reservoir to be full at G, it would be empty at Y_1 and would be full again at H

Between H and F the reservoir would remain full and all inflow in excess of demand would spill, whose value is 1.2 x 105 ha-m

Assuming the reservoir to be full at F, it would be depleted to (1.0 x 105 – 0.64 x 105) =0.36 x 105 ha-m at Y_2 and would be full again at J

Determination of reservoir capacity when the demand is not constant

Due to variable demand, the slope of demand curve will vary from point to point

1. Required capacity can be determined in the same way by superimposing the demand on the mass curve from the high points till the two meet again. The largest vertical intercept between the two curves gives the required reservoir capacity

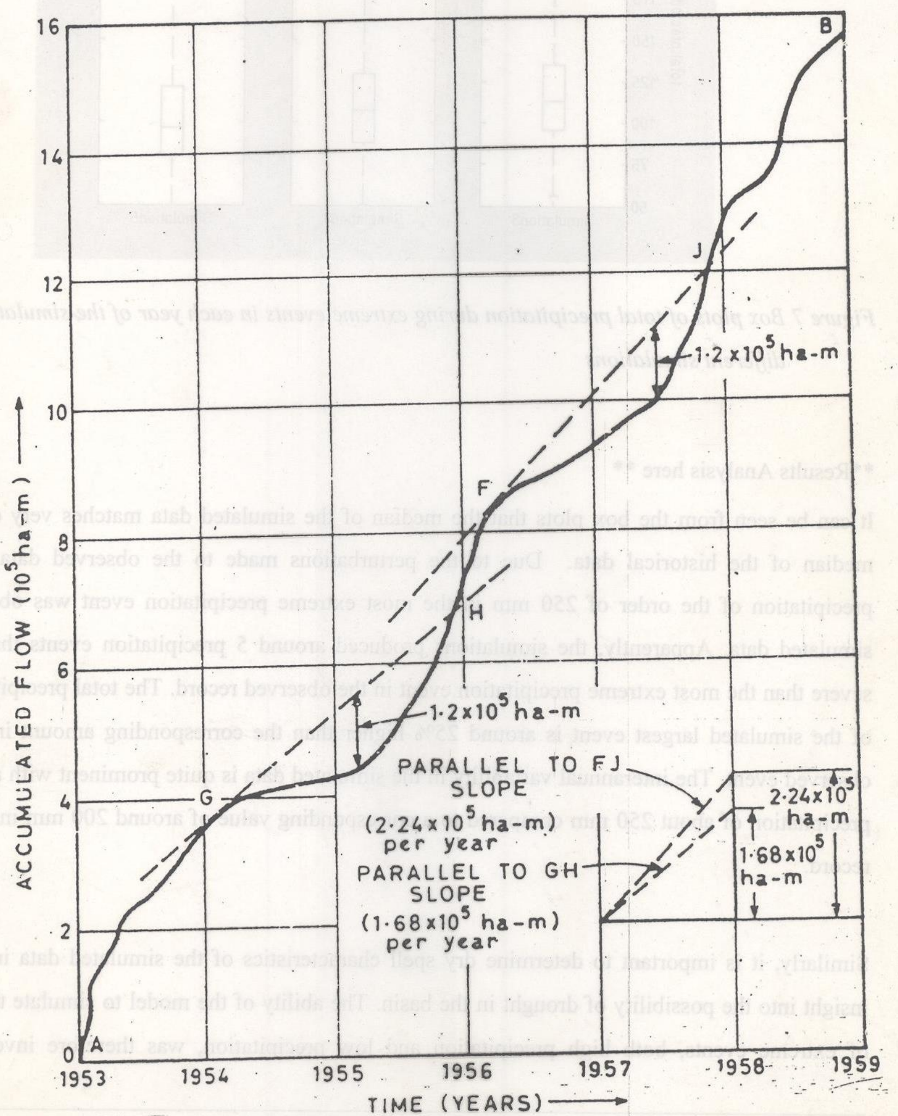
Determination of yield from a reservoir of given capacity

Mass curve may also be used to determine the yield which may be obtained from a reservoir of given capacity

1. Tangents are drawn at the high points G, F, etc. of the mass curve in such a manner that their maximum departure from the mass curve does not exceed the given capacity of the reservoir
2. The slopes of these tangents are measured which indicate the yield which could be obtained each year from the reservoir of given capacity
3. The slope of the flattest demand curve is the safe or the firm yield

The slope of GH is 1.68×10^5 ha-m and that of FJ is 2.24×10^5 ha-m.

For a given reservoir capacity of 1.2×10^5 ha-m, the safe yield of 1.68×10^5 may be obtained.



Determination of Yield

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Determination of yield from a reservoir of given capacity

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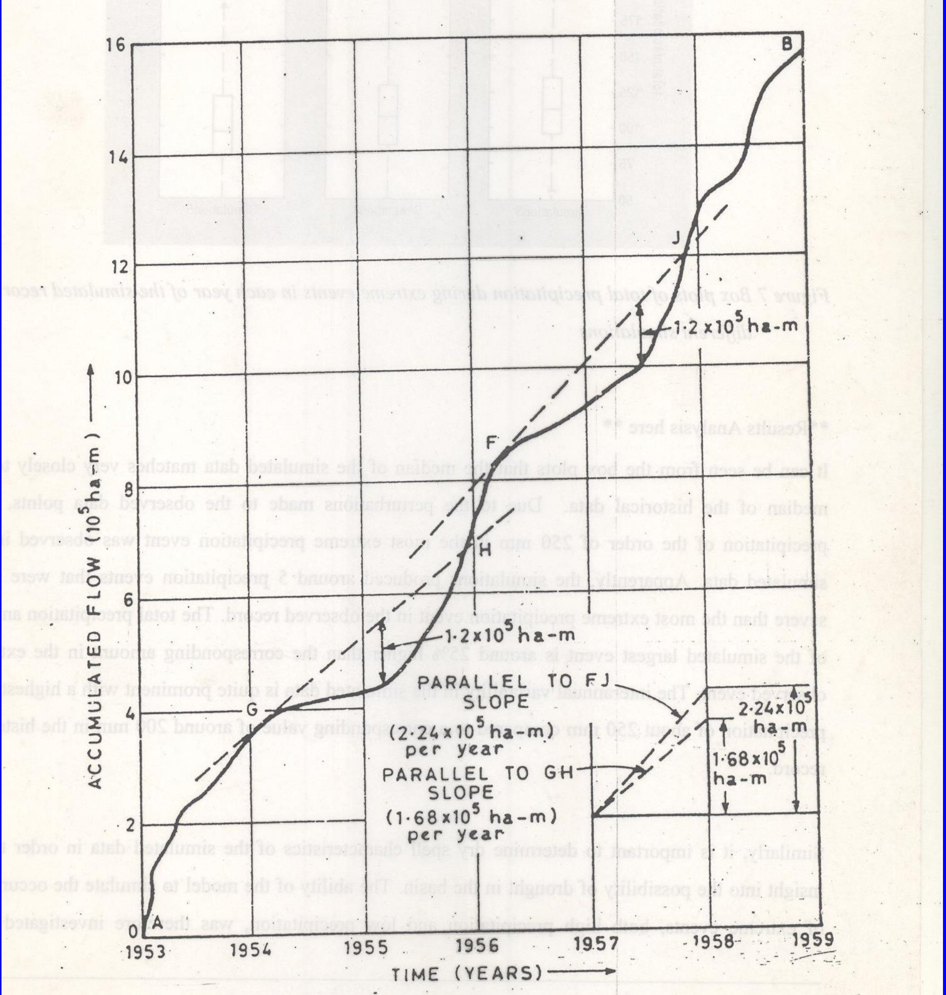


Determination of Yield

5

Storage Computations Using Analytical Method

- Monthly inflows at a proposed reservoir site for a drought period of 12 months along with target demands are given below. Compute the storage required using graphical and analytical methods

Analytical Method-Inflow and Demand Data

Month	Inflow (MCM)	Outflow(MCM)
Jun	250	150
Jul	350	150
Aug	400	200
Sep	200	250
Oct	150	350
Nov	150	400
Dec	100	250
Jan	50	200
Feb	150	150
Mar	300	150
Apr	400	100
May	450	250

Storage Capacity Using Graphical Method

The following table gives the mean monthly flows in a river during 2001. Calculate the minimum reservoir capacity required to maintain a demand rate of 40 cumec.

Storage Capacity UsingGraphical Method

Month	Mean Flow (cumec)
Jan	60
Feb	45
Mar	35
Apr	25
May	15
Jun	22
Jul	50
Aug	80
Sep	105
Oct	90
Nov	80
Dec	70

Yield for a Given Storage Capacity

Month	Mean Flow (cumec)
Jan	60
Feb	45
Mar	35
Apr	25
May	15
Jun	22
Jul	50
Aug	80
Sep	105
Oct	90
Nov	80
Dec	70

Storage Capacity Using Graphical Method Solution

Month	Mean Flow (cumec)	Inflow Volume (cumec-day)	Cumulative Inflow (cumec-day)
Jan	60	1860	1860
Feb	45	1260	3120
Mar	35	1085	4205
Apr	25	750	4955
May	15	465	5420
Jun	22	660	6080
Jul	50	1550	7630
Aug	80	2480	10110
Sep	105	3150	13260
Oct	90	2790	16050
Nov	80	2400	18450
Dec	70	2170	20620

Storage Capacity - Analytical Method

Month	Mean Flow (cumec)	Inflow Volume (cumec-day)	Demand Volume (cumec-day)	Excess Inflow (cumec-day)	Deficit (cumec-day)	Cum. Excess (cumec-day)	Cum. Deficit (cumec-day)
Jan	60	1860	1240	620		620	
Feb	45	1260	1120	140		760	
Mar	35	1085	1240		155		155
Apr	25	750	1200		450		605
May	15	465	1240		775		1380
Jun	22	660	1200		540		1920
Jul	50	1550	1240	310		310	
Aug	80	2480	1240	1240		1550	
Sep	105	3150	1200	1950		3500	
Oct	90	2790	1240	1550		5050	
Nov	80	2400	1200	1200		6250	
Dec	70	2170	1240	930		7180	

Inflow and Demand Data

Month	Inflow (MCM)	Outflow(MCM)	Cum Inflow (MCM)	Cum. Outflow (MCM)
Jun	250	150	250	150
Jul	350	150	600	300
Aug	400	200	1000	500
Sep	200	250	1200	750
Oct	150	350	1350	1100
Nov	150	400	1500	1500
Dec	100	250	1600	1750
Jan	50	200	1650	1950
Feb	150	150	1800	2100
Mar	300	150	2100	2250
Apr	400	100	2500	2350
May	450	250	2950	2600

Analytical Method

Month	Inflow (MCM)	Outflow (MCM)	Excess (MCM)	Deficit (MCM)	Cum. Excess (MCM)	Cum. Deficit (MCM)
Jun	250	150	100		100	
Jul	350	150	200		300	
Aug	400	200	200		500	
Sep	200	250		50		50
Oct	150	350		200		250
Nov	150	400		250		500
Dec	100	250		150		650
Jan	50	200		150		800
Feb	150	150	0		0	
Mar	300	150	150		150	
Apr	400	100	300		450	
May	450	250	200		650	

Storage Capacity

- The yield of water in MCM from a catchment area during each successive month is given in the table below. Determine the minimum capacity of a reservoir required to allow the above volume of water to be drawn off at a uniform rate of 4.78 MCM per month assuming that there is no loss of water over the spillway.

Inflow Data

Month	Inflow (MCM)
Jun	1.40
Jul	2.10
Aug	2.80
Sep	8.40
Oct	11.9
Nov	11.9
Dec	7.70
Jan	2.80
Feb	2.52
Mar	2.24
Apr	1.96
May	1.68

Analytical Demand

Month	Yield (MCM)	Demand (MCM)	Excess (MCM)	Deficit (MCM)	Cum. Excess (MCM)	Cum. Deficit (MCM)
Jun	1.40	4.78		3.38		3.38
Jul	2.10	4.78		2.68		6.06
Aug	2.80	4.78		1.98		8.04
Sep	8.40	4.78	3.62		3.62	
Oct	11.9	4.78	7.12		10.74	
Nov	11.9	4.78	7.12		17.86	
Dec	7.70	4.78	2.92		20.78	
Jan	2.80	4.78		1.98		1.98
Feb	2.52	4.78		2.26		4.24
Mar	2.24	4.78		2.54		6.78
Apr	1.96	4.78		2.82		9.60
May	1.68	4.78		3.10		12.70

Sequent Peak Algorithm

Month	Inflow (MCM)	Outflow (MCM)	Cumulative Inflow (MCM)	Cumulative Outflow (MCM)	Col4-Col5
Jun	250	150			
Jul	350	150			
Aug	400	200			
Sep	200	250			
Oct	150	350			
Nov	150	400			
Dec	100	250			
Jan	50	200			
Feb	150	150			
Mar	300	150			
Apr	400	100			
May	450	250			

Unit 2: Reservoir Sedimentation

- Rivers carry certain amount of sediment load. The sediment particles tend to settle down to the river bottom due to the gravitational force, but may be kept in suspension due to the upward currents in the turbulent flow which may overcome the gravity force
- Due to these reasons, the rivers carry fine sediment in suspension as suspended load and larger solids along the river bed as bed load
- When the silt-laden water reaches a reservoir in the vicinity of a dam, the velocity and the turbulence are considerably reduced

Reservoir Sedimentation

- The bigger suspended particles and most of the bed load, therefore, gets deposited in the head reaches of the reservoir
- Fine particles may travel some more distance and may finally deposit farther down in the reservoir.
- The process of deposition of sediments in the reservoir is known as Reservoir Silting or Reservoir Sedimentation
- Some very fine particles may remain in suspension for much longer period, and may finally escape from the dam.

Reservoir Sedimentation

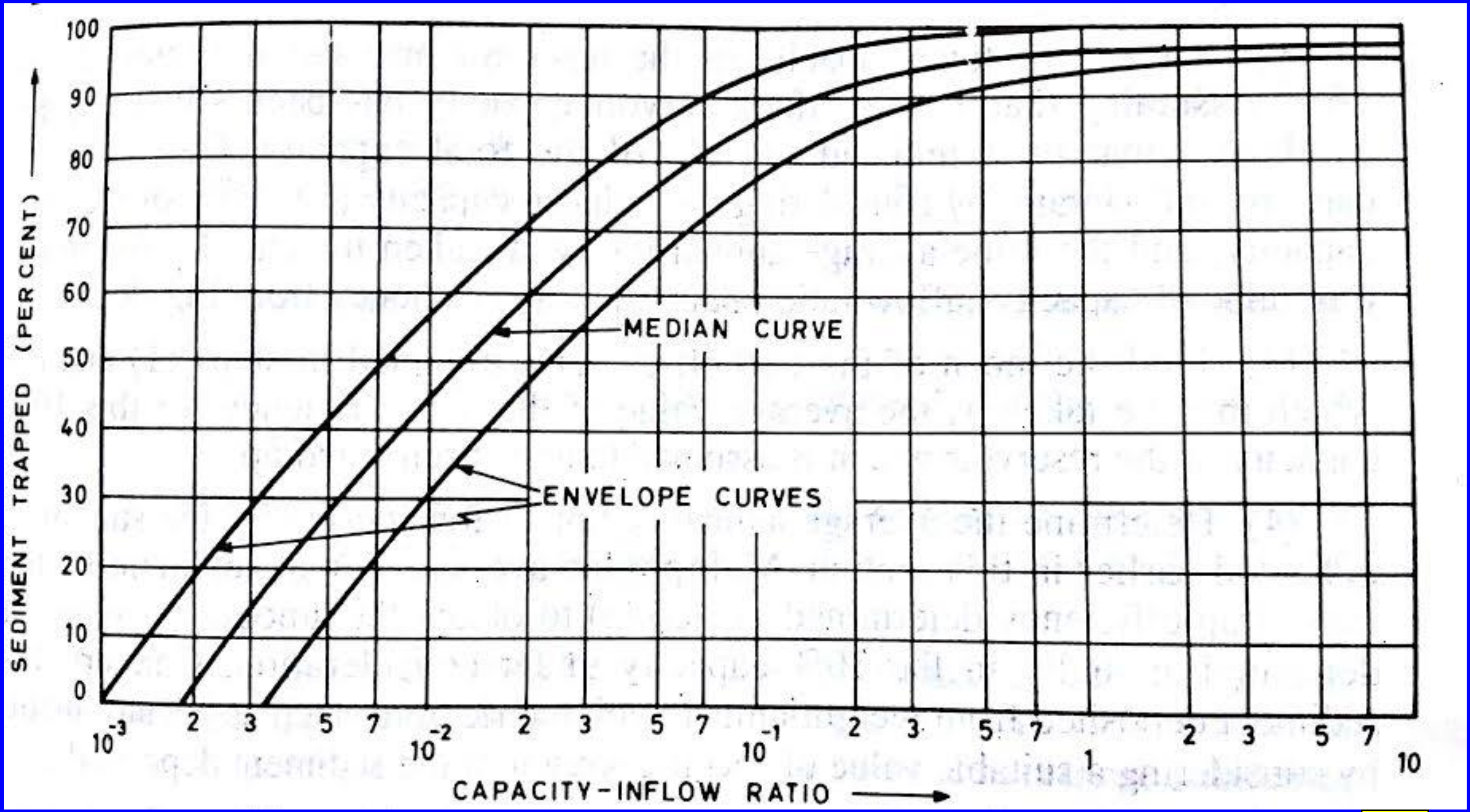
- The deposition of the sediment will automatically reduce the water storage capacity of the reservoir and if this process of deposition continues longer, a stage is likely to reach when the whole reservoir may get silted up and finally become useless
- Moreover, with the passage of time the reservoir capacity will go on reducing

Reservoir Sedimentation

- Storage loss is one of the many types of sedimentation problems that can effect reservoirs
- Operation of storage reservoirs is severely impacted by the time half the volume has been sedimented, but severe sediment –related problems can appear when only a small percentage of the storage capacity has been lost
- Sediments can enter and obstruct intakes and greatly accelerate abrasion of hydraulic machinery, thereby decreasing its efficiency and increasing maintenance costs

Reservoir Sedimentation

Capacity-Inflow Ratio vs. Percentage Sediment Trapped



Reservoir Sedimentation

Trap Efficiency

- **Trap efficiency is defined as the percentage of sediment deposited in the reservoir even after taking precautions and measures to control its deposition.**
- **Most of the reservoirs trap 95% to 100% of the sediment load flowing into them. Even if various silt control measures are adopted, it has not been possible to reduce trap efficiency to below 90%.**
- **Capacity-inflow ratio – The ratio of the reservoir capacity to the total inflow of water in it is known as capacity-inflow ratio. It is an important factor because the trap efficiency has been found to be a function of capacity-inflow ratio**

Useful Life of Reservoir-Numerical Example

- **Find the probable life of a reservoir with an initial capacity of 3700 ha-m if the average annual inflow is 7400 ha-m and the average annual sediment inflow is 2.0 x 10^6 KN. Assume a specific weight of sediment as 11.2 KN/m^3. The useful life of the reservoir will terminate when 80 % of its initial capacity is filled with sediment. The values of trap efficiency for different values of capacity-inflow ratio are as follows.**

Capacity Inflow Ratio	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Trap Efficiency (%)	87	93	95	95.5	96	96.5	97.0	97.3	97.4	97.5

Useful Life of Reservoir-Numerical Example

- **A reservoir has a capacity of 40 million cubic metres and a drainage area of 250 sq. km. The annual inflow is equivalent to 375 mm of runoff from the given drainage area, and annual sediment production is equivalent to a weight of 12.50 million N per km^2 of drainage area. The sediment has an average specific weight of 14.715 KN/m^3. Assume dead storage as 15% of initial reservoir capacity, and an average value of trap efficiency of 88% . Determine the number of years it will take for the dead storage to be filled with sediment.**

Useful Life of Reservoir-Numerical Example

- A reservoir is contemplated on a stream which has an annual average runoff of 500 Mm^3. Measurements indicate that the average sediment inflow is 2×10^6 KN/year. Assume that the settled sediment will have a specific gravity of 1.2. The original capacity of the reservoir is 24×10^6 m^3. Trap efficiency = $$100\left[1-\frac{1}{(1+\alpha x)}\right]^2$$
- where x = capacity-inflow ratio and $\alpha = 65$
- Determine the design life of reservoir based on sedimentation of 60% of the original capacity

Measures to Control Sedimentation

- Generally the life of reservoir is taken as 100 years
- It has been experienced that the rate and amount of silt inflow into the reservoir generally exceeds the one assumed in project design
- Main reasons for increased sedimentation are
  - Uncontrolled felling of trees
  - Continuous and heavy pressure on grazing
  - Shifting cultivation
  - Faulty agricultural practices
  - Poor watershed management

Measures to Control Sedimentation

- Silting of the reservoir starts right from the time of impounding
- Silt always gets deposited at higher elevations, that is in the live storage before it is drawn down to the dead storage
- To increase the life of the reservoir it is necessary to control the sediment from its source to the point of final disposal
- There are several methods for the control of reservoir siltation

Measures to Control Sedimentation

Measures can be classified into six groups

- Selection of a reservoir site
- Provision in the design of a reservoir
- Control of sediment inflow
- Control of sediment deposition
- Removal of sediment deposits
- Watershed erosion control

Measures to Control Sedimentation – Selection of Reservoir Site

- **Geological Factors**
- **(i) Geology of the catchment area**
- **Firstly, the infiltration losses should be minimum to yield greater runoff**
- **Secondly, runoff should not carry excessive silt and sand load along with it**
- **(ii) Geology of the dam site**
- **Entire length of the dam should be founded on a sound water tight rock foundation**
- **Percolation below the dam should be minimum**

Measures to Control Sedimentation – Selection of Reservoir Site

- (iii) Geology of the reservoir basin
- The soil formation of the basin should offer high resistance to percolation of water
- Soil should not contain any of the objectionable soluble minerals and salts
- As far as possible, reservoir site should be selected where the beds are not excessively folded or faulted

Measures to Control Sedimentation – Provision in the design of reservoir

- **Despite taking several measures to control siltation, it is not possible to prevent some amount of sediment to enter into the reservoir**
- **While designing the reservoir, it is essential to provide adequate storage space to take care of the silt deposition that is likely to occur during the probable life of the reservoir**

Measures to Control Sedimentation – Control of Sediment Inflow

- Some bunds called check dams are constructed across the tributaries of the main drainage
- Check dams create settling basins in the upstream
- Silt load settles down in the settling basin and the clear runoff water passes over the check dam to enter the reservoir

Measures to Control Sedimentation – Control of Sediment Inflow

Measures to Control Sedimentation – Control of Sediment Inflow

Measures to Control Sedimentation – Control of sediment deposition

- Sedimentation can also be controlled by operating the gates in such a manner as to allow relatively less sediment load to settle in the reservoir
- Idea is to permit selective withdrawal of water having a higher than average sediment load
- Water contains higher concentration of silt load at lower levels
- During the time of heavy inflow, these outlets are operated to drain off silt laden water

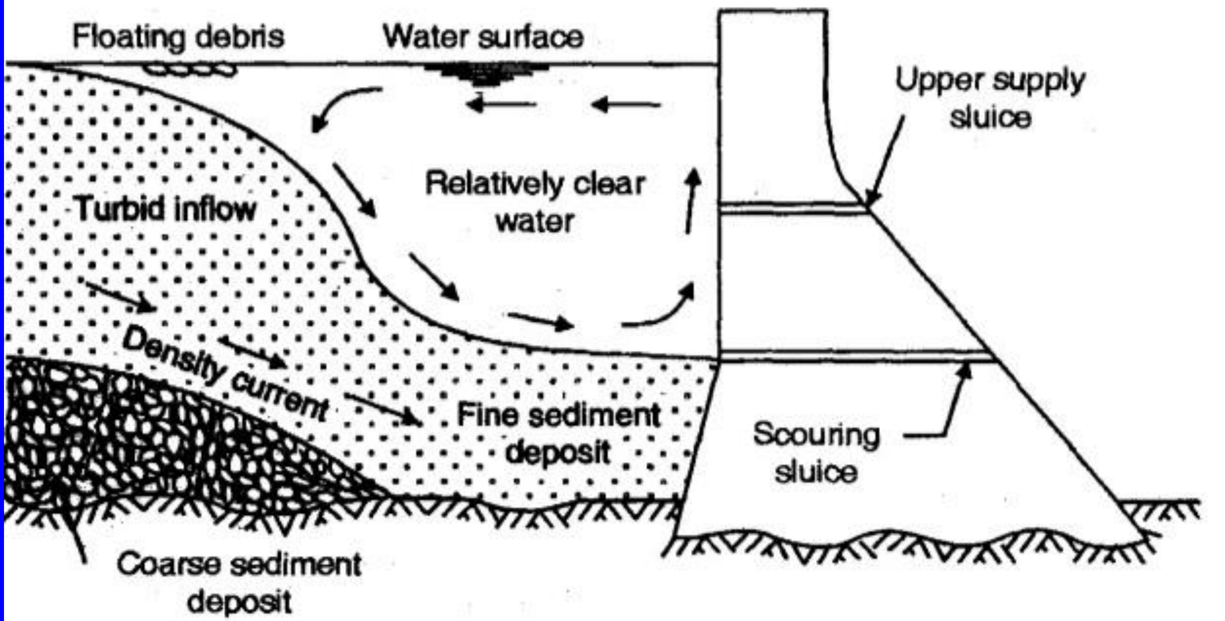
Measures to Control Sedimentation – Control of sediment deposition

Important factors – nature of soil at the catchment area

The sediment transported by the river - divided into two heads.

1.Bed load – the bed load is dragged along the bed of the stream.

2.Suspended load – the load is kept in suspension because of the vertical component of the eddies formed due to friction of flowing water against the bed. The bed load is generally smaller. It is only 10-15% of the suspended load. The coarser particles settle down near the dam in the dead storage due to reduced velocity.



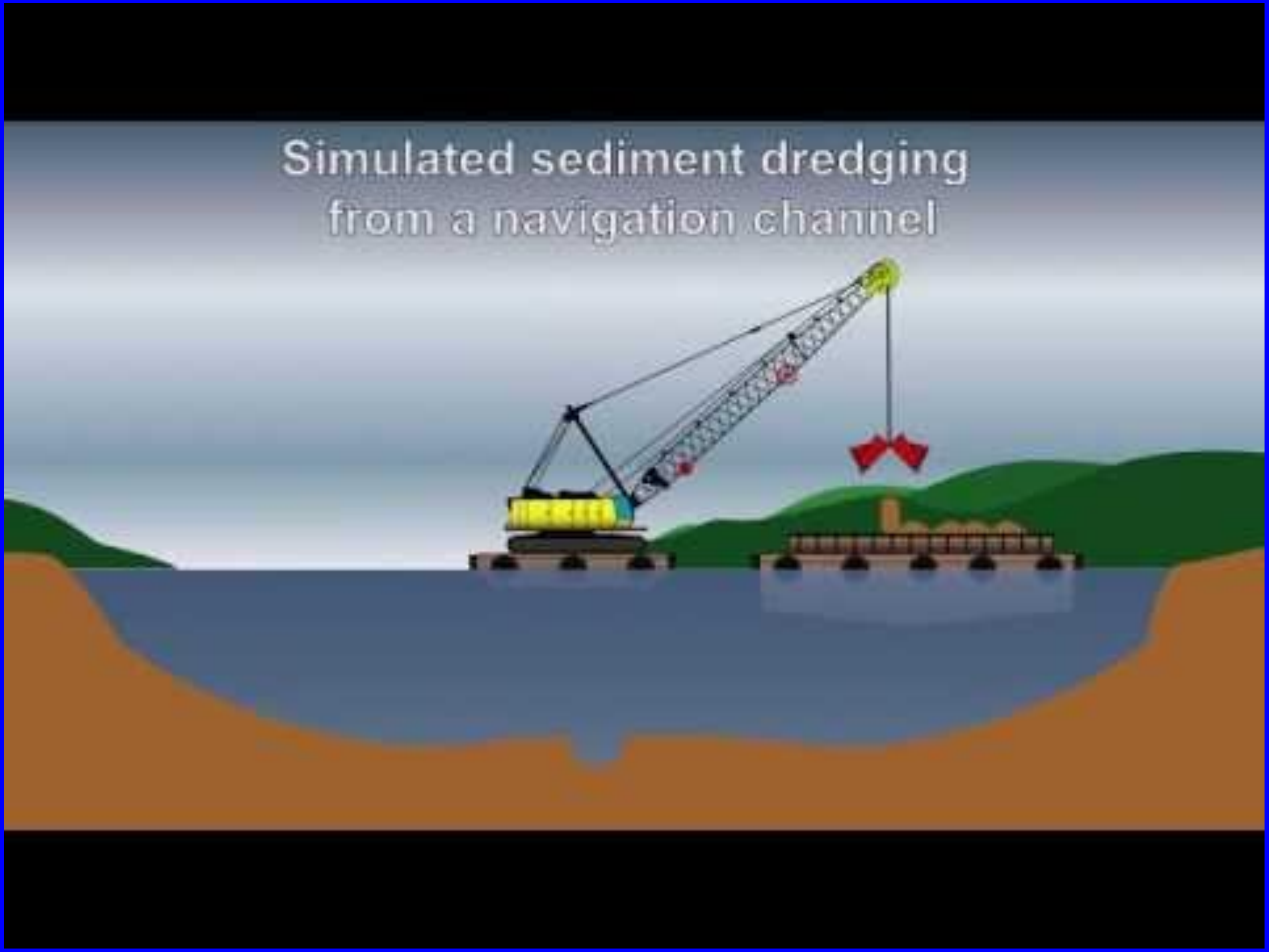
Measures to Control Sedimentation – Removal of sediment deposits

- **Sluicing and Flushing**
- **This is achieved by venting the water and sediments through bottom outlets fitted with suitable gates to control the outflow**
- **If the conditions are favorable and density currents are formed in the reservoir, sediments can be flushed through openings in the dams at appropriate level**

Measures to Control Sedimentation – Removal of sediment deposits

- Dredging
- On relatively smaller reservoirs used primarily for water supply, dredging can be undertaken to remove the deposited sediments
- Dredging basically means clearing the bed by scooping out sediments with the help of a dredge
- Dredging is, however, quite costly when used on large dams as the disposal of huge volumes of sediments is usually problematic

Measures to Control Sedimentation – Removal of sediment deposits



Measures to Control Sedimentation – Removal of sediment deposits

Measures to Control Sedimentation – Removal of sediment deposits

- **Removal by hydro aspirator or hydraulic syphon suction**
- **The hydro aspirator is connected to intakes of outlets and the suction head of hydro aspirator is used to suck out the deposits from under the water**
- **A flexible pipeline connects the intake and transports the muddy water into the downstream channel**
- **Sediment deposits are sucked due to hydraulic pressure and high velocity near the head and transported to the pipeline which finally discharges downstream**

Measures to Control Sedimentation – Removal of sediment deposits

Measures to Control Sedimentation – Watershed erosion control

- **Soil Conservation**
- **In addition to the methods outlined earlier, it is essential to adopt some preventive measures to reduce sedimentation**
- **The catchment area of the reservoir should not be easily erodible**
- **The methods of soil conservation can be divided into two categories; agronomic and engineering**

Measures to Control Sedimentation – Watershed erosion control

- **Agronomic practices**
- **Afforestation – it is essential to prevent deforestation by enforcing legal restrictions. Forests should be protected against fires. A scheme of afforestation should be planned and followed rigorously in the catchment area**
- **Crop rotation – erosion of fields can be successfully checked by adopting a suitable sequence of crops for rotation. The sequence commonly followed is a cultivated crop, a small grain, and then grass**
- **Strip cropping – the cultivated crops and the cover crops are sown in alternate strips, which are generally kept parallel to the contours**

Measures to Control Sedimentation – Watershed erosion control