WATERSHED

- A watershed is the area of land where all of the water that falls in it and drains off of it goes to a common outlet.
- Watersheds can be as small as a footprint or large enough to encompass all the land that drains water into rivers that drain into Chesapeake Bay, where it enters the Atlantic Ocean.

Difference between River basin & Watershed

1.A river basin is a body of land where water from different sources converge while a watershed may also mean the same as a water basin, but it also refers to the drainage divide or land form that divides river systems.

2.A river basin drains out towards a larger body of water such as the ocean or the sea while a watershed may drain towards a smaller body of water if it is referred to as a water basin.

3.A river basin collects water and moisture from different sources, such as those that come from the drainage systems of homes, and drains them out into other bodies of water while a watershed divides the river basins or collection points that contain the water that is collected.

Classification of Watershed

Classification based on size

a. Micro watersheds
b. small watersheds
c. Large watersheds, etc

Small watersheds:

- "Small watersheds are those where the overland flow is the main contributor to peak runoff / flow and channel characteristic do not affect the overland flow".

Large Watersheds:

- "Large watersheds are those give peak flows are greatly influenced by channel characteristics and basin storage".

Size: Size of watershed determines the quantity of rainfall received retained and disposed off [runoff]. Larger the watershed, larger be the channel and storage of water in basin. Large watershed characteristics are topography, geology, soil, climate and use and vegetation

Shape: Watershed may have several shapes like square triangular rectangular, oval, palm, fern leaf shape etc.

Shape of watershed determines the shape index [form factor Ff = WB/Lb]

That is the length: width ratio which in turn has a great effect on runoff disposal. Larger the watershed, higher is the time of concentration and more water will infiltrate, evaporate or get utilized by the vegetation. Reverse is the situation when watershed is shorter in length as compared to width.

Classification watershed based on area		
S No.	Types of Watershed	Area Coverd
1	Micro Watershed	0 t0 10 Ha
2	Small Watershed	10 to 40 Ha
3	Mini Watershed	40 to 200 Ha
4	Sub Watershed	200 to 400 Ha
5	Macro watershed	400 to 1000 Ha
6	River Basin	Above 1000 Ha

Morphological characteristics of watershed

- Each individual watershed has several remarkable characteristics, which affect its functioning. Seven such characteristic have been identified.
- Size [area]
- Shape.
- Topography
- Geology, rock and soil
- Climate
- Vegetation
- Land use

Compactness, Topography & Geology of the Watershed

Compactness coefficient Cc:

"Compactness coefficient of a watershed is the ratio of perimeter of watershed to circumference of circular area which equals the area of the watershed". The C.C. is independent of size of watershed and dependent only on the slope.

Topography:

Slope, length, degree and uniformity of slope affect both disposal of water and soil loss. Degree and length of slope also affect time of concentration [Tc] and infiltration of water.

Drainage: Topography regulates drainage. Drainage density [length of all drainage channels – unit area], length, width depth of main and subsidiary channel, main outlet and its size depend on photography. Drainage pattern affect time of concentration.

Geology rock and soil:

Geological formation and rock types affect extent of water erosion, erodibility of channels and hill faces, sediment production. Rocks like shale's, phyllites erode easily where as igneous rocks do not erode.

Physical and chemical properties of soil, specially texture, and structure and soil depth influence disposition of water by way of infiltration, storage and runoff.

Climate, Vegetation and Land use

Climate:

Climate parameters affect watershed functioning and its manipulation in two ways.

Rain provides incoming precipitation along with its various characteristic like intensity, frequency and amount of rainfall.

Parameters like rainfall, temperature, humidity, wind velocity, etc. regulates factors like soil and vegetation.

Vegetation:

Depending upon the type of vegetation and its extent, this factor regulates the functioning of watershed ex. Infiltration, water retention, runoff production, erosion, sedimentation etc.

Land use:

Type of land use, its extent and management are the key factors which affect watershed behaviour. Judicious land use by users [human beings] is of vital importance to watershed management and functioning.

Reservoir Sedimentation

- **Reservoir sedimentation** is filling of the **reservoir** behind a dam with **sediment**carried into the **reservoir** by streams.
- The flow of water from the catchment upstream of a **reservoir** is capable of eroding the catchment area and of depositing material either upstream of the **reservoir**, or in the still water of the **reservoir**.
- From the stand point of sediment management the relative size, termed as hydrologic size or capacity inflow (C: I) ratio is more important than absolute size of the reservoir and is computed as the ratio of total reservoir capacity to mean annual inflow.
- **Effect of Sedimentation on Reservoir Storage:**
- According to a survey during the year 2012 across 122 reservoirs in India, 0.44% of reservoir storage is being covered with deposition of sediment every year.
- In case of Srisailam reservoir in Andhra Pradesh which was commissioned in 1976, the storage capacity is now reduced to about 79.5% of it’s original storage in a span of 35 years. Similarly the capacity in Nagarjuna sagar is reduced to about 80.5% of it’s designed capacity.
- The project ‘Nizamsagar’ in Telangana region of Andhra Pradesh has lost about 60% of its live storage even within 50 years of its existence.

Hydrologic size of the Reservoir

- Hydrologic size is a primary factor influencing the rate of sediment accumulation (Brune, 1953) and is also a primary determinant of types of sediment management techniques that can be used.
- Hydrologically small reservoirs have short residence time and typically spill a significant part of the stream flow downstream during floods. They can be manipulated by encouraging release of sediments together with that part of annual discharge that is spilled. A reservoir having capacity inflow ratio exceeding 50% may be considered hydrologically large and may have significant year to year carryover storage capacity.
- Having a large capacity relative to runoff, these reservoirs spill little water and there is limited opportunity to periodically draw down or empty these larger reservoirs for sediment management because the associated water loss would be unacceptable.
- Reservoir pool geometry has a major influence on hydraulic behavior and the pattern of sediment transport within the impoundment. Relatively shallow reservoirs may attract less sediment deposit rather than deep reservoirs.
- For any reservoir, the crest elevation of un gated spillway (or) the design normal water level against the crest gate is the full reservoir level (FRL) and the higher design level during floods is termed as maximum water level (MWL).
- The minimum operating level is determined from requirements of particular intake design and is the minimum at which the lowest level intake can be operated. Thetotal storage volume created upstream of dam may be derived in to several zones as illustrated in Figure below.
- The dead storage is the volume that is below the lowest outlet level which cannot be drained by gravity. Active or conservation storage is the volume that can be manipulated for beneficial use, but excluding flood storage.

Reservoir Storage

- The dead storage is the volume that is below the lowest outlet level which cannot be drained by gravity.
- Active or conservation storage is the volume that can be manipulated for beneficial use, but excluding flood storage.
- However rivers carry less quantity of sediment and
- take much more time to fill a reservoir.
- The accumulated sediment can normally be ignored at the time of designing a project.
- Extracting of water from a reservoir is much easier but removal of sediment is becoming difficult under normal operating conditions of a reservoir.
- **Loss of storage:** Storage in the reservoirs will be reduced or radually eliminated due to deposition of sediment within the reservoir pool geometry.
- Thus reservoir become defunct without completing it's designed reservoir life.
- **Over flowing dam at risk:** The flood storage is lost due to accumulation of sediment and the reservoir spillway which is designed for a specific flood storage may become unsafe.
- **Delta deposition:** With the deposition of coarser portion of sediment from the rivers entering reservoirs, delta deposits are formed which deplete the reservoir storage and also cause channel agradation extending many kilometers beyond reservoir pool in the upstream.
- **Channel agradation:** Common problems because of sediment transport in the channel include water logging in agricultural lands and infrastructure areas along the channel of flood plains, abnormal increase in levels of ground water, soil salinity, reduction in normal clearance below bridges effecting navigation and sediment accumulation across upstream intake structures etc.,

Other sediment related problems

- **Navigation:** The sediment accumulation may interfere in to the normal waterway of channel and adversely effect the navigation facilities.
- **Earthquake hazard:** The sediment deposits having bigger mass density may increase the risk of additional loads on the dam that influences the earthquake forces on the structure.
- **Abrasion:** Presence of sediment coarser than 0.10 mm may damage the hydropower facilities including turbine runners and wheel nozzles resulted in reduction in power generation.
- Sediment accumulation also blocks the intakes and low level outlets of dam head works, making them ineffective.
- **Shoreline erosion:** Reservoirs may fill with land slides and debris along the shoreline and shoreline erosion may create problem of maintenance of designed reservoir capacity.
- **Ecological problem:** Accumulation of sediment within the pool of reservoir adversely changes the ecology and effects the species and fish.
- **Downstream consequences:** Alteration of hydro period and nutrient dynamics, reduction of sediment load, temperature changes etc., are the consequences due to flow reduction on downstream of a reservoir and creates environmental issues.
- Trapping of sediment by the dam also has important engineering consequences on the downstream like scouring of stream bed on account of clear water in the river channel, increase in bank height and bank erosion due to channel degradation, increase in scour depth downstream of bridges etc.

Sediment Management

- Protection of river basins is possible by preserving the precipitation optimally without draining so that it could be percolated for recharging of ground water resource.
- Modern farming techniques with participatory5 management of farmers is required for optimized use of water resources. Country’s economic growth is possible with effective conservation of rain water.
- To achieve long term benefits sediment reservoirs need to be converted as sustainable reservoirs for which adequate changes are to be initiated in the design and operation of every reservoir.
- Concept of reservoir life limited by sedimentation needs replacement by concept of better management of water and sediment to sustain reservoir function.

sediment control strategies

i. Inflow of sediment in to the reservoir can be minimized by adopting erosion control and upstream sediment trapping techniques within the catchment.

ii. Inflowing sediment either completely or partly can be routed hydraulically beyond the reservoir storage pool with techniques like drawdown operations during sediment laded floods, construction of off stream reservoirs, sediment bypass and venting of turbid density currents etc.,

iii. Periodical removal of deposited sediment with techniques like dredging or excavation during dry period of the reservoir, hydraulic flushing through scour vents etc.,

iv. Reservoir benefits may be considered sustainable if a storage volume is provided that exceeds the volume of expected sediment supply in the turbidity watershed. The sediment storage volume may be included within the reservoir pool or in one or more upstream impoundments.

v. Deposition of sediment may be in areas where its subsequent removal is facilitated or where it minimizes interference with reservoir operations.

- The concept of sustainable sediment management with conversion of present sediment reservoirs into resources that will benefits future generations. The basic principle is to alleviate reservoir sedimentation by slicing density current and hyper concentrated density current and storing clear water and flushing turbid water

Conclusion

- Greatest challenge before dam builders is to set in place an efficient system of Sediment management to conserve every drop of water for useful means of mankind to meet the present and future requirements.
- For a reservoir planned, certain life is assumed (say 100 years) and its capacity is designed so as to meet the storage needs of the stakeholders duly giving suitable allowance for the loss of capacity due to sedimentation.
- However we are failing to take adequate steps to control the encroachment of excess sediment due to the least importance being given by the stakeholders to implement different sediment management techniques.
- We should take precautionary measures from reservoir planning stage itself, by adopting the following measures for sustainable development of reservoirs
- **Project planning stage:**
- Assess the correct rate of sediment**.**
- Predict how and where the sediment to be deposited.
- Assess the period of time when the sediment will interfere with the useful functions of the reservoir.
- **Project design stage:** Adopt designs which conserve resources, minimize environmental effects and not impact natural preserves.
- Make provision for reservoir sedimentation measures in the project cost and simultaneously implement along with the project construction.

Conti.

Infrastructure function:

- Design and operate essential infrastructure for the delivery of services for continuous period (or) provide for its eventual replacement with improved infrastructure at the end of its economic service life
- **Anticipation of change:** Collection of data continuously and analyze trends to anticipate change. Revise strategic plans regularly and up date design and operations to reflect better data, new technologies and evolving needs.
- **Project operation stage:** Monitor reservoir- elevation- area capacity and sedimentation status to assess the adequacy or otherwise of the sedimentation design standards adopted and implement corrective measures for extending useful life of the reservoir.
- **Sustainability goals:** Integrated watershed management approach with active participation of all beneficiaries should be emphasized in the catchments of reservoirs for control of sedimentation on a sustainable basis to achieve the goals.

sustainable development

- For sustainable development of water resources, the major stakeholders including Reservoir owners who are responsible for carving the projects, beneficiary farmers who are getting water for Irrigation, domestic/ industrial consumers benefitting from the project through water and hydro power , agencies connected to tourism/ fisheries and research organizations etc., shall come together and formulate solutions to the problem of sedimentation.
- Engineers associated with water resources should take a lead role in appraising all the stakeholders on the importance of implementing different sediment management techniques to tackle the future global water deficit.

Recommendations of NATIONAL SYSTEM SURVEILLANCE COMMITTEE to the State Governments.

- i) The sediment observation stations in the major streams and important tributaries should be equipped with latest equipments and manned by qualified and well trained staff.
- ii) Capacity surveys on regular intervals of once in 5 years for all major reservoirs should be carried out by the project authorities.
- iii) Cultivation in the fore-shore is to be prohibited as per existing instructions of Govt. Of India to reduce entry of silt into reservoirs. In any case, ploughing should not be allowed. However, broadcasting can be permitted to limited extent wherever possible.
- iv) There should be a data bank of sediment inflow, outflow and sedimentation of reservoirs at States and Central level with easy accessibility.
- Since the silting of reservoirs is of vital concern for the functioning of the projects, it is necessary that all the major/medium reservoirs are monitored regularly.
- For this purpose, the erstwhile Ministry of Water Resources, Government of India has declared Watershed & Reservoir Sedimentation Directorate of CWC as the nodal agency.
- The Watershed & Reservoir Sedimentation Directorate would compile the available data and publish the same at regular intervals.

Sedimentation Process

Sedimentation and consequent reduction of capacity is a gradual process, which can be classified in following phases:

Phase-1: The reservoir shows no adverse effect and is able to deliver full planned benefits.(Phase-I is depicted as the ‘Full service Time)

Phase-II: The reservoir delivers progressively smaller benefits, but its continued operation for the reduced benefits is economically beneficial.(end of Phase-II is called the ‘Feasible Service Time)

Phase-III: The sedimentation causes difficulties in operation such as jamming the passage of flow in channels or flow in canals or through turbines.

Phase-IV: The phase-III difficulties become so serious that the operation becomes impossible.(beginning of phase-IV will depict the end of physical life. Similarly beginning of phase-IV (A) will depict the end of economic life.)

Phase-IV A: The benefits reduce to such an extent that it is not longer beneficial to operate the reservoir.

- However, there are no instances of Phase-IV or IV (A) having been reached amongst the modern projects.
- Planning of sedimentation includes prefixing the required period of full service period and feasible service period including the sediment levels and capacities to meet these targets.

Bureau of Indian Standards (BIS) 12182(1987)

The theories of silting followed upto 1960 were not tallying actual data observed as such BIS has given its own standards.

1. The sedimentation rate is to be decided on the basis of observations of river sedimentflow and reservoir surveys
2. Methodologies for trap efficiency and sediment distribution have been specified.
3. The live storage is to be so planned that the benefits do not reduce for a period of 50 years (full service time) for irrigation or 25 years for hydropower on account of sedimentation.
4. The feasible service time for irrigation projects shall not be less than 100 years after start of operation. For hydropower projects the feasible service time should not be less than 70 years.
5. For simulation, if sedimentation is not serious, the simulation studies for conditions expected at the end of the full service period may be made. If the problem is serious, studies are to be done by more realistic method. It should be sufficient to consider sediment trapped in every 10 years block, and to use the expected sedimental elevation area capacity curve at the end of each 10 year block for simulation of that block.

SEDIMENTATION MEASUREMENT TECHNIQUES

There are broadly two methods for measurement of sedimentation in reservoirs

i) Stream flow analysis and

ii) Capacity survey

STREAM FLOW ANALYSIS:

- Stream flow analysis is a continuous observation process consisting of measurement of inflows and outflows with sediment sampling. Apart from the measurements, accuracy of analysis is also vital for the proper estimation of unit-mass of the deposited material from the point of view of volumetric conversion.
- In this method, the sediment inflow into the reservoir including estimated bed load and the outflow there from is measured at all significant points of entry and exit.
- The difference gives the quantity of deposit during the period of analysis. The point of measurement should be sufficiently close to the reservoir periphery and particular care must be taken to complete outflow sampling before it meets the credible channel downstream.

Conti.

The analysis consists of two main parts

(1) measurement of water inflows and outflows and

(2) simultaneous measurement of sediment concentration.

- This method gives quantity of deposit in gravimetric terms and conversion into volumetric units calls for the estimation of the average unit mass off the deposited sediment material.
- A direct method of doing this is by collecting systematic samples of the deposit in an undisturbed state from all over the reservoir bed and finding out a correlation between the average dry unit mass and the fractional composition of different grains such as clay, silt and sand.

CAPACITY SURVEY

CONVENTIONAL METHOD:

- The conventional method of conducting sedimentation surveys in the reservoirs involves the use of conventional equipments e.g. theodolite, plane table, sextant, range finders, sounding rods, echo-sounder and slow moving boat etc.
- The depths of the reservoirs are recorded with the help of echo.
- With the help of data collected from the site by the above surveys the volume of silt deposited in the reservoir is calculated between the two successive surveys.
- The normal frequency of the surveys is supposed to be around five years interval.
- However, in practice it is found that the interval between two successive surveys has been varying from, 1 to 15 years or even more in some cases.
- This could be either due to lack of resources like equipment, man and material etc. with the project authorities or due to some other reason.
- The surveys conducted conventional methods are time consuming and sometimes, they take up to three years to complete just one survey of a major reservoir (like Hirakud).
- Even the accuracy of the survey cannot be ascertained in realistic terms.

MODERN TECHNIQUES (HITECH SYSTEM)

- The system consists of the following components:
- i) Positioning System : This includes GPS Unit in differential mode
- ii) Depth Measuring Units : This consists of Echo-sounder and Transducers
- iii) Computer System: This includes Plotter, Printer, Disc Drive, Monitor etc.
- The survey is carried out in a rapid and efficient manner. A boat equipped with the bathymetric (measurement of depth in water bodies) equipment, the GPS system mounted on board and a lap-top computer is used for bathymetric survey while its reference station is positioned in a known geographical benchmark.
- The survey software enables fixing of grid lines and interfacing of bathometer and DGPS and taking X,Y and Z values at required interval/grid. Boat navigation is also controlled by the software so that boat tracks the grid line accurately. The surveys can also be carried out at random mode.
- The data collected is then processed and analysed using specially developed software to obtain the results in various forms e.g. point plots contour and three dimensional maps of reservoirs bed, area capacity elevation tables and cross-sections of reservoir.

Conti.

- DGPS hydrographic surveying allows faster data acquisition with better accuracy than any previous hydrographic survey technique.
- The line of sight from the base station to the boat is not necessary. The base station is set up only once per day, instead of the usual once per cross section.
- A DGPS survey can be completed between control points (even on opposite side of a mountain) without having to traverse or even to see the other point.
- Other advantages are the ability to achieve accuracy and the ability to efficiently collect large amount of data.
- The data collecting system with GPS is compact and can be accommodated in smaller boats.
- Central Water Commission has carried out capacity survey of thirty six (36) important reservoirs in the country through consultants available in the field using this technique.

Conti.

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REMOTE SENSING

- Remote Sensing is the art and science of collecting information about earth's feature without being in physical contact with it.
- Various features on earth's surface reflect or emit electromagnetic energy depending upon their characteristics.
- The reflected radiation depends upon physical properties of the terrain and emitted radiation depends upon temperature and emissivity.
- The radiations are recorded by the sensor on board satellite and are then transmitted back to the earth.
- Difference between features depends on the fact that response from different features like vegetation, soil, water is different and discernable.
- Data received at ground stations is digitally or visually interpreted to generate thematic maps.
- The data from satellites such as Landsat, SPOT and IRS are more useful for mapping and monitoring the surface water bodies and other land resources based on which better water management strategies can be planned.
- Reservoir sedimentation surveys are essentially based on mapping of water-spread area at the time of satellite overpass.
- Multi-date satellite data is needed which covers the operating level of reservoirs at close interval. Water spread area is the water level contour at that level.
- Using different contours, capacity between them is calculated

Conti.

- With the sedimentation, the water spread area of the reservoir reduces at different levels.
- The water spread area and the elevation information is used to calculate the volume of water stored between different levels.
- These capacity values are then compared with the previously calculated capacity values to find out the change in capacity between different levels.
- Remote Sensing based reservoir capacity estimation has certain limitations.
- The capacity estimation works between MDDL and FRL only as these are the levels between which reservoirs operates.
- Thus changes can be estimated only in the live capacity of reservoir.
- For capacity estimation below MDDL corresponding to dead storage conventional hydrographic survey techniques are to be used. Availability of cloud free data throughout reservoir operations also poses limitations in the analysis.
- This can be overcome by combining data from different water years to get full operative range.
- This technique gives accurate estimates for fan shaped reservoir where there is a considerable change in water spread area with change in water level.

Recommendations of the working group for National Action Plan for Reservoir Sedimentation Assessment using Satellite Remote Sensing under the Chairmanship of Member (WP&P), Central Water Commission

- Working Group recommended for laying emphasis and high importance to carrying out reservoir
- sedimentation surveys in the country.
- While using remote sensing technique for the sedimentation survey, composite method coupling both the hydrographic technique (below MDDL) and SRS technique needs to be adopted since the latter does not cover the area of reservoir below MDDL.
- The periodicity of the composite reservoir sedimentation survey can be set as 10 years.
- It has to be complemented by mid-term survey by Satellite Remote Sensing technique every 5 years. In case of high silting reservoirs, the frequency of mid-term survey can be kept as 3 years.
- It is also recommended that the reservoir sedimentation survey of the reservoirs, where no study could be undertaken so far, should be taken up by satellite remote sensing technique on top priority.

It is observed that the actual rate of sedimentation is more than the design rate of sedimentation in most of the reservoirs. The variation in ninety three reservoirs with known design rate of sedimentation

Comparison between actual and designed rate of sedimentation of reservoirs

Ratio of actual rate of sedimentation to the designed rate of sedimentation	No. Of Reservoirs
Less than 1	14
1 to 2	21
2 to 3	17
3 to 4	11
4 to 5	7
Greater than 5	23
Total	93

ESTIMATION OF LOSS OF STORAGE IN RESERVOIRS

- Based on the sedimentation rate of 239 reservoirs, the computed average annual percentage loss in gross storage due to siltation is 0.42% and based on the sedimentation rates of 86 reservoirs the average annual percentage loss in dead and live storage is 0.494 % and 0.04% respectively.
- The observed annual percentage loss in gross storage (minimum, maximum and average) is given in Table 2. The annual percentage loss in gross storage has been worked out as the average based on the data of 239 reservoirs i.e. total annual loss in gross storage of 239 reservoirs X 100/ total gross storage of 239 reservoirs.

Table- 2: Annual percentage loss of gross, live and dead storage capacity of reservoirs					
S No.	Description	Minimum	Maximum	Average	Remearks
1	Annual % loss of Gross Storage	0.03	3.38	0.42	Based on Average data
2	Annual % loss of Dead Storage	0.007	5.23	0.494	Based on average
3	Annual % loss of Live Storage	0.003	3,23	0.04	Based on average

Loss of annual gross capacity in 239 reservoirs		
Range of annual gross storage capacity loss	No. Of Reservoirs with in the range	Average age of the reservoirs in years (From impoundment
Less than 0.1 %	17	53
0.1 to 0.5%	126	42
0.51 to 1%	62	37
More than 1%	34	21

TRENDS IN SEDIMENTATION OF RESERVOIRS

- Dr. A.N.Khosla had observed that in the reservoirs which have small sluicing capacity with respect
- to normal floods and which have no reservoirs above them, the siltation rate is comparatively high
- in the first 15-20 years and thereafter it decreases.
- This is because the obstruction by the dam causes the dips and flanks of the storage basin to fill up with silt in the early years. A stage comes when the river section is adjusted to carry the normal discharge and disposal of suspended load in the area of the reservoir is harmonized with the condition of the flow.
- Besides, the progressive development of deltas above reservoirs helps in trapping some of the silt load. Further shrinkage and settlement of deposited silt also takes place due to weathering action and superimposed loads of additional silt load.
- This results in reduction in silt volume thereby reducing the sedimentation rate.
- To verify the above phenomenon, 11 reservoirs data have been selected where capacity survey data after 9 to 11 years of first impoundment is available, and also subsequent more number of capacity surveys has been conducted.
- Analysis of results of capacity surveys of these reservoirs considering average rate of siltation at the end of every 10 years from the year of impoundment indicate that the rate of sedimentation is higher in initial period of operation of reservoir and decreases with passage of time.
- The percentage decrease in rate of siltation in respect of these reservoirs is given in Table 3.

Table 3: Percentage decrease in rate of siltation of reservoirs								
S No.	Name of Reservoir (State)	Rate of Sedimentation Thousand Cu m/Sq km/year				Total period between mid points of two blocks in years	% Decrease in siltation in the total period	% Decrease in siltation per year
		1st period of 10 Years	Rate of Siltation	Last period of 10 Years	Rate of Siltation			
1	Panchat (Jarkhand)	1956- 66	0.973	1986-1996	0.313	30	67.83	2.261
2	Maithon (Jarkhand)	1955- 65	1.170	1984-1994	1.132	29	3.24	0.117
3	Pong (H P)	1974- 84	2.558	2002- 12	1.750	28	31.58	1.128
4	Tungabhadra (Karnataka)	1953-63	1.789	1993-2003	0.720	40	59.75	1.49
5	Hirakud (Odisha)	1957-67	0.657	1990-2000	0.377	33	42.62	1.29
6	Bhakra (H P)	1958-68	0.605	2002- 12	0.969	44	-	-
7	Lower Bhavani (T N)	1953 -63	0.306	1973 -83	0.246	20	19.60	0.980
8	Vaigai (T N)	1958 -68	0.409	2002 -12	0.1989	44	51.36	1.167
9	Matatila (U P)	1956 -66	0.849	1989 -99	0.223	33	73.73	2.23
10	Dukwan (U P)	1907- 17	0.042	1970 -80	0.012	63	71.43	1.138
11	Damanganga (Gujarat)	1983 -93	0.549	1998- 08	0.058	15	89.43	5.96

CONCLUSIONS

1. The surveys conducted during last four decades have indicated that sedimentation rates in some of the reservoirs are higher than that envisaged at the planning stage.
2. The variation in actual sedimentation rate with the rate assumed at the time of design is due to the fact that enough reliable data on Indian reservoirs was not available earlier at their planning stage.

The earlier assumption that the sediment would settle within the dead storage is no longer supported by the experience gained in India as well as other countries.

The hydrographic surveys have clearly indicated that the sedimentation takes place not only in dead storage but also in live storage of the reservoirs.

3. The present design practice (*followed progressively since 1965) incorporates that the design* sedimentation inflow rates be based on the basis of reservoir survey data as well as actual observed sediment inflow data available from key hydrological station /network of CWC.

This practice has already been incorporated in the IS: 12185 (1987)"Guidelines of determination of effects of sedimentation on planning and performance of reservoirs", to make this a national practice.

4. Regarding apprehension about the higher rates of sedimentation in reservoirs and that they will not last for their planned life, the analysis of data collected for various reservoirs show that the sedimentation rates are not so alarming.

Further it has been experienced that the sedimentation rate in reservoirs is higher during the initial period of their operation and thereafter it reduces significantly.

Even some of the reservoirs having completed their planned life are still continuing to serve and provide substantial benefits.

Conti.

5. DGPS enabled bathymetric survey techniques in conducting capacity surveys of reservoirs saves time and obtain more reliable results.
6. Since sedimentation study of reservoirs using remote sensing technique is fast and economical but considering its limitation that sedimentation taking place below MDDL cannot be measured, it would be appropriate to conduct hydrographic surveys at longer intervals and remote sensing based sedimentation surveys are carried out at shorter intervals to make both surveys complementary to each other.
7. It is observed that the rate of sedimentation is maximum in the reservoirs lying in West flowing rivers beyond Tapi and South Indian rivers i.e. the region No. 7. Median value of sedimentation observed in this region is 2.1325 mm/year (21.325 a.m./100sq.km./year).

Second highest rate of sedimentation is observed in the Himalayan rivers (1.581 mm/year i.e.15.81 Ha.m./100sq./km year). In the plains of Indus and Ganga, only 0.752 mm/year (7.52 Ha.m./100sq.km /year) is observed.

The rate of 0.678 mm/year (6.78 Ha.m/100sq.km/year) observed in the east flowing rivers up to Godavari.

Rate of sedimentation in the reservoirs constructed in the west flowing rivers upto Narmada is 0.861 mm/year (8.61 Ha.m./100sq.km /year) and in the reservoirs lying in Narmada and Tapi basins is 0.651 mm/year (6.51 Ha.m./100sq.km /year).

The least sedimentation rate of 0.378 mm/year (3.78 Ha.m./100sq.km /year) is observed in the Deccan Peninsular region.

Conti.

8. It is observed that the average annual percentage loss of capacity is 0.42 in gross storages.
9. The average dry density of deposited sediment works out to 1191 kg/cu.m.
10. Density of deposited sediment is predominantly affected by the percentage of clay in the samples and also that the density gradually increases with the distances from the dam.

The lower densities have been observed in the vicinity of dam under submerged conditions, while the higher densities are observed in the upstream portions of the submerged area and also in the exposed regions consequent on periodic drawdown of the reservoir.

11. The clay/silt content is maximum near the dam and reduces towards u/s of the reservoir.

Similarly percentage of sand content is least near the dam and progressively increases while proceeding u/s.