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Sediment Occurrence in Reservoir and Methods of Estimating Sedimentation: A Specific Outline

KEYWORDS: Sedimentation, Reservoirs, Methods of measuring sedimentation, Reservoir operation.

Kaoustubh Tiwari
Assistant Professor, CED, S.P.B Patel, Mehsana

Utkarsh Nigam
Assistant Professor, CED, Smt. S.R. Patel Engineering College, Dabhi,Unjha

AbhaGarg
Research Assistant, Surface Water Hydraulic Division, CWPRS, Pune

S.M Yadav
Professor, CED, S.V.N.I.T, Surat

ABSTRACT All reservoirs of any dam are subjected to some degree of sediment inflow can causes deposition. Monitoring of economic life of reservoir is undertaken by conducting sedimentation survey at regular time intervals because silting up of reservoir is a continuous problem. Sedimentation processes in reservoirs are quite complex because of wide variations in the many influencing factors such as Hydrological fluctuations in water and sediment inflow, Sediment particle size variation, Reservoir operation fluctuations and physical controls or size and shape of reservoir. A realistic estimation of the sediment deposition in the reservoir is most important for estimating the available storage values for management of available water resources.

I.INTRODUCTION

Reservoirs are formed on dams which are constructed on river to impound water that can be later used for multipurpose requirements such as Irrigations, Water Supply, Power Generation, and Recreational cum entertainment purposes, Flood control and Industrial purposes. The variations in flow in the downstream channel can also be controlled by using reservoirs. The sediment transport capacity of flow reduces towards the dam and coarse material gets deposited in the upstream reach while the finer and medium sediments get deposited near the dam. This occurs because when water is impounded in the reservoirs the flow velocity is smallest near the dam. This deposition in reservoir is known as Sedimentation in Reservoir, causes progressively reduction in storage capacity of reservoir. Increase in reservoir sedimentation and simultaneously decrease in reservoir capacity with the passage of time is a very serious problem because it causes the reduction in usable capacity of reservoir and new reservoirs have to be built. As these hydraulic structures like dam and spillway which forms reservoirs are very expansive and can't be easily constructed so the problem of reservoir sedimentation was to be taken as deep concentration and numerous researches has also been done in the past. The large number of methods available to model sediment deposition in reservoirs testifies to the need to predict its influence when designing such a facility. Although a number of deterministic models are in existence (e.g. Bonham-Carter & Sutherland, 1968; Merrill, 1974; Chang & Richards, 1971; Yiicel& Graf, 1973; Asada, 1973; Lopez, 1978) the complexity of the mechanism of sediment deposition is confirmed by the large number of empirical techniques (e.g. Cristofano, 1953; Borland & Miller, 1958; Menné&Kriel, 1959; Hobbs, 1969; Borland, 1970; Szechowycz&Qureshi, 1973; Garde et al., 1978; Croley et al., 1978; Pemberton, 1978; Chien, 1982) that have been developed for this purpose. Sedimentation is a complex hydro-morphological process which is difficult to predict. Design and implementation of sediment control measures as well as in the planning, operation and maintenance phases of the reservoirs is important (Siyam, 2005).

II.SEDIMENT MOVEMENT AND SEDIMENT DEPOSITION IN RESERVOIRS

When the water is flowing into the dam reservoir, it carries some amounts of sediments embedded within turbid inflow into the reservoir. These sediments will deposit along the bed in the dam reservoir as the water velocity is reduced. The longitudinal accumulation of sediments in a reservoir may be separated into three main zones depending on sediment characteristics, namely the zone of coarse sediments, delta, and fine sediments (Morris & Fan, 2008), as conceptually illustrated in the Figure 1.

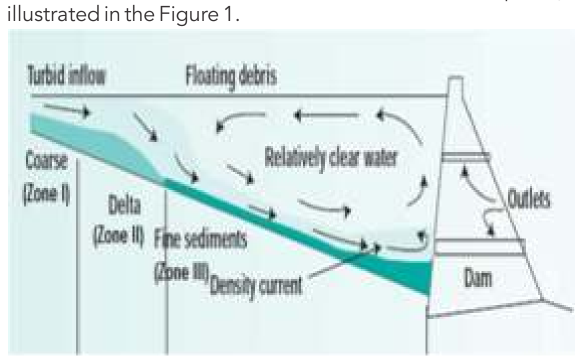

Figure Reservoir sedimentation zones (Palmieri, et al., 2003)

I) Topset beds correspond to delta deposits of rapidly settling sediment. (As per fig.2)
ii) Foreset deposits represent the face of the delta advancing into the reservoir and are differentiated from topset beds by an increase in slope and decrease in grain size.
iii) Bottomset beds consist of fine sediments which are deposited beyond the delta by turbidity currents

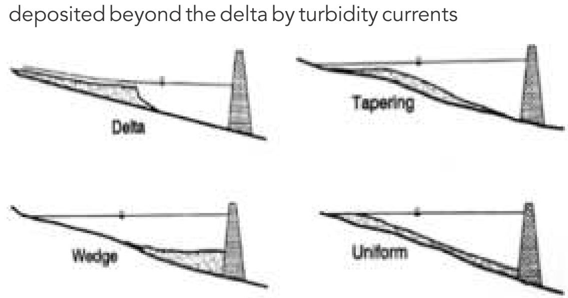

Figure Generalized depositional zones in a reservoir

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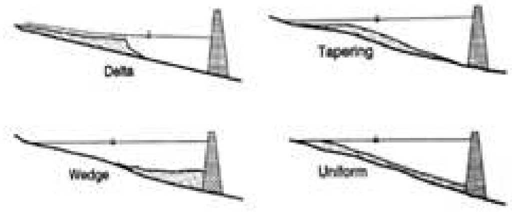

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reservoirs. Multiple patterns can exist simultaneously in different areas of the same reservoir.**

II.1 Longitudinal Deposit (As shown in fig.3)
1. Delta deposits contain the coarsest fraction of the sediment load, which is rapidly deposited at the zone of inflow. It may consist entirely of coarse sediment (d>0.062 mm) or may also contain a large fraction of finer sediment such as silt.
2. Wedge-shaped deposits are thickest at the dam and become thinner moving upstream. This pattern is typically caused by the transport of fine sediment to the dam by turbidity currents.
3. Tapering deposits occur when deposits become progressively thinner moving toward the dam.
4. Uniform deposits are unusual but do occur. Narrow reservoirs with frequent water level fluctuation and a small load of fine sediment can produce nearly uniform deposition depths.

III.METHODS OF ESTIMATING SEDIMENTATION IN RESERVOIRS
There are various methods of estimating sedimentation in the reservoirs as follows:
1. Stream Flow Analysis (Sediment and Water Inflow and Outflow Measurements)
2. Reservoir Capacity Surveys
3. Use of Satellite Imageries
4. Empirical Methods
5. Mathematical Models

1. Stream Flow Analysis (Sediment and Water Inflow and Outflow Measurement)
The analysis consists of (a) measurement of water inflows and outflows and (b) simultaneous measurement of sediment concentration. The method gives quantity of deposit for the estimation of average unit mass of the deposited sediment material.

2. Reservoir Capacity Surveys
i) Conventional Methods: The methods involves the use of conventional equipment e.g. theodolite, plane table, sextant, echo sounder, moving boat etc. The depth of the reservoir are recorded along predetermined range line normally spaced conventionally along the length of the reservoir with the help of collected data volume of silt deposited is calculated within two successive surveys for two consecutive years. This method is time consuming and may take two or three years.

ii) Modern Techniques Hi-tech System: The system consist of following components,
a) Positioning system which includes GPS units,
b) Depth measuring units consisting of echo sounder and transducer,
c) Computer system

3. Use of Satellite Imageries (Satellite Remote Sensing Technology)
Digital image analysis using image processing system on computer is very good for mapping water spread, turbidity levels and aquatic vegetation, multi-date IRS-IC LISS III date is used for image analysis.

4. Empirical Methods
i) Area Reduction Method: This method is based on the fact that there exists a specific relationship between the shape of the reservoir and the percentage of sediment volume deposited up to various depths of reservoirs. The reservoirs are classified in four types. The shape factor 'm' of a reservoir is defined as the reciprocal of the slope of the depth VS capacity plot on a log paper is used as key to decide the reservoir type as given in Table 1.

Table 1. Types of Reservoir

M	Reservoir Type	Standard Type
3.5 to 4.5	Lake	I
2.5 to 3.5	Flood Plane-foot hill	II
1.5 to 2.5	Hill	III
1.0 to 1.5	Gorge	IV

5. Mathematical Models
All Mathematical Models solve water and sediment flow equations (Continuity and Momentum Equation for water and sediment). The model defer from one another in sediment transport laws, consideration of lateral inflows and other effects of simulation. There are various models like one dimensional models such as CHARIMA, HEC-6 / HEC-RAS, MIKE-11 and two dimensional models such as TELEMAC 2D, FLO-2D, MIKE – 21, TIDEWAY which uses the application of flow 1D or 2D.

I) HEC-RAS(HYDROLOGIC ENGINEERING CENTER RIVER ANALYSIS SYSTEM) is a one-dimensional hydraulic simulation allowing for steady flow, unsteady flow, Quasi-unsteady flow and sediment simulations.

ii) MIKE 11 is a computer program that simulates flow and water level, water quality and sediment transport in rivers, flood plains, irrigation canals, reservoirs and other inland water bodies. MIKE 11 is a 1-dimensional river model. It was developed by DHI.There are various modules used to carry-out hydraulic studies:
a) HD module: it provides fully dynamic solution to the complete using 1-D Saint Venant equations, diffusive wave approximation and kinematic wave approximation, Muskingum method and Muskingum-Cunge method for simplified channel routing. It has ability to simulate standard hydraulic structures such as weirs, culverts, bridges, pumps, energy loss and sluice gates.
b) GIS Extension: it is an extension of ArcMap from ESRI providing features for catchment/river delineation, cross-section and Digital Elevation Model(DEM) data, pollution load estimates, flood visualisation/animation as 2D maps and results presentation/analysis using Temporal Analyst.
c) RR module: it is rainfall runoff module, including the unit hydrograph method (UHM), a lumped conceptual continuous hydrological model and a monthly soil moisture accounting model.
d) SO module: it is structure operation module. It simulates operational structures such as sluice gates, weirs, culverts, pumps, bridges with operating strategies.
e) DB module: it is dam break module. It provides complete

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facilities for definition of dam geometry, breach development in time and space as well as failure mode.

f) AUTOCAL module: it is automatic calibration tool. It allows automisation of the calibration process for a wide range of parameters, including rainfall runoff parameters, Manning's number, head loss coefficients, water quality parameters etc.

g) AD module: it is advection dispersion module. It simulates transport and spreading of conservative pollutants and constituents as well as heat with linear decay.

h) ST/GST module: it is noncohesive sediment module. It simulates transport, erosion and deposition of non-cohesive and graded noncohesive sediments, including simulations of river morphology.

I) ACS module: it is cohesive sediment module. It has 3-layer bed description, including quasi-2D erosion.

IV.SEDIMENT RELATED PROBLEMS

Most of the sediment related problems due to sedimentation in reservoirs are relatively confined to the upstream side of the dams. They are listed below:

1. Loss of storage: Storage in the reservoirs will be reduced or gradually eliminated due to deposition of sediment within the reservoir pool geometry. Thus reducing reservoir life.

2. Over flowing dam at risk: The flood storage is lost due to accumulation of sediment and the reservoir spillway which is designed for specific flood storage may become unsafe.

3. Channel aggradations: 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.

4. 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 aggradations extending many kilometres beyond reservoir pool in the upstream.

5. Abrasion: Presence of coarser sediment may damage the hydropower facilities including turbine runners and wheel nozzles resulted in reduction in power generation.

6. Shoreline erosion: Reservoirs may fill with landslides and debris along the shoreline and shoreline erosion may create problem of maintenance of designed reservoir capacity.

7. Navigation: The sediment accumulation may interfere in to the normal waterway of channel and adversely affect the navigation facilities.

8. Downstream consequences: Alteration of hydro period and nutrient dynamics, reduction of sediment load, temperature changes etc., is the consequences due to flow reduction on downstream of a reservoir and creates environmental issues.

9. Ecological problem: Accumulation of sediment within the pool of reservoir adversely changes the ecology and affects the species and fish.

10. 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.

V.MANAGEMENT OF SEDIMENTS

The sediments have to be managed so has to draw long term benefits from the reservoir. The deposition pattern has to be studied and their drain out or removal measures have to be taken in consideration for the management of sediments. The rates of sedimentation in the form of sediment yield in the various river basins are shown in table below.

Table 2. Sedimentation rate of Indian River Basins

River basin	Average annual Sediment Load (MCM)	Catchment area (sq.km)	Sediment Yield (Ha.m./sq.km/year)
Brahmaputra at Pasighat	110	250594	0.0439
Ravi at Chamera-I Dam	6.8	4725	0.144
Satluj at Bhakra Dam	32.48	56980	0.057
Beas at Pong	35.05	12562	0.279
Chenab at Salal	28.42	21500	0.132
Ganges	1036	955000	0.108

VI.CONCLUSIONS AND RECOMMENDATIONS

Reservoirs are constructed on river to impound water that can be later used for multipurpose requirements. The variations in flow and hence sediments in the downstream channel can also be controlled by using reservoirs. The sediment transport capacity and its effect is discussed.Also, Sediment movement and depositional pattern has been discussed in the present paper. As Depositional pattern affect the reservoir capacity and thus the life of a reservoir. This occurs because when water is impounded in the reservoirs the flow velocity is smallest near the dam. This deposition in reservoir is known as Sedimentation in Reservoir, causes progressively reduction in storage capacity of reservoir. Reservoir sedimentation increases and simultaneously reduction in reservoir capacity happens which is a very serious problem because it causes the reduction in usable capacity of reservoir and new reservoirs had to be built.

Methods of estimating sedimentation are dealt. Various methods have been enlisted and outlined in the paper. The importance of empirical methods and advanced mathematical modelling has been discussed including HEC-RAS AND MIKE11. Various sedimentation problems have been discussed. Also the management of sediments have been done. Sedimentation rates of Indian River basins have been discussed.

It can be recommended that as all reservoirs of any dam are subjected to some degree of sediment inflow which may cause sediment deposition. Thus the monitoring of economic life of reservoir is undertaken by conducting sedimentation survey at regular time intervals.

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