Sustainable Reservoir Sediment Management in Indian River Basins

(*By Amrendra Kumar Singh and Anuj Kanwal, Pub. in Water & Energy International, Oct.2021,A-172, pp.6-13*)

DISCUSSOR PROF. S.K. MAZUMDER[1]

Preserving the existing reservoirs and increasing its useful life is essential for sustainable development in order to meet the future water requirements of the country. In a vision paper on reservoir sedimentation , Schleiss et al [1] stated "*an inadequate sediment management can greatly accelerate the process of eutrophication and organisms dissemination at levels which compromise the functions of the reservoir. Dam construction creates an extremely efficient sink of sediments in the valley. Without efficient sediment management, it strongly alters the natural equilibrium between sediment dynamics and morphology in a river catchment. Over the years, as the sediments accumulate, the reservoir loses the storage capacity for which it was initially designed. The installed water storage capacity of reservoirs world wide is about 7000 km^3, from which some 4000 km^3 are used for energy production, irrigation, and water supply . The mean age of existing reservoirs is between 30 and 40 years, and it is estimated that 0.5–1% of the worldwide water storage capacity is lost annually due to sedimentation".*

Accurate estimation of sedimentation rate is essential for the realistic determination of useful life of the reservoir. In this paper authors have made commendable efforts in collecting sediment data in different basins all over the country. As rightly observed by the authors *"The old assumption that the average annual decrease in the Dead Storage of the Dam by 1% at the design stage has been negated in practice with Siltation entering in the Live storages"*. Variation of sediment deposition along depth of reservoir, as shown in Fig.1, depends upon type of reservoir [2] .

In a paper, [3] Deepa et. al predicted the life of Gobindsagar/Bhakra reservoir, constructed on the river Sutlej in Himachal Pradesh. Time-series analysis of the sedimentation rate from a long-term data for the period 1958–2003 obtained from hydrographic survey showed an increasing trend in annual sedimentation rate and reduction of remaining life of the reservoir. The useful life of Gobindsagar reservoir was computed as 300 years in contrast with 500 years estimated at the planning stage. Economic life of the reservoir with accelerated sedimentation was found to be about 165 years only [4]. Actual depth wise distribution of sediments deposited in the Bhakra and some other reservoirs is shown in Fig.1[5]. It is apparent from the figure that the full life of live storage of the reservoir as well as its useful life (at 50% loss of live storage) are reduced considerably due to sediment deposition in live and surcharge space.

CWC [6] undertook a coordinated research scheme of reservoir sedimentation across the country. Sedimentation rate in the major reservoirs (storage capacity >100 MCM) which completed 50 years of useful life was found to vary from 0.3 to 4.89 ha-m/100 km^2/year and those reservoirs which have served less than 50 years of useful life, it varied from 0.34 to 27.85

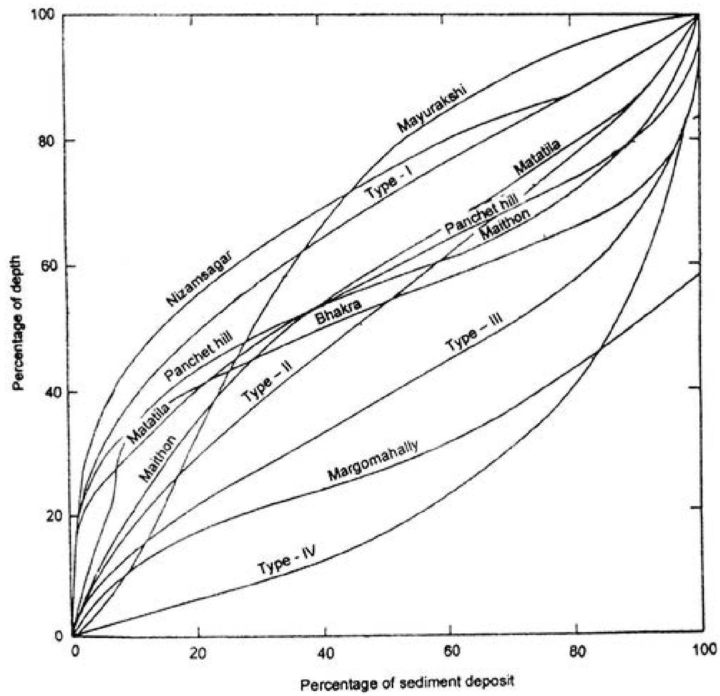

Fig. 1 : Boreland-Miller Curves for Sediment Distribution in Different Types (I,II,III &IV) of Reservoirs (Note: Comparison made with Some Important Reservoirs in India)

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ha-m/100 km²/year. With sedimentation , as the reservoir capacity reduces, the capacity- inflow ratio and the trap efficiency [7,8] decreases (Fig.2) resulting in reduction of sedimentation rate thereby prolonging full life of reservoir up to dam crest. Table-1 shows Sedimentation rate and expected useful life which was found to vary region-wise.

The results of useful life computation of Bhakra /Govindsagar reservoir by different methods are presented in Table 2. The useful life estimated using different criteria is significantly different. Using average sedimentation rate, the useful life can approximately be taken as 140 years. According to Bhakra Management Board, the time period for 100% depletion of dead storage is 260 years which is much higher. The discrepancy may be due to the assumptions made during the planning stage that entire fine silt including clay i.e. 10% of suspended silt load and 5% of the remaining silt load will be passing over the spillway during flood and through dam sluice outlets as density currents. With C/I value of 0.59, the trap efficiency of the reservoir is nearly 99% which makes the assumption invalid. Most of the suspended silt load is trapped in the live and dead storage zones, reducing the useful/economic life of the reservoir.

The rate of sedimentation for reservoirs in the Himalayan region (Indus, Ganga, Brahmaputra basin) was found to vary from 5.658 to 27.85 ha-m/100 km²/year. Based on the different approaches, the Bhakra Project Authority computed the useful life as shown in Table 2

Using Churchil's sedimentation index method, Mazumder [11], studied the life of a Himalayan reservoir in Sikim province and determined the life by area incremental method to find the loss of reservoir capacity at an interval of every 6 years (Fig. 3). Sedimentation rate was found to be decreasing with time.

Satellite Remote Sensing (SRS) technique was used by Santosh Wagh et.al [12] and Pandey,et.al [13] to estimate spatial, temporal, and spectral attributes for evaluating the sediment distribution pattern . The main advantage of satellite data over the conventional procedure includes its repetitive coverage over a long period. The results obtained by remote sensing survey are relevant with the hydrographical survey. The remote sensing technique is time and cost-effective for the development of revised elevation–area–capacity curves for a reservoir with the objective of determining the loss of reservoir space due to sedimentation.

MIKE-3 hydrodynamic model, a commonly used mathematical model system, was applied to simulate cohesive sediments, flows, water quality, and ecology in lakes, rivers, estuaries, bays, coastal areas, and seas in three dimensions[14] . The model was developed to estimate the

Table 1 : Sedimentation rate of some of the Indian reservoirs

Sl. No	Name of reservoir	Gross storage capacity (M-m³) & (year)		Average sedimentation rate (%)	Seriousness of sedimentation	Loss of gross capacity till 2014 (%)	Calendar year in which useful life shall be
		Initial survey	Last survey				
1	Matatila	1133 (1956)	764 (1994)	0.86	Serious	49.76	2014
2	Hirakud	8105 (1957)	6146 (1994)	0.65	Serious	37.24	2034
3	Maithon	1349 (1955)	1085 (1994)	0.50	Serious	29.60	2055
4	Tungabhadra	3751 (1953)	3158 (1993)	0.40	Significant	24.13	2078
5	Koyna	2798 (1961)	2779 (1986)	0.03	Insignificant	2.73	3628

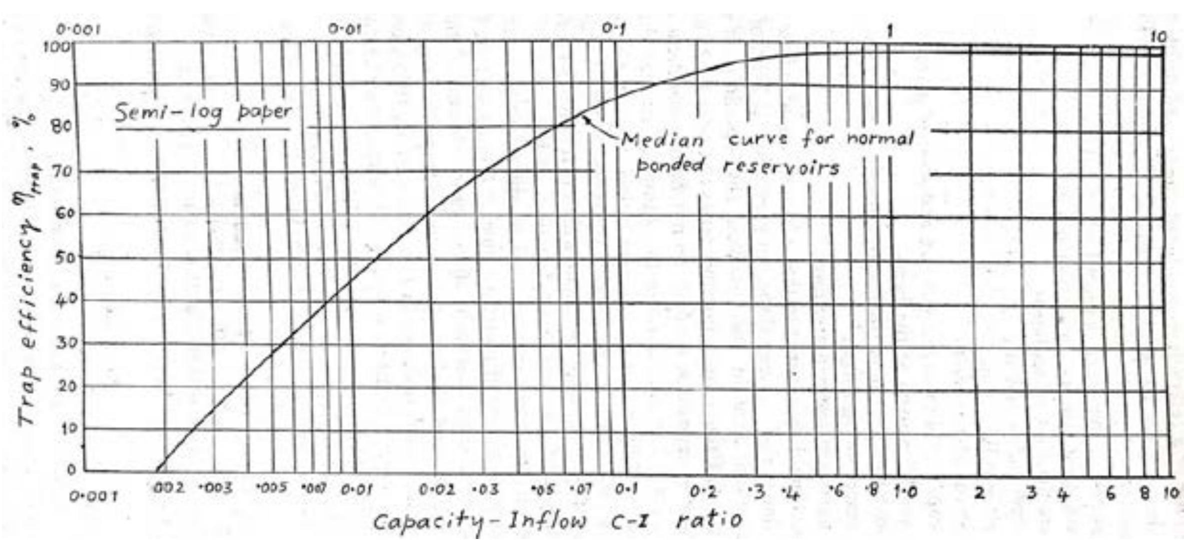

Fig. 2 : Variation of Trap Efficiency with Capacity- Inflow Ratio

Table 2 : Useful Life of Gavindsagar/Bhakra Reservoir Differerrt Approaches [9,10]

Data & period	Methodology	Approach & criteria	Useful life (yrs)	Calendar year in which useful life shall be over
Sedimentation rate based on Hydrographic survey data (1958 & 1998)	Extrapolation	100% depletion of dead storage capacity	138	2096
		@ 17.62 M-m^3/year	109	2067
		50% depletion of gross storage capacity@ 34.76 M-m^3/year	142	2100
Sedimentation rate based on Hydrographic survey (1958–2003)	Extrapolation	Time-series analysis using increasing trend in annual sedimentation	127	2085
Annual sedimentation inflow observation (1958–1998)	Gill's approach	50% depletion of gross storage capacity assuming a dominant coarse sediment inflow	143	2101
Annual sedimentation inflow observation during planning stage (prior to 1957)	Brune's step method	50% depletion of gross storage capacity considering variation in trap efficiency with time	150	2108
Design criteria employed during planning stage (prior to 1957)	Analogy of Lake Mead and Elephant Butte reservoirs	100% depletion of dead storage capacity based on the advance of delta formation towards the dam	260	2218

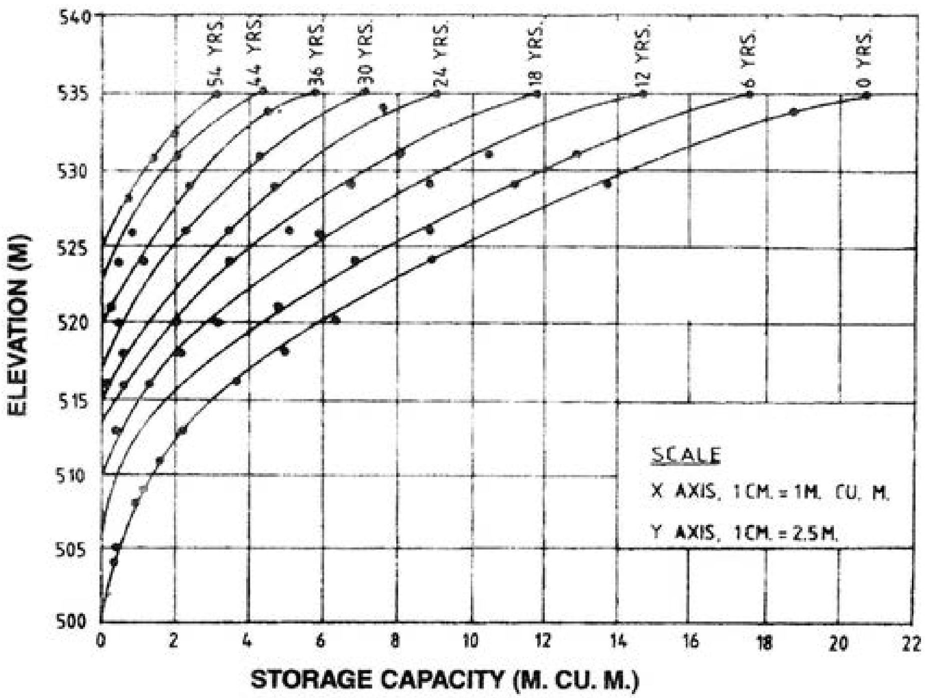

Fig. 3 : Loss of Storage Capacity in Kirichu Dam in Sikim (Using Churchil's Method)

sedimentation in the Xiaolangdi Reservoir on the Yellow River, China. The flow and sedimentation were well estimated by the model. The model results revealed that the sedimentation elevation is lower than the permissible value.

Discusser wishes to bring to the notice of the authors following points stated clause wise below:

Clause 2 :

- Statement regarding 2% annual storage loss has not been established
- The following statement "*The Change in the Hydraulics and storages for flood cushion which may lead to Overtopping, or dam disasters. Sediment Induced hydraulic wave and induced seismicity, in which weight increase by silt layers add stress to both sub-strata and the power-dam itself*".

Silt pressure and Hydro-dynamic pressure due to earthquake are considered in stability analysis/ stress analysis of rigid dams like gravity dams. It may be explained how sediment content in water can further aggravate the situation.

Clause 3 :

- Apart from the amount of sediment concentration, Sediment deposited in a reservoir depends also on trap efficiency governed by C/I ratio and type of reservoir
- Sediment delivery ratio (not rate) depends on sediment yield of basin governed by several basin parameters and reservoir characteristics
- No link has been established between urbanization and sedimentation of reservoirs as mentioned by the authors in the abstract.

References given within the body of the manuscript should have been listed at the end as per CBIP norms.

The value of the paper would have further increased if authors could add a Para or so regarding sediment removal /flushing from reservoirs to extend their useful life.Fig. 4 shows Sediment Deposit in Lewis and Clark Lake - reservoir created by Gavins Point Dam on the Missouri River. It's 30 percent full of sediment and could be half full by 2045 [15] . Discusser mentioned few methods of sediment removal during his talk in ISWEE 16].

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Fig. 4 : Sediment Depostion in Rreservoir Behind Gavins Point Dam on the Missouri River