SEDIMENT YIELD AND DEPOSTION PATTERN IN LONG CONICAL TEHRI RESERVOIR.

Dhirendra Veer Singh CMD, THDCIL, Rishikesh, Uttarakhand, India.
R.K. Vishnoi D(T), T.S. Routela GM(R&D), A.K. Badoni DGM (R&D), *THDC India Limited, Rishikesh (Uttarakhand) India*
Email: anilbadoni@thdc.co.in, thdc.rd@gmail.com

Abstract: Tehri Storage Dam constructed across the mighty river Bhagirathi with a catchment area of 7511 km^2 is located at Tehri which is 85 km from the famous holy place Rishikesh, Uttarakhand, India. Tehri HPP (100 MW) is already commissioned and Tehri PSP (1000 MW) is in advance stage of construction. The long and conical shaped reservoir of the Tehri Dam with a gross storage of 35.40 billion m^3 and a live storage of 26.15 billion m^3 spreads in an area of approx. 42 km^2. Sedimentation of reservoirs is a matter of great concern as it not only occurs in dead storage but also encroaches the live storage capacity thus impairing the intended benefits from the reservoir.

Depositional patterns of sediment in reservoir vary with differences in hydrologic conditions, sediment grain size, and reservoir geometry. In reservoirs with fluctuating water levels like Tehri reservoir, previously deposited sediments may be extensively eroded and reworked by stream flow, failure of exposed slopes, and wave action. Also in long and narrow reservoirs like Tehri reservoir, the bathymetric profile commonly associated with delta deposits may be absent, but an area characterized by a rapid shift in grain size, marking the downstream limit of coarse material deposition, may still be present. Sediment deposition is initially focused in the deepest part of each cross section, creating deposits having a near-horizontal surface regardless of the original cross section shape. Because the upstream area of such long and narrow reservoir is shallow with little storage capacity, the longitudinal growth of the delta may initially be very rapid and sometimes sedimentation can also result in deltas becoming exposed above the reservoir pool.

Distribution of both fine- and coarse-grained sediment deposits in a reservoir can be predicted by both empirical and numerical techniques. The hydrographic survey is a direct method to find out the depth of sediment deposition, the pattern of sediment deposition and the loss of the reservoir capacity. Considering generally weak nature of Himalayan rocks and steep valley slopes in the catchment of the project, CWC has recommended bed load as 15 % of the suspended sediment load for Tehri reservoir and accordingly total sediment load is assumed to be about 161.84 lac t /year for the reservoir. Periodic bathymetric survey since 2005 is being conducted at Tehri reservoir and based on the analyses of survey data collected so far, the overall reduction rate of the live storage of Tehri reservoir since the year 2005 comes to be 4.23 MCM / year. The pattern of sediment deposited at different depth of Tehri reservoir after 2013 survey, plotted on the figure given by USBR for classification of reservoirs, shows that the current pattern of deposition lies reasonably close to type – III reservoir curve.

This paper provides an insight of the methodology adopted in the study and results of the analyses of survey data for deposition pattern of sediment in long conical Tehri reservoir.

Keywords: Reservoir, Sediment Yield, Reservoir capacity, Deposition pattern, Live storage.

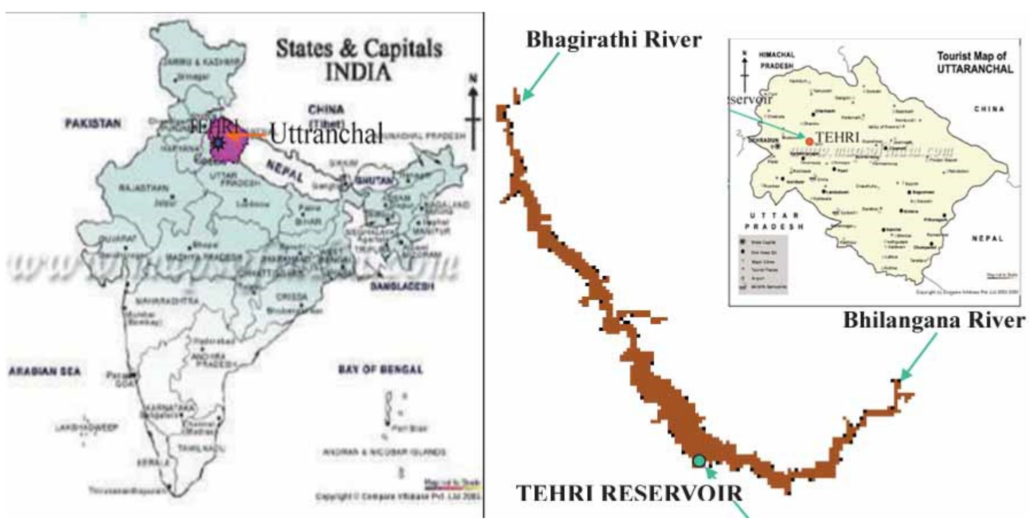
1. INTRODUCTION:

Tehri Storage Dam built across the mighty river Bhagirathi with a catchment area of 7511 km^2 is located at Tehri which is 85 km from the famous holy place Rishikesh, Uttarakhand, India. Tehri HPP (100 MW) is already commissioned and Tehri PSP (1000 MW) is in advance stage of construction. The long and conical shaped reservoir of the Tehri Dam with a gross storage of 35.40 billion m^3 and a live storage of 26.15 billion m^3 spreads in an area of approx. 42 km^2. The reservoir at FRL of 830.0 m extends about 44 km along river Bhagirathi and about 25 km along the tributary river Bhillangana. The full reservoir level and minimum draw down level are fixed as El 830.0 m & El 740.0 m respectively.

Sedimentation of reservoirs is a natural phenomenon & matter of great concern and it is not only occurs in dead storage but also encroaches the live storage capacity, which impairs the intended benefits from the reservoir. Therefore the problem of sedimentation needs to be carefully addressed. Besides, the capacity surveys should be carried out at regular intervals to assess the volume of silt accumulated and its distribution, rate of silting and updating the elevation-capacity curve for efficient management and operation and to adopt the appropriate measures to prolong the useful life and derive the maximum benefits from the reservoir.

Periodical capacity surveys of reservoir help in assessing the rate of siltation and reduction in storage capacity. This information is necessary for efficient management of the reservoir. Periodical capacity survey of reservoirs in a basin is also necessary to arrive at a realistic siltation index for planning of future reservoir projects in the basin. The reports from CWC for the 23 reservoirs indicate that the actual rate of siltation is higher than the design rate. The annual loss in live storage capacity is 214.2 MCM that is 0.912% of the original live storage capacity. This has huge implications as this means significant reduction in benefits from the reservoirs in terms of hydropower generation, irrigation, water supply and flood management.

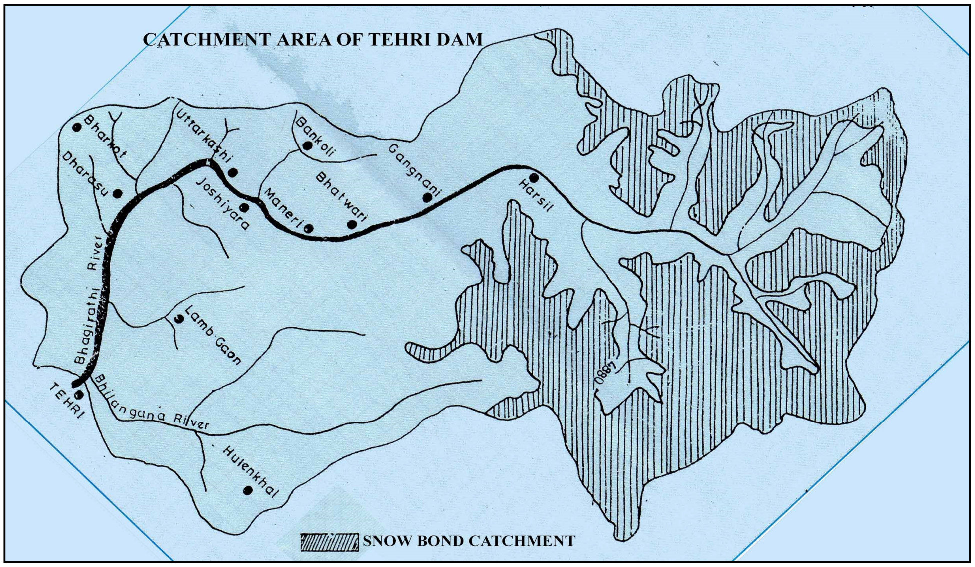
A study has been conducted for sediment yield and deposition pattern of sediment in Tehri reservoir.



2. Catchment Area and sediment Characteristics for Tehri Reservoir:

The catchment area of Tehri dam covers about 7511 sq. km. and is spread over a length of 187 km. Out of total catchment area about 31 % is snow bound, 32% is reserve forest land and remaining 37 % comprises of cattle grazing and private agriculture land. The snow bound catchment contributes run off only in non-monsoon periods due to snow melt. The balance 69 %

of the catchment suffers about 100 to 263 cms average annual precipitation, 80 % of which is received during monsoon period only. The valley receives heavy torrential rains causing floods in the river. The both valleys i.e. Bhagirathi and Bhilangna river valleys have steep side slopes and are quite narrow. The bed slopes are quite high varying from 10m / km at mid distance to 5m / km near the dam site. The valley at certain places is prone to land slide and has deep deposits of debris, hillside wastes and colluvial talus. Furthermore, the rocks are susceptible to considerable weathering and erosion.



3. Silt Data for Tehri Catchment

Due to weaker rocks, steep bed slopes and similar valley characteristics, river Bhagirathi carries sizable amount of suspended sediment and bed load. The most of the sediment is carried by the river during monsoons and the ratio of sediment transported by the river during monsoon and non- monsoon period is very large. Ganga Basin Water Resources Organisation of Central Water Commission collected data for suspended sediment since 1972. The suspended silt data from year 1973 to 1993 are given in Table- 1. Considering generally weak nature of Himalayan rocks and steep valley slopes in the catchment of the project, CWC has recommended bed load as 15 % of the suspended sediment load for Tehri reservoir. Thus with the help of Table-1, total sediment load is assumed to be about 161.84 lac t /year for Tehri reservoir.

4. Methodology for Determining Capacity of a Reservoir

4.1 Inflow-Outflow Method:

In this method, the incoming and outgoing sediment load is estimated on the basis of observations for discharge and sediment samples taken on upstream and downstream of reservoir. The volume of the sediment retained in the reservoir is determined by establishing volume-weight relationship on the basis of analysis of undisturbed sediment samples collected from the reservoir bed. The loss in capacity by the method is determined from the observations in each flood season. This method is usually not much reliable due to following reasons:

- It is difficult to measure accurately the incoming discharge in high floods.
- Sampling of suspended load at varying depths is difficult.
- Sampling of bed load at high velocities is almost impossible.

4.2 Hydrographic Survey

The hydrographic survey is a direct method to find out the depth of sediment deposition, the pattern of sediment deposition and the loss of the reservoir capacity. To compute capacity of reservoir and volume of sediment deposit by this method, reservoir is surveyed for its topology with the help of echo-sounder by range line method along the prefixed range lines. The portion which is not under water is surveyed by ordinary ground survey methods. The depths of the reservoir are recorded with the help of echo sounders along a pre-determined range line across the reservoir. These range lines are normally spaced one to two kilometre apart along the length of the reservoir. 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.

4.3 Remote Sensing Technique

Satellites provide land surface imageries at regular intervals from which water spread areas of the reservoirs can be identified. The satellite imageries for various dates and corresponding gauge observations enable the development of the area-elevation relationship between the maximum and minimum reservoir levels. The relationship can be utilised for calculation of available reservoir capacities at various elevations and the current elevation–area-capacity curves can be obtained. The comparison of the current elevation-capacity curve with the earlier years enables computation of total volume of silt deposited.

The technique is being applied in sedimentation studies of 25 Reservoirs in India by Central Water Commission, NIH and other agencies and it has been reported that the difference between the water spread area measured by ground survey and satellite imageries were within 10 %. The only constraint in this technique is that the silting below minimum water level, is required to be measured using the conventional method of hydrographic survey.

5. Scope of work under the study:

Scope of the study consist of analysing the hydrographic and topographic survey data -2013 for Tehri reservoir w.r.t. pre impoundment survey in the following frame work:-

- Preparation of upgraded X-sectional and L-section.
- To upgrade Elevation Area capacity curve of the reservoir.
- Estimation of Sediment trapped after the last survey and its distribution in reservoir.
- To predict sediment distribution pattern with assessment of NZE
- Loss of storage and prediction of useful life of reservoir.

6. Data Analysis:

The analysis / calculation of data was performed by a tailored computer programme having capability to calculate area of cross section at each range line and submerged area at fixed/given interval of elevation with the help of Trapezoidal formula from the field data. The cross sectional areas and submerged areas are then used to calculate the capacity of reservoir at corresponding elevations. The basic data required for execution are as follows:-

- Total number of range lines
- Distance between consecutive range lines
- Full reservoir level
- Bed level of reservoir
- Elevations corresponding to distances along the range lines.
- Interval of elevations on which capacity of reservoir is to be computed.

6.1 Elevation–Area Computations

On the basis of data, elevation area calculation for the reservoir were computed and the area of the reservoir at FRL (830.0M) is 43.37 Sqkm, 42.69 Sqkm and 41.97 Sqkm for the year 2005 (pre-impound survey), 2008 and 2013 respectively. The small difference in area for 2008 and 2013 may be attributed to small landslides encroaching into the reservoir at that elevation.

6.2 Elevation–Capacity Computations

The reservoir capacities at various elevations have been computed with the same methodology using trapezoidal formula. The capacity of the reservoir has been computed at an interval of 0.10 m up to El. 840.0 m. The capacity of the Tehri reservoir for pre impounding survey (2005), 2008 and 2013 was compared and is shown in Figure-3.The capacity of reservoir for respective surveys at MDDL, FRL AND MWL is shown below:

Table-1: Capacity at different reservoir levels

Res. Elevation	Reservoir Capacity (MCM)		
	2005	2008	2013
740.00 (MDDL)	916.209	910.682	907.45
830.00 (FRL)	3548.51	3527.504	3505.85
840.00	3994.97	3976.272	3973.35

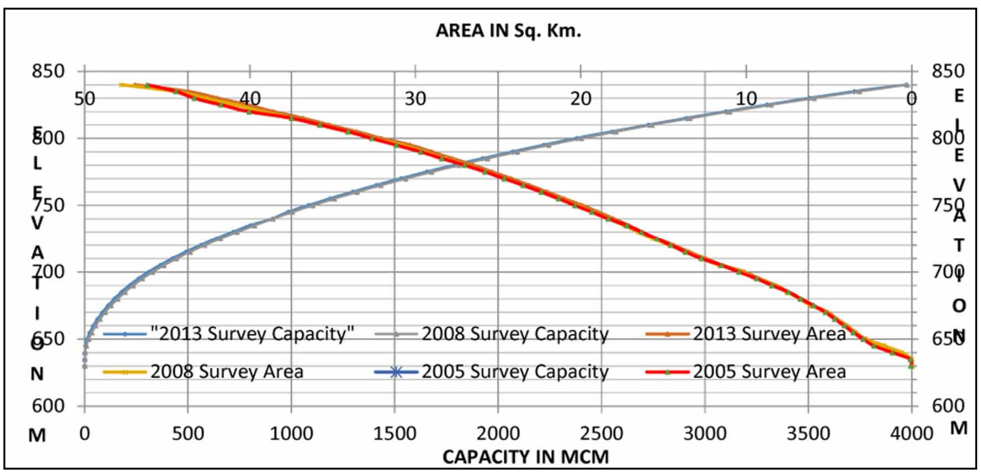


Figure-3: Area capacity curves 2005,2008 & 2013 survey

It may be seen from the above Table-1 that live storage reduced at a rate of 5.16 MCM / year in a period from 2005 to 2008 while latter on from a period of 2008 to 2013(5 years), the rate of reduction of live storage was reduced to 3.68 MCM / year. The overall reduction rate of the live storage of Tehri reservoir since the year 2005 comes to be 4.23 MCM / year. Similarly, the reduction rate in total reservoir capacity of the reservoir at FRL is 7.00MCM/Year from 2005 to 2008 and 4.33 MCM/ Year for a period of 2008 to 2013. The reduction in flood capacity (El.830.0 m to El.840.0m) is very substantial from year 2008 to year 2013. The reduction may be summarized as below:-

Time Period	Reduction in Reservoir Capacity (MCM)		
	Live Capacity	Gross Capacity	Flood Area Capacity
2005-2008	15.48	21.01	18.65
2008-2013	18.42	21.65	2.92

6.3 Evaluation of Trapped Sediment:

It may be seen from the above table that drastic reduction in sediment yield has occurred after 2008. It has been reported in many cases that for any reservoir more increase in sediment yield in the first five years is due to loosening of top soil by the activity of planting vegetation or other activities. A higher reduction in the next 3-5 years should follow, after which a slower rate would ensure until the rate stabilizes about the likely lower limit. The average volume of sediment trapped during the first 3 years (2005-2008) was 7.0 M Cum / year which is reduced to 4.33 MCM/Year from 2008 to 2013 (5 years).

7. SEDIMENT DISTRIBUTION PATTERN&CLASSIFICATION OF RESERVOIR:

Depending upon the percentage of sediment deposition with respect to depth of the reservoir, U.S.B.R. has classified the reservoirs into four standard types (Figure-4) The pattern of sediment deposited at different depth of reservoir after 2013 survey is also plotted on the same figure and it may be seen that the current pattern of deposition lies quite close to type – III reservoir curve, therefore, the Tehri reservoir under the present conditions may be classified as Type –III reservoir.

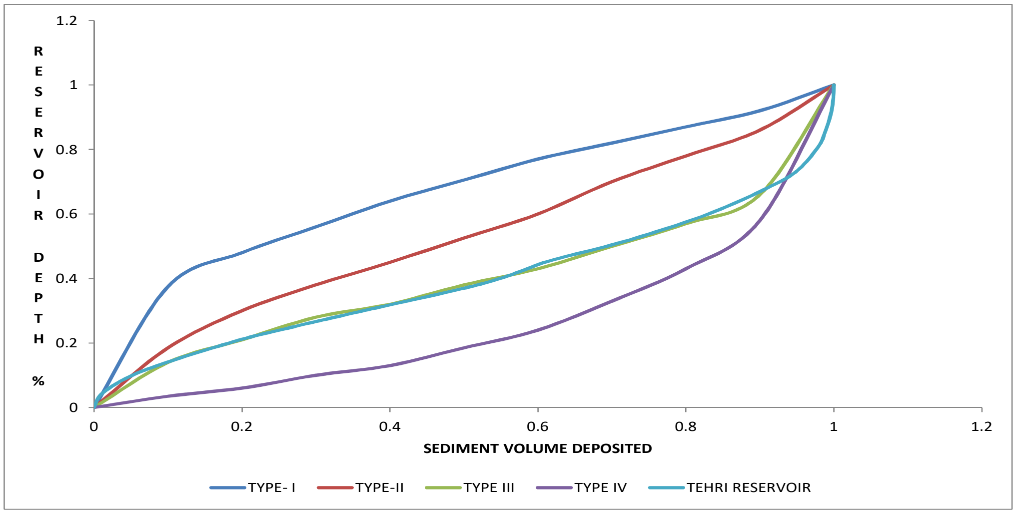


Figure-4: USBR classification of reservoirs and status of Tehri reservoir

Further the depth to capacity relationship also defines the shape of the reservoir. The standard curve adopted for determining the Shape of the reservoir is shown in Figure-5.

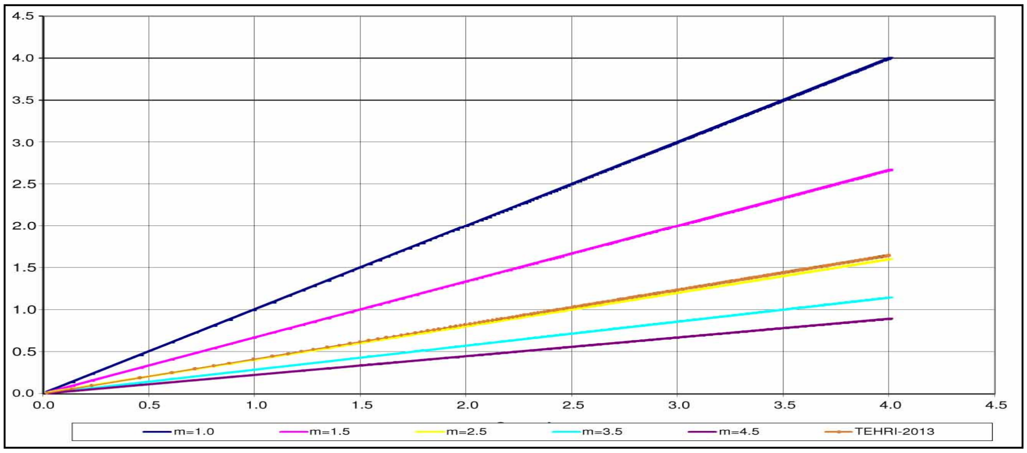


Figure-4: Determination of shape of reservoir

It may be seen that log of depth plotted against calculated value of M (2.433) lies almost on the line of curve with M=2.5 (Type –III reservoir), therefore, the present shape of Tehri reservoir is classified with type III reservoir.

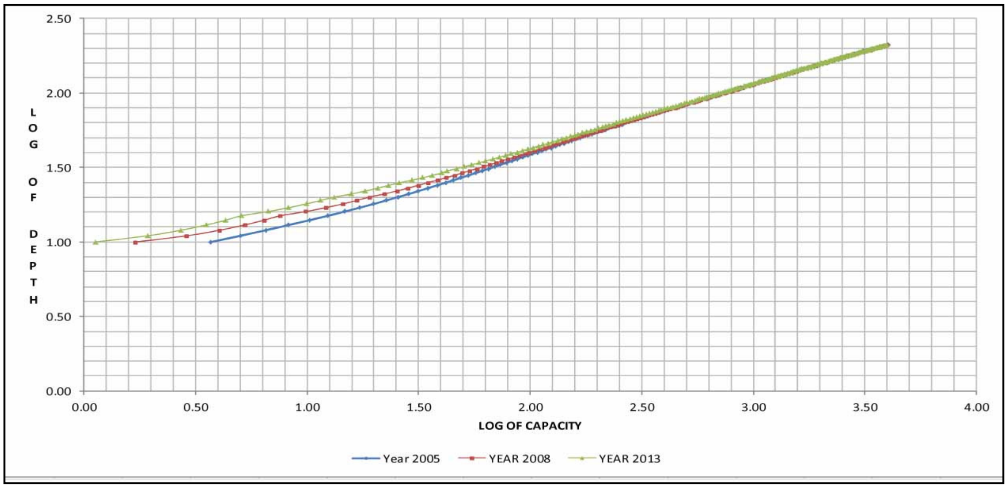


Figure-6: Log plot of reservoir depth vs reservoir capacity (slope "M")

Utilizing the data of 2005-Survey, Nov-Dec 2008 survey and that of Jan-Feb 2013, the slope 'M' has been computed and depicted in Figure-6, the values of calculated 'M' for different surveys is given below also:

Year	M	Type
2005-Survey	**2.21**	**III**
2008-Survey	**2.50**	**III**
2013-Survey	**2.43**	**III**

8. Prediction of Sediment Distribution:

8.1 Empirical Area Reduction Method:

8.1.1 Design Curves for Tehri Reservoir and NZE Calculations:

Using the surveys data of Tehri Reservoir, the design curves appropriate for Tehri reservoir have been developed for use in finding out the New Zero elevation. The standard area design curves and the area design curve appropriate for Tehri reservoir has been plotted in Figure-7. The area design curve for Tehri reservoir resembles with reservoir Type-III curve.

Using the design curve of Type-III reservoir, new zero elevation (NZE) is computed as 634.0 m by empirical area reduction method. The New Zero elevation has also been calculated by Area increment method which indicates the NZE to be 635.7. New Zero elevation as per 2013 year survey is 634m. However, the capacity below El 635m does not significantly alter the subsequent area-capacity curves. Therefore, the NZE can be taken as 634.0m.

Vertical distribution of sediment volume (accumulated sediment volume as % of total Vs relative depth) is plotted in Figure- 8. Further, the Elevation-area-capacity curve for years 2005 and 2008 is shown in Figure-9.

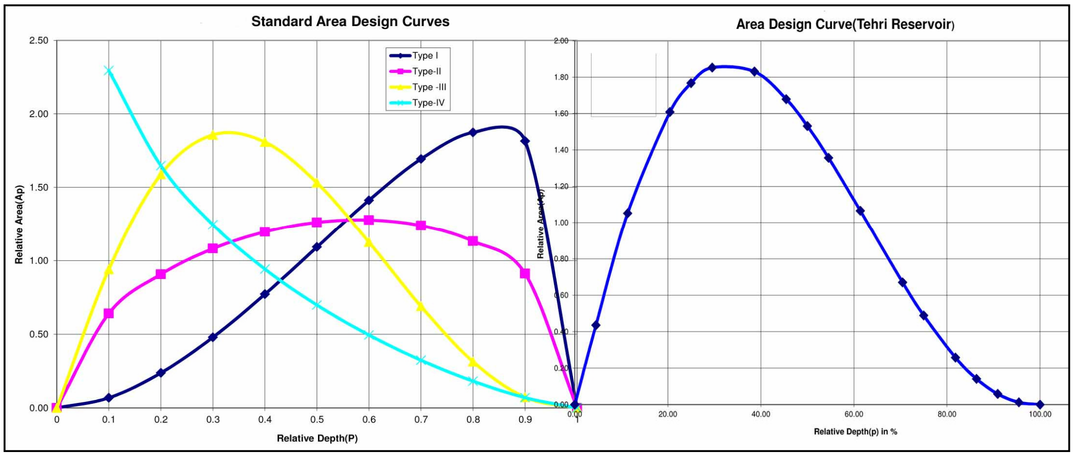


Figure-7: Standard and Tehri reservoir area design curves

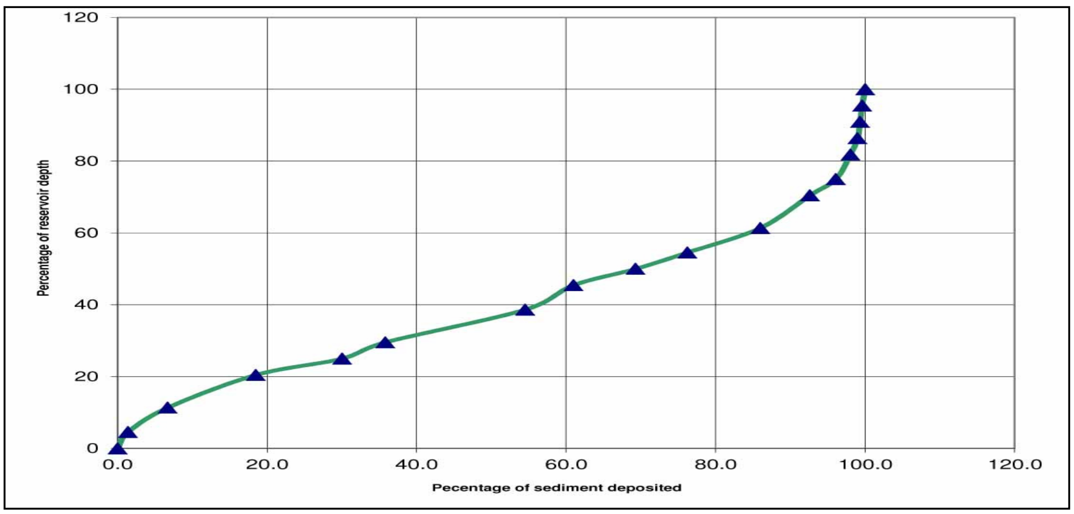


Figure-8: Vertical distribution of sediment volume.

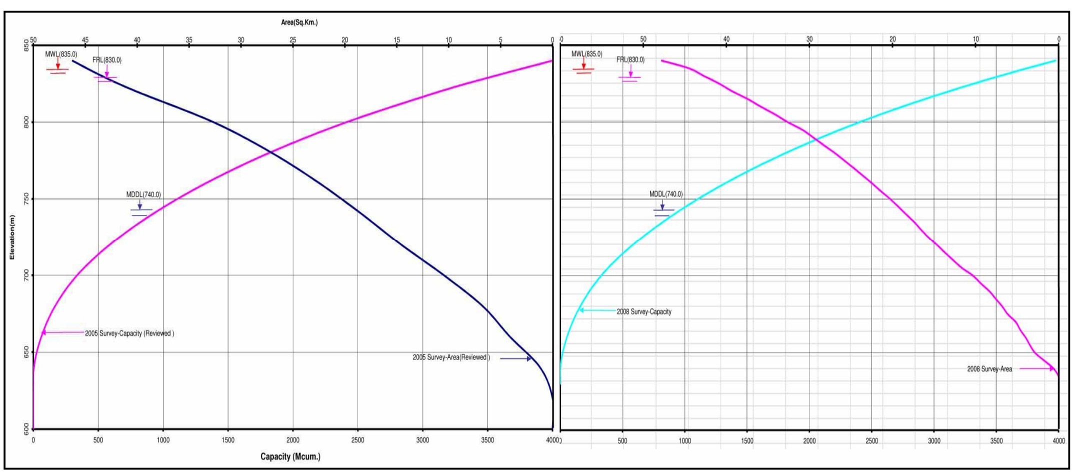


Figure-9: Elevation area capacity curve for 2005 & 2008 (Left & Right figures).

8.1.2 SEDIMENTATION IN DIFFERENT ZONES AND LOSS OF STORAGE:

In order to access the quantity of sediment deposited in different reaches of the reservoir, the reservoir survey area was divided into eight (8) zones as given below and marked in Figure-10

(i) Zones – 1. 2 and 3 from entry of the Bhilanganariver into the reservoir.
(ii) Zones – 5, 6, 7 and 8 cover the Bhagirathi River
(iii) Zone – 4 confluence of Bhagirathi and Bhilangana Rivers nearest to Dam

Table 4: Sediment deposit in different zones of reservoir

Zone	Capacity at FR: 2008-Survey (MCM)	Capacity at FRL: 2013- Survey (MCM)	Reduction of Capacity (MCM)	% Capacity Reduction
I	32.425	32.187	0.238	0.734
II	231.851	231.345	0.506	0.218
III	527.596	523.311	4.285	0.812
IV	982.456	975.913	6.543	0.666
V	896.607	893.802	2.805	0.313
VI	500.718	499.36	1.358	0.271
VII	280.055	276.159	3.896	1.391
VIII	75.796	73.773	2.023	2.669
Total	3527.504	3505.85	21.654	0.614

It may be seen from Table-4 that the siltation is mostly confined to the zones close to the reservoir namely, Zone III and IV. The situation is almost same as was in previous years of analysis.

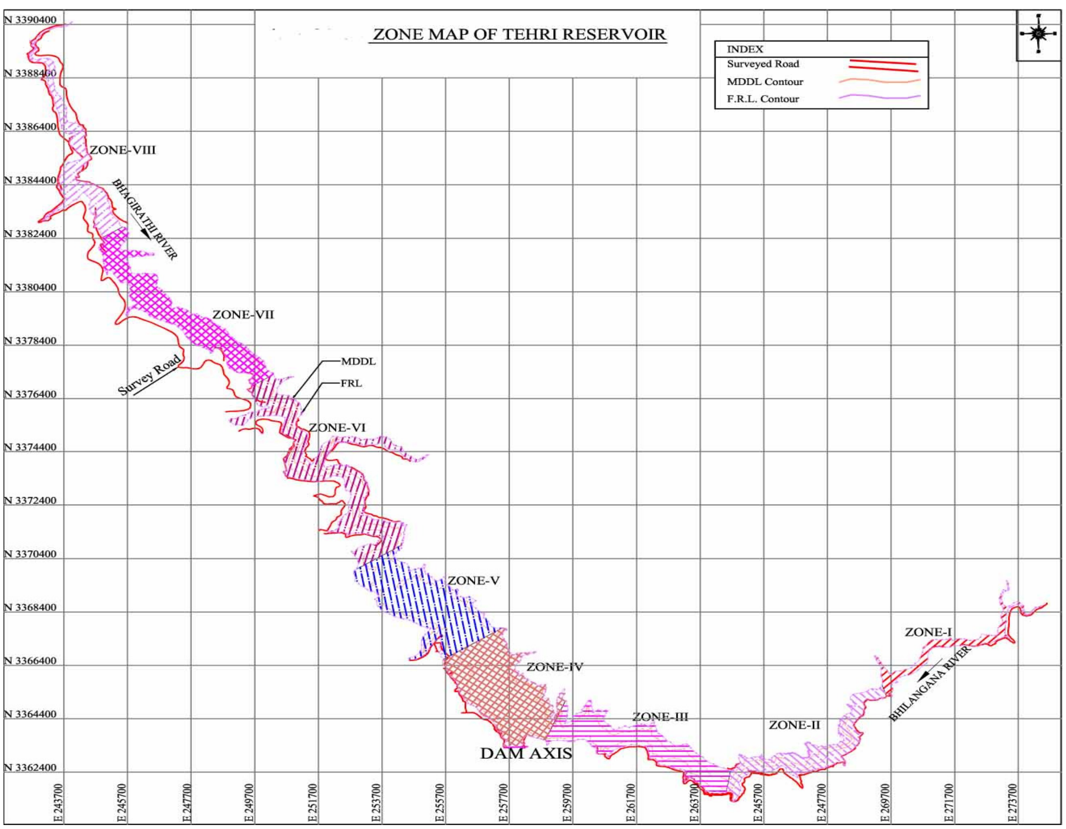


Figure-10: Zone map of Tehri reservoir

8.2 Loss of Storage from 2008 to 2013:

Table 4: Siltation of Tehri reservoir (loss of reservoir) from 2008-2013.

Levels	Total silt deposited (MCM)	% Loss of capacity	Rate of siltation MCum / 100sq km / year
In MDDL storage	3.232	0.355	0.0086
In LIVE storage	18.422	0.704	0.0490
Total up to FRL	21.654	0.614	0.0576

8.3 Assessment of useful life of reservoir:

Reservoirs formed by dams on natural rivers are invariably subjected to sedimentation. The term "life of reservoir", as loosely used denotes the period during which whole or a specified fraction of its total or active capacity is lost. As per the assessment criteria "*Useful capacity of reservoir = 70% of the original capacity (assumed)*", useful life of the reservoir has been computed as 465.8 Yrs and as per the assessment criteria "*Useful capacity of the reservoir = Pre pounding storage up to MDDL (740 m)*", useful life of the reservoir computed as 171.8 Yrs.

9. Summary and Conclusion of the Report:

The computation and analysis of the survey data for the capacity of Tehri reservoir reveals that:

- Since impounding of the reservoir, loss of area up to MDDL is 0.313 Km2 while at FRL the area loss is 1.4 Km2.
- The overall reduction rate of the live storage of Tehri reservoir since the year 2005 comes to be 4.23 MCM / year.
- The pattern of sediment deposited at different depth of Tehri reservoir after 2013 survey, if, plotted on the figure given by USBR for classification of reservoirs (Fig.12) , it may be seen that the current pattern of deposition lies quite close to type – III reservoir curve, therefore, the Tehri reservoir under the present conditions may be classified as Type –III reservoir.
- Using the design curve of Type-III reservoir, new zero elevation (NZE) is computed (Table 10) as 634.0 m by empirical area reduction method. The New Zero elevation has also been calculated by Area increment method. It indicates the NZE to be 635.7 (Table-11). However, the capacity below El 635m does not significantly alter the subsequent area-capacity curves. Therefore, the NZE can be taken as 635.0m.
- For more detailing and validation of results, the reservoir sedimentation study is recommended to be done through mathematical modelling.