Journal of Spatial Hydrology
Vol.8, No.2 Fall 2008

Estimation of useful life of a reservoir using sediment trap efficiency

Vaibhav Garg [*] *and V. Jothiprakash* [**]

Abstract The most important practical and critical problem related to the performance of reservoirs is the estimation of storage capacity loss due to sedimentation process. The problem to be addressed is to estimate the rate of sediment deposition and the period of time at which the sediment would interfere with the useful functioning of a reservoir. Fairly a large number of methods and models are available for the estimation, analysis and prediction of reservoir sedimentation process. However, these methods and models differ greatly in terms of their complexity, inputs and computational requirements. In the present study, the rate of sedimentation and useful life time of a reservoir were estimated using the trap efficiency (T_e) approach. The empirical relationship suggested by Brune (1953) to estimate reservoir sediment T_e and Gill (1979) approach to estimate useful life of a reservoir are modified to suit Gobindsagar Reservoir (Bhakra Dam) on Satluj River in Bilaspur district, Himachal Pradesh, in the Himalayan region of India. Based on Brune (1953) curves the sediments were found to be mostly of coarse grained in nature. Bhakra Beas Management Board (BBMB), the controlling agency of the reservoir, estimated that the dead storage would be filled with sediments (useful life) in 142 years, considering sediments incoming mostly to be medium grained in nature. By using the Capacity Inflow ratio (C/I), T_e, sediment density and different sediment characteristics, in the present study, it is found that the useful life of this reservoir is three fourth of the period estimated by BBMB.

Keywords: reservoir sedimentation; trap efficiency (T_e); capacity inflow ratio (C/I); useful life of reservoir; Brune (1953) method; Gill (1979) method.

1. Introduction

The primary functions of a reservoir are to smoothen out the variability of surface water flow through control and regulation and make water available when and where needed. Reservoirs have well known primary purposes such as water supply, irrigation, flood control, hydropower and navigation. The total storage capacity of reservoirs in the world has been estimated by various sources. One such estimation is 4000 to 6000 x 10^9 m^3, and another is 5 per cent of the total runoff in the world (38830 x 10^9 m^3), i.e. 2 000 x 10^9 m^3 (Yang, 2003). According to Siyam et al. (2005), the potential quantity of water that can be controlled in the future varies between 9000 and 14000 km^3 annually. Thus the reservoirs are key infrastructures for mankind survival and well being.

Reservoir sedimentation is the process of sediment deposition into a lake formed after a dam construction. A dam causes reduction in flow velocity and consequently the turbulence, which causes the settling process of the materials carried by the rivers. There are many causes of reservoir sedimentation; however, watershed, sediment and river characteristics are the main natural

[**] *Correspondence to: V. Jothiprakash, Assistant Professor, Department of Civil Engineering, Indian Institute of Technology Bombay, Powai, Mumbai – 400 076, Maharashtra, India. E-mail: vprakash@iitb.ac.in, Ph: +91-22-25767315, Fax: +91-22-25767302*

contributing factors. The dominant factors that influence the rate of silting in a reservoir are: (a) Capacity to Inflow Ratio *(C/I),* (b) sediment content in the water flowing in, (c) texture and size of the sediment, (d) trap efficiency (T_e) of the reservoir, and (e) the method of reservoir operation (Arora and Goel, 1994). Globally, the overall annual loss rate of reservoir storage capacity due to sedimentation is estimated as 1 to 2 per cent of the total storage capacity (Yoon, 1992; Yang, 2003). Some reservoirs are filled very rapidly, while others are hardly affected by sedimentation. In India, many reservoirs have been subjected to reduction in their storage capacities due to sedimentation. Analysis of sedimentation survey details with respect to 43 major, medium and minor reservoirs in the country indicated that the sedimentation rate varies between 0.34 – 27.85 ha m/100 km^2/ year for major reservoirs, 0.15 – 10.65 ha m/ 100 km^2/ year for medium reservoirs and 1.0 – 2.3 ha m/ 100 km^2/ year for minor reservoirs (Shangle, 1991).

Methods to predict reservoir sedimentation have been the subject of several empirical studies since the 1950's. Prediction of reservoir useful lifetime is the final target of all reservoir designers making the issue as an important subject within hydraulic research (Lagwankar et al. 1994). Most of the empirical methods considered T_e as the important parameter for estimating sedimentation in reservoirs. In the present study, the T_e of Gobindsagar Reservoir (Bhakra Dam) on Satluj River in Bilaspur district, Himachal Pradesh, in the foothill of Himalaya, India is estimated by modifying the Brune (1953) method. After classifying the type of sediment the Gill (1979) approach is modified and employed to estimate the useful life of the reservoir.

2. Study area

The Bhakra dam is one of the oldest dams in India, commissioned in 1958, on Satluj River in Bilaspur district, Himachal Pradesh, in the foothills of Himalayan region, India; which ultimately led to creation of Gobindsagar Reservoir (as shown in Fig. 1). According to (Morris and Fan, 1998), reservoirs having C/I ratio more than 50% may be considered hydrologically large, therefore, this reservoir is categorized as large reservoir. It has a total storage capacity of 9867.84 x 10^6 m^3 with water spread area of 168.35 km^2 at full reservoir level. The river Satluj originating from Mansarover Lake along with its tributaries has a catchment area of 56,876 km^2. The reservoir is fed by the flow consisting of contribution from rainfall and snowmelt. Singh and Kumar (1997) have studied precipitation distribution for several Himalayan basins and found that the maximum contribution to annual rainfall (42–60%) is received during the monsoon season, whereas the minimum (5–10%) is received in the post-monsoon season.

The time series plot of annual inflow from 1963-2003 (40 yrs.) is shown in Fig. 2 along with the annual rainfall. From Fig. 2, it can be seen that the rainfall is showing slightly decreasing trend over the observed years. On the other hand, the inflow is showing a prominent increasing trend. The reason for increase in inflow may be due to snow melt in the catchment area. This shows that the average annual inflow rate is increasing year by year, which in turn is reducing the C/I ratio and hence, pushing the reservoir from major to medium reservoir. While negotiating through vivid terrains, the increased inflow transports lot of silt into the reservoir affecting its life. The natural factors that also attribute to high levels of sediment transport from the study region are steep topographic gradient (causing landslides and slips), poor structural characteristics of soils; clay rich rocks such as Spiti Shale and Schist; and the widespread existence of limestone deposits (Sharma *et al.*, 1991).

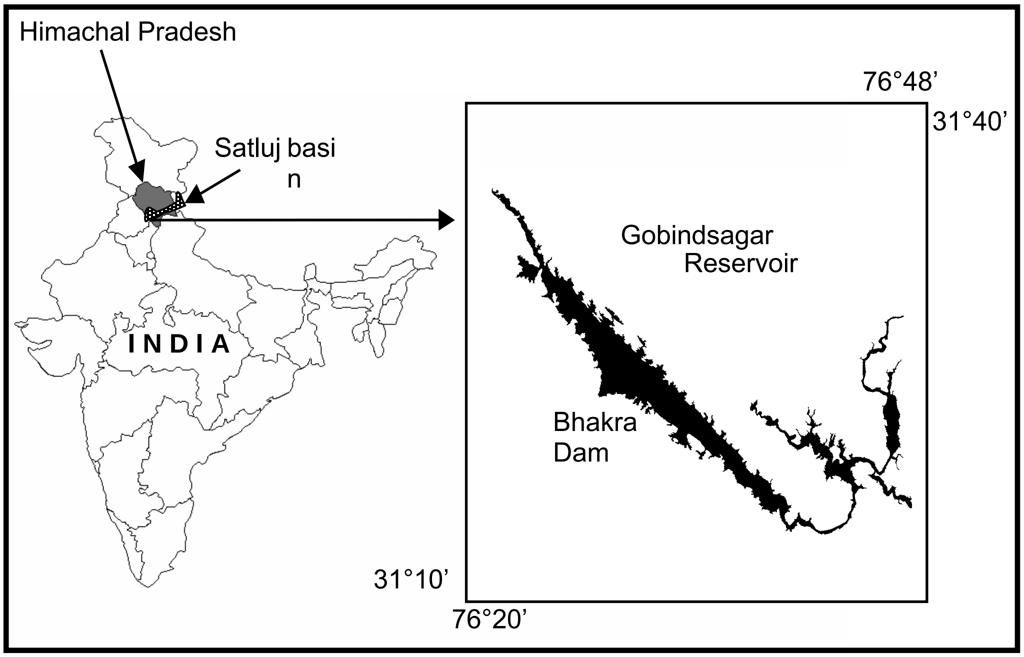

Figure 1 The location of Gobindsagar Reservoir on Satluj River
(Source: Jain et al. 2002)

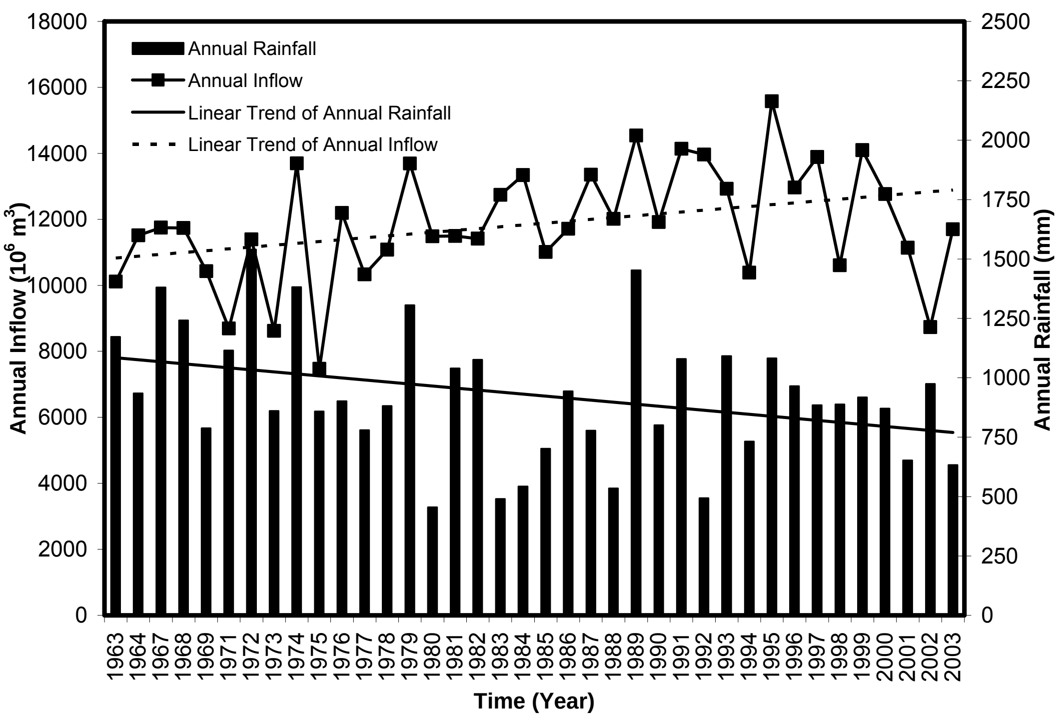

Figure 2 Time Series Plot of Annual Inflow and Rainfall

3. Trap efficiency (T_e) estimation

Heinemann (1981) considered the T_e to be the most informative descriptor for reservoir sedimentation estimation. T_e is the proportion of the incoming sediment that is deposited or trapped in a reservoir and is often expressed in percentage as given in eq. 1.

$$T_e = \frac{V_i - V_o}{V_i} \times 100\% \qquad \text{Equation (1)}$$

where, V_i is the inflowing sediment load and V_o is the outflow sediment load. The T_e, even though it is estimated from inflow and outflow of sediment actually T_e is dependent on several parameters, including sediment size, distribution; the time and rate of water inflow to the reservoir; the reservoir size and shape; the location of the outlet structure and water discharge schedules (Morris and Fan, 1998; Verstraeten and Poesen, 2000; Campos, 2001; Yang, 2003).

Many empirical studies; (Brown, 1944; Churchill, 1948; Brune, 1953; Borland, 1971; Dendy, 1974; Gill, 1979; Heinemann, 1981) showing the relation between reservoir storage capacity, water inflow, and $T_{e;}$ have been conducted. The Brune (1953) is probably a most widely used method for estimating the sediment retention in reservoirs. Brune (1953) curves were drawn based on data from 44 normal ponded reservoirs in the United States. Brune (1953) plotted the T_e against the reservoir *C/I*. The Brune (1953) graph is composed of three curves, one median and two envelop ones. Borland (1971) added the data from desilting basins and semi-dry reservoirs to Churchill's curve and concluded that there was good correlation between observed data and Churchill's curves. A comparison between the Churchill (1948) and the Brune (1953) was made by Trimble and Carey (1990) for 27 reservoirs in the Tennessee River Basin. The sediment yield was calculated based on the two *Te* curves and sediment accumulation data for these reservoirs. The estimated T_e values according to Brune (1953) were estimated equal to or higher than the T_e values according to Churchill (1948), but, in general, the two values were similar (Trimble and Carey, 1990). It was concluded that, for a system of reservoirs, the Churchill method, which accounts for sediment received from an upstream reservoir, provides a more realistic estimate of sediment yields than the Brune method. Bube and Trimble (1986) used the original data of Churchill (1948) and those added by Borland (1971) to revise the curves proposed by Churchill (1948). Trimble and Bube (1990) revised these curves again by decreasing the variance of the local sediment yields as calculated by these curves through the use of an optimization technique.

Although the use of the Churchill curves may give a better prediction of T_e than the Brune curves, it is very difficult to obtain the input data for calculating the sedimentation index. This is probably the reason why Brune's approach is used so extensively as opposed to that of Churchill. Especially for small dry or semi-dry reservoirs where the outlet is located at the bottom of the embankment, it is very difficult to calculate these data as these outlets only operate during infrequent, short-lasting events (Dendy, 1974). There are a few studies that have attempted to compare the different empirical models discussed above for selected reservoirs and storm events. Rowan et al. (1995) indicated that, for one reservoir, the prediction of T_e according to Heinemann (1981) was 30% lower than according to Brown (1944), with Brune (1953) in between the two. For two water supply reservoirs in the southern Pennines (UK), Butcher et al. (1992a,b) measured the in- and outflowing sediment for four and five storm events, respectively. A comparative study was carried out between the measured T_e

and the T_e predicted by Brown (1943), Churchill (1948), Brune (1953) and Heinemann (1981). Although there is not much difference between the selected models, it was concluded that the Brown (1944) curves are the most appropriate. This is reasonable because the reservoirs had the same hydrologic regime as the ones Brown used in his study. The Brown curves are, of course, the simplest to use, certainly when runoff data are lacking. On other hand, Soler-López (2003a) used Brune (1953) method for estimating T_e of Lago El Guineo and Soler-López (2003b) for Lago Guayabal, Puerto Rico. Siyam et al. (2005) compared the trap efficiencies of the five reservoirs (Koka, Roseiris, Girba, Angerib, Nasir) on Nile River using this approach.

Gill (1979) developed empirical equations (eqs. 2-4) which provided a very close fit to the three curves proposed by Brune.

Primarily Highly Flocculated and Coarse Grained Sediments:

$$T_e = \frac{(C/I)^2}{[0.994701(C/I)^2 + 0.006297(C/I) + 0.3\times 10^{-5}]} \qquad \text{Equation (2)}$$

Median Curve (for Medium Sediments) Morris and Wiggert (1972):

$$T_e = \frac{(C/I)}{(0.012 + 1.02C/I)} \qquad \text{Equation (3)}$$

Primarily Colloidal and Dispersed Fine-grained Sediments:

$$T_e = \frac{(C/I)^3}{[1.02655(C/I)^3 + 0.02621(C/I)^2 - 0.133\times 10^3 \times (C/I) + 0.1\times 10^{-5}]} \qquad \text{Equation (4)}$$

4. Useful life estimation

The period up to which the reservoir can serve the defined purpose is called usable life, the period after which the cost of operating the reservoir exceeds the additional benefits expected from its continuation is called economic life, design life is generally the useful life, full life period is that when no capacity is available in the reservoir for useful purpose (Murthy, 1980; Kulkarni et al. 1994). Useful life is the period during which the sediment collected does not affect the intended primary use of the reservoir (Arora and Goel, 1994; Kulkarni et al. 1994, Agrawal and Singh, 1994). In most of the developed countries full life said to be arrived, when half of the total capacity of reservoir is depleted. While in case of Trinity River basin reservoirs (Texas), it was considered as the period when the useful storage would be completely destroyed (Arora and Goel, 1994). Useful life is an important design parameter of a reservoir which may affect the economic feasibility and sustainability of a water resources project (Gill, 1979).

A direct method for useful life estimation of a reservoir was proposed by Gill (1979) which correlates the reservoir capacity with age in years algebraically. With the relationship between sedimentation rates, T_e, specific weight of sediment deposited, the storage available after sedimentation for a given period Δt was estimated using the following equation:

$$C_o - C = \frac{G \times T_e \times \Delta t}{\bar{\gamma}} \qquad \text{Equation (5)}$$

where, C_o is the initial capacity of reservoir; C, is reduced capacity of reservoir at any time t; G, is characteristic weight of annual sediment inflow; Δt is a short interval of time in years in which capacity is reduced from C_o to C ; and $\bar{\gamma}$ is specific weight of sediment deposited.

Assuming a period in which the initial reservoir capacity will reduce to half (means C = Co/2) as useful life of a reservoir and by substituting the value of T_e from the eqs. 3 or 4 in eq. 5, Gill (1979) derived equations for estimating the useful life of a reservoir and are reported here in as eq. 6 to 8.

Primarily Highly Flocculated and Coarse Grained Sediments:

$$T_L = \left(\bar{\gamma}\frac{I}{G}\right)\left(0.49735\frac{C_o}{I} + 0.3 \times 10^{-5} \times \frac{I}{C_o} + 0.00436\right) \qquad \text{Equation (6)}$$

Median Curve (for Medium Sediments):

$$T_L = \left(\bar{\gamma}\frac{I}{G}\right)\left(0.008 + 0.51\frac{C_o}{I}\right) \qquad \text{Equation (7)}$$

Primarily Colloidal and Dispersed Fine-grained Sediments:

$$T_L = \left(\bar{\gamma}\frac{I}{G}\right)\left(0.51328\frac{C_o}{I} - 0.133 \times 10^{-3} \times \frac{I}{C_o} + 0.153 \times 10^{-5} \times \left(\frac{I}{C_o}\right)^2 + 0.018167\right) \qquad \text{Equation (8)}$$

where T_L is useful life of reservoir in years, e.g., time in which the initial reservoir capacity C_o will reduce to half.

4.1 Specific weight of sediment deposited

The above Gill (1979) approach has the following drawbacks (i) it assumed a constant specific weight of sediment deposit, however the specific weight may increase with time due to consolidation which occurs when fresh sediment gets deposited over the old deposited sediment. (ii) the T_e approach does not take into consideration the location of sedimentation, but only gives the quantity of sediment deposited anywhere inside the reservoir. To account for the increase in specific weight of sediments Lane and Koelzer (1953) suggested a widely used formula with time (Yang, 1996).

Lane and Koelzer formula:

$$\gamma = \gamma_1 + B \times \ln(t) \qquad \text{Equation (9)}$$

where γ is specific weight of sediments at an age of t years; γ_1 is specific weight at the end of 1 year; and B is a constant with dimensions of specific weight. Lane and Koelzer (1953) have also given the values of γ_1 and B for different degree of submergence of sediments of different sizes as shown in Table 1.

Table 1 Values of γ_1 in kg/m^3 (lb/ft^3) and B for estimating specific weight of reservoir sediments

Reservoir Operation	Sand		Silt		Clay	
	γ_1	B	γ_1	B	γ_1	B
Sediment always submerged or nearly submerged	1550 (97)	0	1120 (70)	91 (5.7)	416 (26)	256 (16.0)
Normally a moderate reservoir drawdown	1550 (97)	0	1140 (71)	29 (1.8)	561 (35)	135 (8.4)
Normally considerable reservoir drawdown	1550 (97)	0	1150 (72)	0.0	641 (40)	0.0
Reservoir normally empty	1550 (97)	0	1170 (73)	0.0	961 (60)	0.0

(Source: Morris and Fan, 1998; Annandale, 1987)

Sediments coming to the reservoir are usually mixture of sand, silt and clay in different proportion. The specific weight of this sediment mixture can be determined by adding the fractional weights of sand, silt and clay. Substituting the values of γ_1, B and *t* in eq. 9, specific weight at the end of *t* years can be calculated. Eq.10 or 11 can be used to determine the average specific weight.

$$\bar{\gamma} = \left(\frac{1}{t-1}\right)\int_1^t \gamma dt \qquad \text{Equation (10)}$$

or,

$$\bar{\gamma} = (\gamma_1 - 0.434B) + \left(\frac{Bt}{t-1}\right)\ln(t) \qquad \text{Equation (11)}$$

5. Modification, application and results

Bhakra Beas Management Board (BBMB) has carried out capacity surveys for Gobindsagar reservoir from 1963 to till date to measure the actual silt deposited (Initially up to 1977 it was carried out annually and thereafter these surveys are being carried out on alternate year). According to the survey carried out recently, the average annual rate of siltation was worked out as 34.552 x 10^6 m^3 (BBMB, 2003). BBMB also worked out the average T_e as 99.4% and the overall capacity loss of reservoir as 15.67%.

In the present study as an initial step, the T_e of Gobindsagar reservoir has been estimated using Brune (1953) curves. The T_e measured (BBMB, 2003) is first plotted on Brune (1953) curves as shown in Fig. 3. It can be seen from Fig. 3 that the T_e follows the trend just above the trend of Brune (1953) primarily highly flocculated and coarse grained sediments envelope curve. Therefore, a best fit equation based on the original Brune (1953) Primarily Highly Flocculated and Coarse Grained Sediments envelope curve was developed for this reservoir to calculate the T_e. The developed best fit equation for the Gobindsagar Reservoir is given in eq. 12.

$$T_e = \frac{\left(\frac{C}{I}\right)^2}{\left(\frac{C}{I}\right)^2 + 0.0025 \times \left(\frac{C}{I}\right) + 0.00003} \qquad \text{Equation (12)}$$

The T_e estimated using Gill (1979) eq. (2) and present study eq. (12) along with the observed T_e and C/I ratio is reported in Table 2. The observed and estimated sediment volume is also presented in Table 2. From Table 2 it can be seen that the C/I ratio is gradually decreasing because of increasing inflow as well as decrease in capacity. This shows that overall the reservoir is moving from large reservoir category to medium reservoir category. Thus the relationship developed by other studies could not be applied directly to this type of reservoir. Both Gill (1979) and present study approach reported in Table 2 are showing the general decreasing trend of observed T_e. On closer look of the values, it is found that present study closely follows the observed T_e even for lower C/I ratio. However, Gill (1979) method underestimates the T_e especially for the recent past years (from 1987). This comparison is also shown in Fig. 4. The observed T_e, the trend of observed T_e, T_e estimated using Gill (1979) approach and T_e estimated using present study are plotted chronologically from 1987. Even though the observed T_e shows variations, the trend is showing a decrease in T_e with increase in life of reservoir. On the other hand, From Fig. 4 it can be observed that as, time increases present study is estimating better and is closer to the trend of observed T_e. Gill (1979) approach is underestimating the T_e and is moving away from the trend of observed T_e.

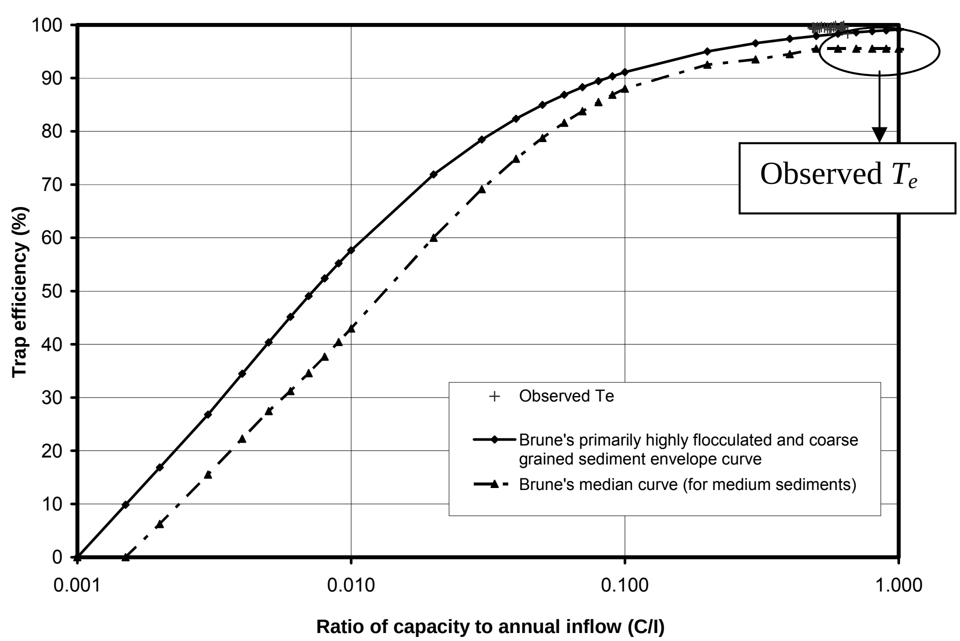

Figure 3 Brune's Curve for Estimating Sediment Trapping Efficiency
(Source: Brune, 1953)

Table 2 Comparison of observed and estimated trap efficiencies and sediment volume

Year	C/I Ratio	Observed T_e (%) using Eq. 1	Estimated T_e, (%) Gill Eq. 2	Estimated Te, (%) Present Study Eq. 12	Observed Sediment Volume (10^6 m^3)	Estimated Sediment Volume (10^6 m^3) Using present study approach
1963	0.651	98.4	99.56	99.60	23.34	23.63
1964	0.641	98.4	99.55	99.60	30.20	30.17
1967	0.630	99.8	99.53	99.60	44.73	44.63
1968	0.628	99.7	99.53	99.60	29.76	29.73
1969	0.627	99.5	99.53	99.59	24.52	24.54
1971	0.623	99.0	99.52	99.59	18.38	18.48
1972	0.621	99.6	99.52	99.59	39.55	39.58
1973	0.620	99.0	99.52	99.59	18.44	18.54
1974	0.616	99.6	99.51	99.59	50.66	50.66
1975	0.615	99.4	99.51	99.59	21.44	21.47
1976	0.613	99.5	99.50	99.59	39.01	39.03
1977	0.613	99.3	99.50	99.59	16.76	16.79
1979	0.588	99.8	99.46	99.57	51.90	52.21
1981	0.579	99.6	99.44	99.56	28.98	28.97
1983	0.566	99.5	99.42	99.55	33.64	33.66
1985	0.560	99.1	99.41	99.55	21.23	21.33
1987	0.550	99.4	99.39	99.54	49.31	49.36
1989	0.536	99.5	99.36	99.53	54.22	54.24
1991	0.522	99.6	99.33	99.51	42.12	42.09
1993	0.513	99.4	99.31	99.50	27.45	27.49
1995	0.504	99.5	99.28	99.49	45.58	45.57
1997	0.497	99.3	99.27	99.49	38.88	38.95
1999	0.491	99.2	99.25	99.48	37.99	38.10
2001	0.487	99.5	99.24	99.48	43.88	43.88
2003	0.485	99.4	99.24	99.47	35.88	35.90
Average		**99.36**	**99.42**	**99.55**	**34.714**	**34.76**
Average from 1987 onwards		**99.42**	**99.29**	**99.49**		

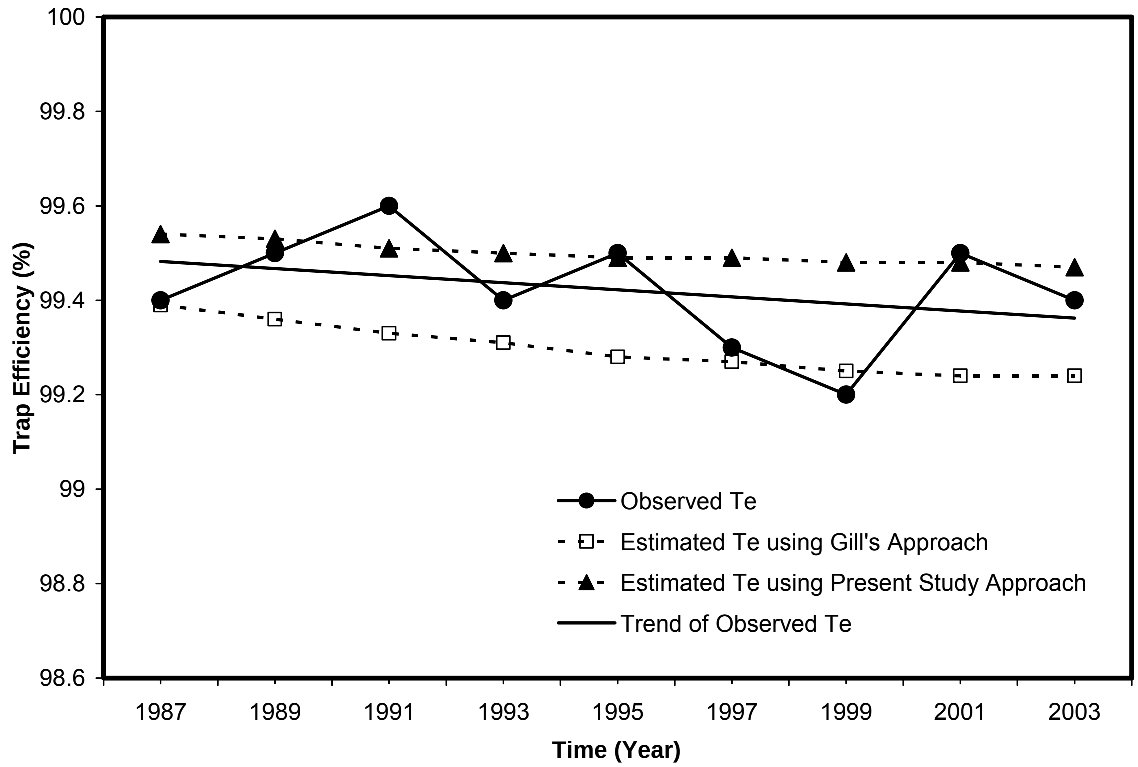

Figure 4 Comparison of Observed and Estimated T_e (from 1987 onwards)

Since, the present study T_e shows closer fit to the observed, it is used to estimate the volume of sediment. The volume of sediment estimated using present study is also listed in Table 2 along with the observed sediment volume. The average annual sediment volume is 34.76 x 10^6 m^3 which is very close to the average value of the observed sediment (i.e., 34.714 x 10^6 m^3).

The useful life of Gobindsagar reservoir has also been estimated using the similar analytical approach as described in the preceding section. The eq. 5, C_o-C can be replaced by ∆C and can be written as eq. 13 in differential form for an infinitesimally small period of time.

$$\frac{dC}{dt} = \frac{G\,T_e}{\bar{\gamma}} \qquad \text{Equation (13)}$$

The useful life (T_L) reported in eq.14 was derived by integrating the general equation of change in storage (eq.13) within C_o to C limits and by replacing T_e with eq. 12 as shown below.

$$T_L = \left(\bar{\gamma}\frac{I}{G}\right)\left[\frac{(C_o - C)}{I} + 0.0025 \times \ln\left(\frac{C_o}{C}\right) - 0.3 \times 10^{-5}\left(\frac{I}{C_o} - \frac{I}{C}\right)\right] \qquad \text{Equation (14)}$$

As Gobindsagar is a large reservoir and sediments deposited are generally remain submerged in reservoir water, the specific weight of the sediments at the end of 1 year (γ_1) and B values for sands, silts and clays as 1550, 0; 1120, 91; 416, 256 respectively (from Table 1) are considered to estimate the useful life. On the basis of the above estimated T_e, it was found that the sediments coming to this particular reservoir are generally coarser in nature and mixture of the sediment consists of 60 % sands, 25 % silt and 15 % clays. The specific weight of this sediment mixture was determined by adding the fractional weights of sands, silts and clays.

The useful life of Gobindsagar Reservoir has been estimated by considering various scenario of filling the storage with sediment. To determine the useful life, time periods at which 100% of dead storage; 25%, 50%, 75%, 99.99% of live storage would fill with sediment are considered. As reported earlier, BBMB (2003) estimated the volume of sediment retained using hydrographic survey method, and then rate of sedimentation and T_e (using Brune (1953) median curve, assuming sediments are generally medium-grained in nature) were estimated. Using this rate and T_e, BBMB (2003) has estimated the life of reservoir at these time steps. The estimated useful life of Gobindsagar Reservoir using Gill (1979) approach, present study approach along with BBMB's estimation is shown in Table 3.

From Table 3, it is found that present study useful life estimation shows good agreement with BBMB estimation except for dead storage accumulation. Present study estimation is also very close to Gill (1979) approach of coarse sediment estimation. It is reported by BBMB that the reservoir has lost a volume of 1546 x 10^6 m^3 at the sediment rate of 34.35 x 10^6 m^3 per year, which is equal to 63.5 % of the dead storage (i.e. 2431.8 x 10^6 m^3). If the same rate of sedimentation continues, the total dead storage volume will be filled up in 71 years, which is very close to present study estimation. Thus, the present study T_e equation and sediment rate equation may be applied to the Gobindsagar Reservoir for the future estimation.

Table 3 Comparison of useful life of the reservoir

Loss in Capacity	Estimated by BBMB (assuming medium sediments)	Gill (1979) Approach		Present Study
		Estimated Life Time (assuming medium sediments)	Estimated Life Time (assuming coarse sediments)	Estimated Life Time (assuming coarse sediments)
100 % Dead Storage	142	99	95	95
25 % Live Storage	154	175	168	168
50 % Live Storage	186	251	242	240
75 % Live Storage	245	330	316	314
99.99 % Live Storage	363	460	387	368

6. Conclusions

The present study, elaborated the methods to calculate T_e (sedimentation) and useful life of the Gobindsagar reservoir. As an initial step the data pertaining to this large reservoir has been collected and analysed for a period of 40 years (1963-2003). A general regression equation has been developed for coarse sediment curve of Brune (1953) method for estimating the T_e and then, this equation has been modified for the Gobindsagar Reservoir. The T_e estimated using present study is compared with the observed as well as the Gill (1979) approach. The useful life of the reservoir estimated using Gill (1979) approach and present study closely follow the BBMB's estimation except for dead storage. On comparing the actual silt deposited so far, it is found that the present study suits better than the Gill (1979) method.

References

Agrawal, B.G., and Singh, K. (1994) Sedimentation Studies for Tehri Dam Reservoir. Proceedings of Workshop on Reservoir Sedimentation held in Mysore, Karnataka, on May 17- May 19 1994, pp. 171-179, India.

Annandale, G.W. (1987) Reservoir Sedimentation. New York: Elsevier Science Publishers.

Arora, P.K., and Goel, M.P. (1994) Estimating Life of a Reservoir. Proceedings of Workshop on Reservoir Sedimentation held in Mysore, Karnataka, on May 17- May 19 1994, pp. 4-11, India.

BBMB (2003) Sedimentation Survey Report. Bhakra Beas Management Board (BBMB), Bhakra Dam Circle, Nangal: India

Borland W.M. (1971) Reservoir Sedimentation, in: River Mechanics, edited by H.W. Shen, Chapter 29, Forth Collins: Water Resources Publication.

Brown C.B. (1944) Discussion of Sedimentation in Reservoirs. Proceedings of the American Society of Civil Engineers, edited by J. Witzig, 69, pp. 1493-1500.

Brune G.M. (1953) Trap Efficiency of Reservoirs. Trans. Am. Geophysical Union 34(3), 407-418.

Bube, K.P. and Trimble, S.W. (1986). Revision of the Churchill reservoir trap efficiency curves using smoothing splines. Water Resources Bulletin 22, 305–309.

Butcher, D.P., Claydon, J., Labadz, J.C., Pattinson, V.A., Potter, A.W.R. and White, P. (1992a). Reservoir sedimentation and colour problems in southern Pennines reservoirs. Journal of the Institute of Water and Environmental Management 6, 418–31.

Butcher, D.P., Labadz, J.C., Potter, A.W.R. and White, P. (1992b). Assessment of catchment erosion in the southern Pennines, United Kingdom, using reservoir sedimentation monitoring. In Bogen, J., Walling, D.E. and Day, T.J., editors, Erosion and sediment transport monitoring programmes in river basins (proceedings of the Oslo Symposium, August 1992). IAHS Publication 210, Wallingford: IAHS Press, 443–54.

Campos R. (2001) Three-Dimensional Reservoir Sedimentation Model. PhD Thesis, Department of Civil Engineering, University of Newcastle: Newcastle.

Churchill M.A. (1948) Discussion of “Analysis and Use of Reservoir Sedimentation Data”, Proceedings of Federal Interagency sedimentation Conference, edited by L. C. Gottschalk, Denver, pp. 139-140, USA.

Dendy F.E. (1974) Sediment Trap Efficiency of Small Reservoirs, Trans. of ASAE, 17(5), 898-988.

Gill M.A. (1979) Sedimentation and Useful Life of Reservoirs, Journal of Hydrology, 44, 89-95.

Heinemann H.G. (1981) A New Sediment Trap Efficiency Curve for Small Reservoirs, Water Resources Bulletin, 17(5).

Jain, S.K., Singh, P., and Seth, S.M. (2002) Assessment of Sedimentation in Bhakra Reservoir in the Western Himalayan Region using Remotely Sensed Data, Hydrological Sciences Journal 47(2), 203-212.

Kulkarni, D.N., Shukla, S.Y., and Oka, V.S. (1994) Sedimentation of Reservoirs in Maharashtra. Proceedings of Workshop on Reservoir Sedimentation held in Mysore, Karnataka, on May 17- May 19 1994, pp. 158-165, India.

Lagwankar, V.G., Gorde, A.K., and Patil, K.D. (1994) Trends in Reservoir Sedimentation in India and Abroad. Proceedings of Workshop on Reservoir Sedimentation held in Mysore, Karnataka, on May 17- May 19 1994, pp. 127-134, India.

Lane, E.W., and Koelzer, V.A. (1953) Density of Sediments Deposited in Reservoirs. Report No. 9, In A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams, Hydraulic Lab, University of Iowa.

Morris, G.L., and Fan, J. (1998) Reservoir Sedimentation Handbook. New York: McGraw Hill.

Morris, H.M, and Wiggert, J.M. (1972) Applied Hydraulics in Engineering. New York: Ronald Press Co.

Murthy, B.N. (1980) Life of Reservoir. Technical Report No. 19, Central Board of Irrigation and Power (CBIP): New Delhi, India.

Rowan, J.S., Goodwill, P. and Greco, M. (1995). Temporal variability in catchment sediment yield determined from repeated bathymetric surveys: Abbystead Reservoir, UK. Physics and Chemistry of the Earth 20, 199–206.

Shangle, A.K. (1991) Reservoir Sedimentation Status in India. Jalvigyan Sameeksha, INCOH VI (1&2): NIH Roorkee, India.

Sharma, P.D., Goel, A.K., and Minhas, R.S. (1991) Water and Sediment Yields into the Satluj River from the High Himalaya, Mountain Res. Devel, 11(2), 87–100.

Singh, P., and Kumar, N. (1997) Effect of Orography on Precipitation in the Western Himalayan Region, Journal of Hydrology 199, 183–206.

Siyam, A.M., Mirghani, M., El zein, S., Golla, S., and El-sayed, S.M. (2005) Assessment of the Current State of the Nile Basin Reservoir Sedimentation Problems. NBCN-RE (Nile Basin Capacity Building Network for River Engineering), River Morphology, Research Cluster, Group – I Report.

Soler-López, L.R. (2003a) Sedimentation Survey of Lago El Guineo, Puerto Rico, October 2001. U.S. Geological Survey Water-Resources Investigations Report 03-4093.

Soler-López, L.R. (2003b) Sedimentation History of Lago Guayabal, Puerto Rico, 1913- 2001. U.S. Geological Survey Water-Resources investigations Report 03-4198.

Trimble, S.W. and Bube, K.P. (1990). Improved reservoir trap efficiency prediction. The Environmental Professional 12, 255–72.

Trimble, S.W. and Carey, W.P. (1990). A comparison of the Brune and Churchill methods for computing sediment yields applied to a reservoir system. USGS Water Supply Paper 2340, 195–202.

Verstraeten, G., and Posen, J. (2000) Estimating Trap Efficiency of Small Reservoirs and Ponds: Methods and Implications for the Assessment of Sediment Yield. Progress in Physical Geography 24, 219-251.

Yang, C.T. (1996) Sediment Transport: Theory and Practice. New York: McGraw-Hill.

Yang, X. (2003) Manual on Sediment Management and Measurement. World Meteorological Organization, Operational Hydrology Report No. 47, WMO-No. 948, Secretariat of the World Meteorological Organization – Geneva: Switzerland.

Yoon, Y.N. (1992) The State and the Perspective of the Direct Sediment Removal Methods from Reservoirs, International Journal of Sediment Research 7(20), 99–115.