SEDIMENT MANAGEMENT FOR RESERVOIR

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ABSTRACT

All natural lakes and reservoirs whether on rivers, tributaries or off channel storages are doomed to be sited up. Pakistan has two major reservoirs of Tarbela and Managla and shallow lake created by Chashma Barrage. Tarbela and Mangla Lakes are losing their capacities ever since first impounding, Tarbela since 1974 and Mangla since 1967.

Tarbela Reservoir receives average annual flow of about 62 MAF and sediment deposits of 0.11 MAF whereas Mangla gets about 23 MAF of average annual flows and is losing its storage @ average 34,000 MAF annually.

The loss of storage is a great concern and studies for Tarbela were carried out by TAMS and Wallingford to sustain its capacity whereas no study has been done for Mangla as yet except as part of study for Raised Mangla, which is only deskwork.

Delta of Tarbela reservoir has advanced to about 6.59 miles (Pivot Point) from power intakes. In case of liquefaction of delta by tremor as low as 0.12g peak ground acceleration the power tunnels 1, 2 and 3 will be blocked. Minimum Pool of reservoir is being raised so as to check the advance of delta. Mangla delta will follow the trend of Tarbela.

Tarbela has vast amount of data as reservoir is surveyed every year, whereas Mangla Reservoir survey was done at five-year interval, which has now been proposed to be reduced to three-year interval.

In addition suspended sediment sampling of inflow streams is being done by Surface Water Hydrology Project of WAPDA as also some bed load sampling.

The problem of Chasma Reservoir has also been highlighted, as it is being indiscriminately being filled up and drawdown several times a year without regard to its reaction to this treatment.

The Sediment Management of these reservoirs is essential and the paper discusses pros and cons of various alternatives.

MANGLA RESERVOIR

Gross storage capacity of the reservoir has been reduced form 5.88 MAF to 4.76 MAF as per year 2000 hydrographic survey with average annual sediment load of 34,000 AF. Total loss in gross storage capacity amounts to about 19% in 34 years operation of the project and reservoir is losing its capacity at a rate of 0.6% annually. Loss of storage capacity is as per Table 1. Analysis of data as per Table 2 shows that sediment was brought more during the years when high floods occurred in the years 1976, 1978, and 1992.

Original dead storage capacity of the dead storage capacity of the reservoir has reduced from 0.54 MAF to 0.14 MAF about 74% of dead storage capacity has been exhausted.

Flood of 1992 brought sediment and also pushed the delta deposits in the dead storage zone.

Lowering the reservoir close to minimum operating level and longer stay due to low flows in Rabi and early Kharif seasons in the years 1994 and 1997 also pushed sediment into the dead storage.

Live storage capacity of the reservoir has reduced from 5.34 to 4.62 MAF. Sediment deposited in this zone is 0.73 MAF and loss of live storage is about 15%.

The reservoir consist of six pockets Fig 1 namely Jhelum Upper, Jhelum Lower, Kanshi, Poonch, Main and Khad & Jari pockets as shown in Table-3.

The major delta is advancing toward the dam and at present its pivot point is at apporx. 5 miles upstream of the Main Dam as shown in Table – 4. The delta pivot is at El. 1054. 9, which is 15 ft above the dead storage level. The depths of sediment deposited at the pivot point and in front of intake structures are 149ft and 59 ft respectively. Slope of the foreset of major delta is 25 ft/mile while that of the bottom set is about 4 ft/mile Fig 2.

MANGLA RESERVOIR STATUS

Unlike Tarbela Reservoir, the rate of depletion of reservoir capacity is much lower (Mangla 34,000 A/ft/year Tarbela 0.110 MAF/year). The delta advancement consequently has so far been not a threat, although tremors with more than 0.15g acceleration can occur. Because of the shape of reservoir and the inlet, streams entering the reservoir directly (Jhelum Main, Poonch and Kanshi River) the delta formation of the three streams has to be watched. Jhelum brings 80% of the inflows and sediments and delta formation has been discussed, however, the Poonch and Kanshi Basin will have peculiar problem of delta advancement blocking the flows at low reservoir levels and isolating the reservoir pockets of Kanshi and Poonch. The prediction of the blockage occurring has not been studied so far.

CHASMA RESERVOIR – STATUS

Chasma Reservoir is a low depth reservoir although its spreads more than Tarbela and Mangla (Chasma Reservoir 137 sq miles, Tarbela 93 sq miles, Mangla 97 sq miles). Its gross capacity at completion was 0.870 MAF, live capacity 0.720 MAF and dead storage 0.150 MAF. The last survey in 1987 showed that the gross capacity depleted to 0.497 MAF, live capacity to 0.435 MAF and dead storage remaining as 0.062 MAF.

The delta has spread to the Barrage like a braided stream and typical delta formation of the river near its joining the sea Fig 3.

There is no threat of delta liquefaction or slope failure blocking the wide barrage (about a mile width). The main problem is the river control to offset any deposition off main creak Reservoir which is 06 miles wide at the Barrage and 13 miles at upper periphery.

TARBELA RESERVOIR STATUS

Annual sediment load deposited in the reservoir is given in Table 5. Total deposition in the reservoir including Siran Pocket and Barandu River (upto September 2000) is about 2.838 MAF (3.5 BCM) taking 84 ibs/cu. ft. as the density of sediment the total sediment trapped in Tarbela Main Reservoir in a period of 26 years 5042.2 MST about 195 MST annual. The gross capacity of the reservoir has been reduced from 11.620 MAF (BCM) to 8.782 MAF (10.84 BCM) i.e. (24.42%) and the usable capacity from 9.679 (11.94 BCM) to 7.973 MAF (9.84 BCM) i.e. (17.63%).

The survey also indicates that the delta pivot point is at Range Line 13 Fig. 4, 4A, 4B & 4Cat 6.59 miles form Main Dam at an elevation of 1328 feet and there is deposition of sediments from Range Line 13 to 42 and from Range Line 60 to 73.

During year 2000, the reservoir had to be drawn down to 1321 feet elevation twice in view of acute shortage of water in the Indus River System. This resulted in:

1. Sediment out flowed from Tunnel 4 and also sediment deposits in dead storage reducing it to 0.809 MAF from 1.941 MAF.
2. Delta pivot point moved from Range Line 16(9.07 miles) to the present position at 6.59 miles (Range Line 13) Fig. 4.

   The designed minimum pool level is 1300 feet. Whereas it was increased to 1320 feet because turbines were vibrating faster than acceptable subsequently, the delta advancement had to be checked by raising the minimum pool level. It was desired that minimum pool level be about 10 feet higher than the elevation of "Pivot point of top set and this world require raising the minimum pool level by 4 feet every year. Presently the pool has been taken to 1369 feet. The delta pivot point advances towards the dam when reservoir is operated at low levels and there is relationship between the operation at lower level and movement of delta pivot point Table 6.
3. Erosion from Range Line 73 to Range Line 14 and deposition form Range Line 14 to Main Embankment Dam.
4. There was deposition of 20-25 feet sediments in the vicinity of intakes of Tunnels 3 and 4.
5. The filters of units 11-14 got choked and remained closed for 14 days.

The movement of delta front has been restricted so that the intakes are not blocked in the event of delta liquefaction in case of a significant tremor (acceleration greater than 015 g). The foreset slope could also have slides in the event of liquefaction/sliding, the slided mass should not travel and reach the intake.

SEDIMENT MANAGEMENT ISSUES

The reservoirs of Tarbela, Mangla, Chasma have been impounded since 1974, 1967 and 1970. Now the sediment depositions has reached a stage that major problems have occurred which have to be dealt early.

1. Loss of storage capacity
2. Abrasion of equipment and concrete surfaces by sand
3. Threat of blockage of intakes and tunnels
4. Degradation d/s

1. Loss of Storage

All lakes whether natural or man arranged have finite life and doomed to be filled up. There are at present no. facilities to care for the sediments at the three reservoir being discussed. The sluicing bays provided at right and left of the Chasma Barrage are for clearing the Pockets so as to control silt entry into off taking canals which will get silted and deteriorate.

Watershed Management

There is long-term control in the form of Watershed Management. It is possible to control as much as 30% of incoming sediments. At least at one reservoir Guanting, Reservoir in China, 90% of the erosion, of catchment has been stopped by providing extensive vegetative cover.

Figure 5 shows the sediment inflows at the various gauging points along the Jhelum River. It shows that the catchment below Kohala is the main contributor of sediment with 24 MST at Kohala and 107 MST at Mangla in the 3260 sq miles. Assessment of the treatment of the watershed is difficult, only the trend can be determined.

The Tarbela catchment sediment inflows at the gauging stations are as per Figure 6. Only the lower catchment below Barsin has the monsoon rains with 4000 sq miles having, the monsoons contribution while 3000 sq miles is in the shadow of monsoon. The watershed treatment is only possible in this 7000 sq miles, while the catchment u/s fed by snowmelt/glaciers is not susceptible to treatment except that check dams can be made and hold the sediments till these are filled up.

The same benefit is obtained form u/s dams and Tarbela would benefit form Basha or any other upstream storage when it is constructed.

The catchment below Partab Bridge upto Barzin (14,800 sq miles) except for Astore River (4040 sq miles) contributes (44 MST) mainly form channel erosion and weathering due to extreme variation of temperatures. Again, the quantification of watershed treatment effects are vague.

Dredging

The dredging to physically remove sediments is too costly and the quantity involved is in million tons per year. Mangla 34,000 Aft/year, Tarbela 110,000 Aft/year (an acre foot is 43,560 cft).

Dredging can be effective for small reservoirs and for river control as for Chasma storage of 0.897 MAF with annual flows of 90 MAF. The outflows can be kept/restricted to main creek thereby saving the off creek storage intact.

Gravity Flows / Density Currents

The phenomena of gravity flows/density currents have fascinated the operators of the reservoirs. As much as 6% of annual sediment inflows can be effortlessly by passed down stream.

As the name implies, the density current is due to higher density to water. The density difference is at the time of flood flows or even with the temperature difference. Under favourable condition, in some reservoir over 50% of the sediment inflows have been passed.

Flushing, Sluicing to Retard Sedimentations

Lately after the Sanmexia (in China) incident, the subject of sluicing/flushing has caught the attention of the researchers all over the world.

A recent research project for the UK's Department of the Environment Transport and the Regions (DETR), carried out by HR Wallingford and three UK Consulting firms, including Binnie Black & Vetch gives guidance on the factors which influence successful sediment flushing as set out in Table below [3].

From an examination of worldwide experience of flushing, similar factors emerged and White et al. concluded that:

- Successful hydraulic flushing is more likely to be practicable in reservoirs which are hydrologically small which was defined as a storage capacity less than 30% of the main annual flow.
- Flushing is vital for the preservation of long term storage capacity if the annual deposition potential is greater than 1 to 2% of the original capacity.
- Even where the deposition potential is less, flushing should be considered to reduce eventual decommissioning problems;
- Narrow steep-sided reservoirs in valleys with steep longitudinal slope are the easiest to flush.
- Flushing is most effective if under taken with the reservoir virtually empty; and
- The low-level flushing outlets must therefore be low enough and of sufficient capacity to allow the reservoir to be kept nearly empty when flushing is being undertaken; if flushing is carried out in flood seasons larger outlets are required.

TABLE FACTORS INFLUENCING SUCCESSFUL RESERVOIR FLUSHING

Hydraulic conditions required for efficient flushing

Riverine conditions must be created in the reservoir for a significant length of time. The reservoir level must be held low through out the flushing period, possible with minor fluctuation in level to activate sediment movement. To achieve this;

The hydraulic capacity of the by pass (that is the flushing outlet) must be sufficient to maintain the reservoir at a constant level during the flushing period.

Flushing discharges of at least twice the mean annual flow are required.

Flushing volumes of at least 10% of the mean annual runoff should be anticipated.

Quantity of water available for flushing

There must be enough water available to transport the required volume of sediment. This has the following implications;

Reservoirs where the annual run off is large compared with the volume of the reservoir are suitable for flushing.

Reservoirs where there is a regular annual cycle of flows and a defined flood season are generally suitable for flushing. This favours sites in monsoon areas and sites where flood flows generated by annual snowmelt in the spring and summers months.

Reservoirs where the release of significant quantities of water for flushing does not significantly affect the ability to satisfy water demand at other times of the year, are potentially suitable for flushing.

Mobility of reservoir sediments

The nature and quantity of river sediments are important factors in determining whether the quantity of water available for flushing is adequate to remove the desired quantity of sediment from the reservoir.

Graded bed sediments produce conditions, which are the most conducive to the efficient flushing of sediments. Such conditions are typical of Gravel Rivers with the varying bed material composition. In large reservoirs the typical longitudinal bed gradient is between, say, 0.001 and 0.002 and in smaller reservoirs the equivalent range may be 0.002 to 0.005.

From the point of view of sediment size alone, data deposits of fine sand and coarse silt are most easily flushed. Coarser material is difficult to move and tends to deposit at the upstream end of the reservoir. Finer material which deposits in the body of the reservoir outside any incised channel will not be available for reworking during of flushing.

Site Specific Factors

The most suitable conditions for flushing are to be found in reservoirs which approximate in shape to the incised channel, which devolves during flushing. Long, relatively narrow, reservoirs are better suited to flushing than short wide, shallow reservoirs.

TARBELA SCENERIES

Most of the studies have been done for Tarbela and at Tarbela. Also the cause of the large inflows of sediments, 0.110 MAF on an average year which is a sizeable quantity and able to be discerned beyond the limits of accuracy of echo sounding techniques, annul surveys have been done since 1979. This has produced large amount of reliable data. Moreover, the rather quick depletion of reservoir capacity since 1974 and without any other dam on Indus in view, to offset the reservoir capacity so lost, the irrigation requirement would suffer. The capacity so lost means after 28 fillings loss of $11 Billion Tarbela had lot of teething problems, which lasted upto 1983. As a consequence sedimentation and seismic issues did not receive full attention and later lot of studies continued and world renowned experts had to be consulted in the Four Periodic Inspection on 1985, 1991-92, 1993 and 1998.

1. Drisko – Sedimentation of Reservoir and Hydrographic Survey
2. Jey Jeyapalan – Sediment Stability
3. Dr. Sajjad – Mathematical Model for sediment deposits distribution in Reservoir
4. Poulous]
5. Carlos] Liquefaction of Delta
6. John Lowe III]
7. Wude Yi]
8. Zhoo Zhide] Reservoir Sedimentation, Sluicing of Sediment
9. Khalid Mahmood – Sediment Transport within reservoir and sluicing
10. Atkinson, Acker & Whit/Wallingford Studies on Sediment Management

The sediment management issues still remain at a stage where no decision on implementation has been taken even after extensive studies by TAMS and Wallingford on sediment Management which covers 4 volumes. Subsequently physical modeling was also done at Nandipur and Lahore IRI, mainly to assess the effect of sluicing on Ghazi Barotha Barrage Pond[4].

The main catastrophic omission is the protection of Intakes, when delta progresses close to MED (Main Embankment Dam). The tunnels 3 & 4 have low level inlets at 1160 and 1180 SPD. Overtop of it, the monster of delta liquefaction and subsequent travel to the power intakes on tunnel 1,2 and 3, has forced the minimum pool level to be raised so that the delta does not approach the limit of 25; 1 Figures 7 (1-6).

TAMS proposed an underwater dyke in front of intakes which has been debated for the last 2 decades but so far no studies on the design has been done. Wallingford/TAMS have supported the construction of a simpler design, which can have the crest of dyke raised as the delta progresses and advances in height and comes closer whereas Tarbela storage is being lost, not only to the sediments but to the necessary of keeping delta pivot point away as para above.

The raising of intakes of tunnels 3 and 4 requires, providing new intakes and connecting these to the tunnels, the design and studies for the same are required.

The results of the physical model indicates, deposition of coarse fraction on the sluiced flows within the Ghazi Barotha Barrage pond. The sluiced flows cannot be passed through the Barrage Pond but will have to be bye-passed.

The sand portion of the flows have quite an abrasive action on the tunnels, intakes and stilling basin particularly as the grains are quite hard. It has not been therefore experimented to use the available T3 and T4 for sluicing because of the likely damages. The Power House will have to be closed during the sluicing operation for the same reason. T3 has now power installations and for lack of foresight, no wye joint was provided. Even E & M contractor doing the installation of T 3 had to be stopped not to dump any concrete dismantled waste in the T3 outlet stilling basin.

The solutions to the sediment sluicing outflows were several:

i) A tunnel on the other side of T4 with a channel downstream through Ghazi Barotha Barrage embankment in continuations of the Barrage to bye-pass the Ghazi Barotha Barrage Pond.

ii) Use of T3, T4 and T5; these will have to be protected from abrasion including their intakes.

iii) The TAMS / Wallingford proposal to have 4 tunnels under the spillway.

A recent estimate of cost by JICA expert requires $ 689 Million for the tunnels plus water dyke.

With current cost of providing One A/Ft of Reservoir @ $ 2500/AF, the annual loss of storage at Tarbela is one of the order of $ 275 million and loss of live storage of 2.453 MAF according to 2001 Reservoir Sediment Report, means loss of $ 6.1 Billion. At these figures, the JICA remarks that in $ 689 million a new dam could be provided, does not carry any sense. In addition is the loss of dead storages of 1.132 MAF i.e. $ 2.83 Billion loss.

CONCLUSIONS AND RECOMMENDATION

1. a) It is obvious that the sustainability of storages of the Tarbela, Mangla, and Chashma has been ignored and these have lost the storage to a dangerous level.

   b)
   - Tarbela Sedimentation studies were taken up almost after its construction.
   - The sluicing of reservoirs to Manage Sediment Deposition, started only after the Sanmexia disaster in China.
   - No provision was made to have higher intakes and tunnels 3&4 had low level inlets so as to assure safety of the main embankment, designed on observational approach. It could have been possible to have higher intakes also at the same time.

– Tarbela reservoir had a life of only 50 years when designed and this should have been a warring to allow the power tunnels to be operated when delta closes on the intakes.

c) Now the solution is to have an under water dyke which has been subject to prejudice. Embankments have been built on soft clays and this case removal of the bottom set silts/fine sands is possible.

d) Loss of storage of 0.110 MAF plus 4 ft of rise of minimum pool to keep the delta away means an annual loss of 0.4 billion dollar loss and the Irrigation requirements during Rabi are being jeopardized.

f) Mangla has been so far not cared regarding Sedimentation Management and very soon it will be depleted to 4.5 MAF capacity as provided in he Indus Bain Treaty for storages on Jhelum. It has been opined that Mangla will be raised but its long term sustainability is desired.

– Studies have been initiated on the sediment sluicing of Mangla Reservoir and hopefully will be implemented.

g) Chashma Reservoir can be raised to 661 SPD from present conservation level of 649 SPD. This is necessary to use the sluiced flows form Tarbela. However no survey of reservoir has been done since 1987 to plan any augmenting.

– It is necessary that operation of Chashma is not left to IRSA whims. The filling should be done in September with inflows in Indus less than 150,000 cusecs as planned.

2. a) Early action on design of sluicing works at Tarbela is Required.

(i) Initially intakes of tunnels be raised.

(ii) Design and construction of under water dyke.

(iii) Providing wye joint on Tunnel T3.

(iv) T3 be lined and readied for sluicing.

(v) T4 be lined and readied for sluicing.

b) As a first step tunnel 5 with intakes at 1190 SPD be lined fully and trial made on the evacuation of sediments. T5 is not being used at present and only will be required to be operated during change of T4 to power generation.

c) Mangla and Chashma be also dealt as proposed.

REFERENCE

1. Sedimentation of Mangla Reservoir Hydrographic Survey 2000. MDO Report 784.

2. Sedimentation of Tarbela Reservoir 2001 Report No. 161.

3. TAMS H.R. Wallingford: Tarbela Dam Management Study Final Report Volume 1-4.

Table–1

MANGLA DAM PROJECT

ORIGINAL AND PRESENT CAPACITY OF VARIOUS RESERVOIR POCKETS

Sr. No.	Pocket	Capacity (MAF)		Loss (MAF)	% Loss to Individual	Remarks
		Original	Present			
1	JHELUM UPPER	0.61	0.36	0.25	41	
2	JHELUM LOWER	0.36	0.21	0.15	42	
3	KANSHI	0.28	0.22	0.06	21	
4	POONCH	1.28	1.05	0.23	18	
5	MAIN	1.75	1.43	0.32	18	
6	KHAD & JARI	1.6	1.48	0.12	8	
	TOTAL	5.88	4.75	1.13		

Table–2

MANGLA DAM PROJECT

DISTRIBUTATION OF SEDIMENT IN LIVE AND DEAD STORAGE (MAF)

Year	Sediment Deposition (MAF)			Remarks
	Live Storage	Dead Storage	Gross	
1967 to 1970	0.08	0.04	0.12	
1970 to 1973	0.07	0.04	0.11	
1973 to 1979	0.21	0.03	0.24	
1979 to 1983	0.08	0.03	0.11	
1983 to 1988	0.08	0.05	0.13	
1988 to 1993	0.14	0.08	0.22	
1993 to 1997	0.04	0.09	0.13	
1999 to 2000	0.03	0.04	0.07	
Total	0.73	0.4	1.13	
% Loss	64.6	35.4		