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SEDIMENT MANAGEMENT OF TARBELA RESERVOIR

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By

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ABSTRACT

Sedimentation of Tarbela Reservoir was discussed in its 2nd and 5th periodic Inspections of the dam. Sediment Management studies of Tarbela (SMST) reservoir were carried out by M/s Tams and Wellingford in 1998. Investigation of sediments were carried out by bore holes in 1987 and 1989 about 20 Km u/s of the dam on topset of delta. In 2008 boreholes were done at 24 and 26 Km u/s of dam. Shallow hand driven boreholes were done in 2012 on exposed delta. Standard Penetration Tests were carried out in bore holes. Samples were tested for gradation and shear tests.

A comprehensive study comprising of bathymetric survey, delta exploration by drilling boreholes in bottom set and foreset slope of the delta, testing of the sediments samples and the effects of the sediment on the d/s structures when flushed from Tarbela reservoir was carried out by Mot MacDonald in 2011-13.

Sediment Management: Mathematical Model studies of Tarbela reservoir were carried out by H R Wallingford and Mot MacDonald for Wapda in 2013. The feasibility and impact of the following sediment management approaches were studied:-

- The management of the minimum operating level at the reservoir (option 0).
- The release of sediment from the reservoir during hydraulic flushing (option 1).
- The reduction of sediment inflow into reservoir due to future construction of dams u/s Tarbela (option 2).

The evolution of sediment in the reservoir was calculated using RECESS, 1 D model. Since 1 d model cannot describe in detail the deposition patterns near the intakes, a 3 D, TELEMAC 3 D was used for the area near the intakes.

Flushing of Reservoir: The results from numerical model show that flushing is an option to preserve the storage volume of the reservoir. The longer the duration of the flushing, the lower the drawdown and higher the water discharge, the more efficient is the flushing in removing deposited material from the reservoir. However, each option has an implication on the production of energy and the water loss. An optimum option was considered to be flushing with a duration of 30 days, reservoir drawdown to 400 m level and a discharge of 5000 m3 / sec. An elaborate costly and risky arrangement shall have to be made for flushing of sediments. The environmental effects of flushing on d/s existing infrastructure were assessed to be exorbitant.

Dams on u/s of Tarbela: Dams constructed u/s of Tarbela especially storage dams e.g Diamer Basha would store the sediment. Diamer Basha dam would increase the life of Tarbela dam by 35 years. Similarly run of the river hydropower projects would also hold sediments for some time and reduce sediments coming to Tarbela reservoir.

INTRODUCTION

Tarbela dam was built in 1975 with gross storage capacity of 11.62 MAF (14.32 Bm^3) and live storage capacity of 9.679 MAF (11.93 Bm^3). Average annual river flow at Tarbela is 64 MAF (78.9 Bm^3) predominantly snow and glacier melt. Due to high sediment load of river Indus

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about 200 M tons / annum or 5,50,000 tons / day, about 0.1 MAF (0.123 Bm^3) reservoir capacity is lost every year. The gross storage capacity has reduced to 7.57 MAF (9.33 Bm^3) and live storage capacity is 6.5 MAF (8.01 Bm^3). (Bathymetric survey 2012). Loss of live storage is causing reduction in regulated yield of reservoir. This manifests in water shortage for Rabi and early Kharif seasons and also reduction in the firm energy from the project. The sediment delta has progressed to 8 KM from the dam and the river bed has gone up by 200 ft (61 m) at the pivot point. The sediment level near the dam is RL 1240 ft (378 m) and in front of the Intakes it is RL 1160 ft (354 m). During low flow season, the river passes through an incised channel in the delta topset and supplies water to power intakes. Due to rising sediment levels a cup shaped bed profile is developing in front of the tunnel intakes. Trap efficiency is decreasing and more sediments shall pass through tunnels. This would cause abrasion of turbines and concrete structures. In addition to these concerns, it is apprehended that due to seismic activity, the foreset slope may liquefy and clog the tunnels causing disruption to irrigation and power supplies.

Sedimentation of Tarbela was discussed in its 2nd and 5th periodic inspection in 1992 and 2007 respectively. Sediment Management studies of Tarbela reservoir were carried out by M/s Tams and Wallingford in 1998. Investigations of sediments were carried out by bore holes in 1987 and 1989 about 20 Km u/s of the dam on topset of delta. In 2008 boreholes were done at 24 and 26 Km u/s of dam. Shallow hand driven boreholes were done in 2012 on exposed delta and samples tested for its gradation.

A comprehensive study comprising of bathymetric survey, delta exploration by drilling boreholes in bottom set and foreset slope of the delta testing of the sediments samples and the effects of the sediment on the d/s structures when flushed from Tarbela were carried out by Mot Macdonald in 2011-13. Computer models on sediment movement of Tarbela reservoir, Ghazi Brotha and Chashma lakes and the river Indus from Tarbela to Kotri barrage were made by Wellingford. This paper describes the various sediment management options and their implications. Fig 1 shows a schematic sketch of river Indus starting from Diamer Basha Dam site to Arabian sea, and also the tributaries joining it and the canals taking off.

HYDROLOGICAL DATA: Historical data on water flow series and sediment concentrations were collected from Wapda Tarbela. Surface Water Hydrology and Irrigation Departments of Punjab and Sindh. The flow series from 1981 to 2010 was considered for modeling purposes as prior to this the records were not complete. Table No. 1 gives Indus river gauging data statistics. Review of data showed that Besham Qila was showing 6% greater volume than calculated from Tarbela data. Almost all reaches of Indus river, Ghazi Barrage to Sukkur Barrage have shown reasonable water balance. Overall losses and gains in a reach were within a range of $\pm$ 6% of the total flows of the barrage. However the river reach between Sukkur and Kotri Barrage showed an unusual behaviour. The water losses reached upto 32% which are not justifiable.

SEDIMENT DATA: Surface Water Hydrology (SWHP) Department Wapda is collecting data at two dozen gauging stations on river Indus and its tributaries. Besham Qila data from 1981 to 2010 has been used in Tarbela sediment modeling. On the average 200 Million Tons (MT) of sediment enters Tarbela lake. Table No. 2 gives the Besham Qila sediment data. Relationship between flow and sediment load adopted by SWHP for Besham Qila is:

$$SED = 4.37 \times 10^{-8} Q\ 2.54$$

Where SED = Sediment Load in short tons/day

Q = Water discharge in cusecs

Table No. 3 gives volume of sediment deposited in Tarbela reservoir. Table No. 4 gives average annual sediment load of different rivers joining Indus and the load at Barrages.

TARBELA RESERVOIR DELTA INVESTIGATIONS: Fig 2 presents contour plan of reservoir bed and shows the position of pivot point. In order to know the characteristic and gradation of delta, investigations were carried out as follows:

- Bore holes in 1987 and 1989 at range line 24 which is 20 KM u/s of dam on topset of delta.
- Bore holes in 2008 at range lines 27-28 and 29 which are about 24 and 26 Km u/s of dam.
- Shallow hand driven bore holes in 2012 on the topset between range line 13 and 75.
- In 2013 SMST carried out bathymetric survey and bore holes on fore- set and bottom-set of delta closer to dam in order to find the characteristic of the sediment that may be involved in liquefaction and dredging. The findings are as follows:
    - The particle sizes of the deposited sediments within the area investigated (upto Range Line 75) are less than 1 mm in size and generally less than 0.3 mm, particularly downstream part of the reservoir.
    - The sediments vary from uniform fine SAND to silty CLAYS with the bottomset area and former bottom set under the downstream part of the advancing delta being clayey SILTS or to a lesser extent silty CLAYS and with varying, but limited sand fraction. These deposits were normally soft and only became slightly firm towards their base. The SPTs and Piston sampling generally showed self-penetration.
    - The advancing delta face is generally dominated by silty SANDS and sandy SILTS with a small clay fraction. SPT values were normally less than 30.
    - The sub-bottom profiling indicates consistency of the deposits across the bottom-set areas. The layering does not exist in the delta and topset areas. However it is seen that the layering at the toe of the advancing delta face is less distinct suggesting that there has been movement in the deposited sediments. The bathymetric bed profile also suggests movement after initial deposition with evidence of a backscarp and rolling profile at the toe.
    - The composition of the sediments from the investigations and in particular the deep boreholes through the main part of the delta face suggests a composition of clay+silt and sand fractions in approximately equal parts.

Fig 3 shows Tarbela reservoir 2012 bathymetric survey long section.

SEDIMENT MANAGEMENT STUDY TARBELA (SMST)

The feasibility and impact of following sediment management approaches were studied:-

- The management of the minimum operating level at the reservoir (option 0).
- The release of sediment from the reservoir during hydraulic flushing (option 1).
- The reduction of sediment inflow into reservoir due to future construction of dams u/s Tarbela (option 2).

The evolution of sediment in the reservoir was calculated using RECESS, 1 D model. Since 1 D model cannot describe in detail the deposition patterns near the intakes, a 3 D, TELEMAC 3 D was used for the area near the intakes.

Fig 4 presents Tarbela Reservoir Sediment Longitudinal Profiles and the advancement of delta towards the dam with time.

Management of minimum operating level at reservoir

Following three options were considered:-

- Option 0.1: Maintain the minimum reservoir level at elevation of delta pivot point located about 10 KM u/s of dam i.e go on raising minimum level every year. By year 2030, the gross storage is predicted to be of the order of 6,500 Mcm, 27% reduction of current gross storage. The advantage is that it keeps the delta away and upto 2042 sigificant amount of sand does not arrive to the intakes. The disadvantage is less withdrawal of water.
- Option 0.2: Maintain the reservoir level constant at 420 m, do not raise the minimum level. This enhances the transport of the material towards the dam and some of it passes out. The gross storage by the year 2030 is predicted to be of the order of 7,300 Mm^3, 18% less than current gross storage.
- The delta reaches the dam by year 2029. The amount of sand passing the intakes starts to increase from average value in the past 20 MT to 138 MT and wear and tear of turbines starts.
- Option 0.3: Intermediate option, raise minimum reservoir level only when necessary as being done now. The sediment delta is estimated to arrive at the dam by year 2033. The storage capacity is preserved at 7000 MCM by year 2030.

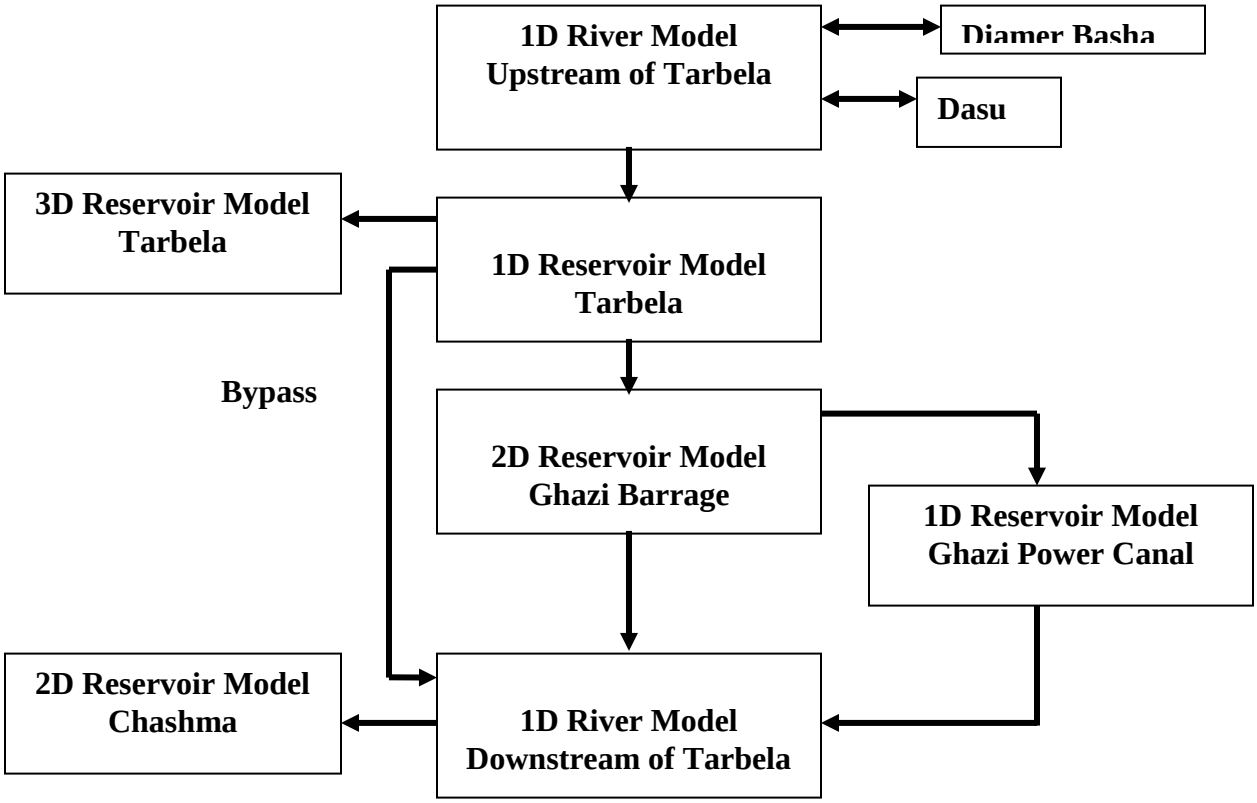
Fig 5 presents longitudinal bed profiles for the three management options.

Fig 6 presents total sediment inflow and outflow for the three options.

Mathematical Model Studies

Mathematical modeling was carried out to examine the sediment transport through the river system below the proposed Diamer Basha site to downstream of Kotri Barrage, Five models were built to examine the main system and two further models were built to examine the local effects around the intakes in Tarbela Reservoir and in the Chashma Head pond area.

The arrangement of the models is shown in following diagram:-



The models were built using data acquired from the SMST surveys and from existing data collected under SMST. The software used was HECRAS 4.1.0 for the river and Ghazi Power Canal, RESSASS for the Tarbela Reservoir and TELEMAC SISYPHE for the 2D and 3D modeling.

The principal findings from the modeling are as follows:-

- **The 1 D modeling of Tarbela Reservoir** shows that:

  It is possible to prevent significant increase in the sediment passing through the turbines and to keep the pivot point away from the dam for the foreseeable future provided if available storage is sacrificed at rate of 150 Mm^3 per year by allowing the minimum drawdown level to rise year-on-year by tracking the topset level upstream of the pivot point (10 Km from dam selected for the modeling) **(Option 0.1);**

  It is possible to sustain the available storage provided it is accepted that the sediment passing through the turbines may significantly increase and the pivot point may encroach on the dam by keeping the minimum drawdown level at its current level of 420 M (1378 ft) **(Option 0.2).**

  This is illustrated in the following table by comparing the remaining gross storage:-

Year	Option 0.1 (BM^3)	Option 0.2 (BM^3)
2020	8.0	8.2
2030	6.5	7.3
2040	5.1	7.0
2050	3.5	6.7

Table 5. Tarbela storage with the two options with passage of time.

The 1 D modeling of Tarbela Reservoir shows that with a flush capacity of 5,000 m^3/s the currently available storage could be sustained, and with a reduced capacity the rate of storage loss could be slowed. To achieve the flushing, the reservoir would need to be drawn down below current operating levels and timed to coincide with the start of the high flow season, when the reservoir is already at its lowest level.

The 3 D modeling of Tarbela Reservoir shows that after starting flushing, the delta is drawn rapidly towards the dam and the sediment levels will build up in front of the power station intakes to between 390 and 393 m (1,280 and 1289 ft) for a 5,000 m^3/s capacity flush, and between 400 and 403 m (1314 and 1322 ft) for a 3,000 m^3 /s capacity flush. With the intakes to Tunnels 1 and 2 being at 373 m (1225 ft) a guard bund will be required to prevent inundation of the intakes with sediment.

Fig 7 shows the advancement of delta towards intakes during flushing.

The 2 D modeling of Ghazi Barotha Barrage Head pond shows that:

> If sediment is flushed from Tarbela through the Head point, it will become sedimented up within 2 years and water levels will rise not only above the maximum flood level of 344.4 m (1,130 ft), but also potentially above the power station plinth level of 349 m (1145 ft);

Fig 8 shows Ghazi Brotha head pond bed levels with Tarbela flushing.

Fig 9 presents Ghazi Brotha head pond bed levels with Tarbela run of the river.

> If Tarbela Reservoir is operated to sustain storage **(Option 0.2)** the discharge of sediment into the Head pond will have a similar, albeit less rapid, impact.

The 1 D modeling of Ghazi Barotha Power Canal shows that the capacity of the canal will decrease after 1 year if Tarbela becomes run-of-river, although this would be extended depending on the effectiveness of the undersluices and / or management of the power canal during heavy sediment load periods.

The 1 D River modeling shows that the sediment intake into the canals for **Option 1.1** will increase as shown in the following table:-

Barrage	Min	Max	Average
Jinnah	76%	517%	214%
Chashma	51%	366%	152%
Taunsa	53%	311%	176%
Guddu	41%	315%	165%
Sukkur	42%	335%	153%
Kotri	19%	281%	118%

Table 6. The sediment at the d/s barrages with Tarbela flushing.

The 2 D model of Chashma Headpond shows that sand bars develop in front of the barrage in the pockets, in front of the canal head regulators and across the entrance channel to the power station. At lower sediment loads it is possible to manage these deposits by sluicing through the barrage which can be achieved at times of high flows.

However, at periods of repeated highloads, as will occur with Tarbela Reservoir flushing, the sand bars build up in the power channel. The model indicates that a sand bar will develop across the entrance and result in a head drop into the channel as well as the potential for higher concentrations through the power station and in the main barrage, section canal head regulator pockets additional sluicing may be required. Fig 10 shows Chashma Head pond levels with Tarbela flushing.

Dams u/s of Tarbela: The impact of the development of the Diamer Basha Project is to significantly slowdown the loss of storage in Tarbela and to similarly reduce the impacts on the Tarbela-Ghazi and downstream systems such that they will be similar to the existing situation until it is necessary to flush Diamer Basha, which is understood to be in $\pm$ 40 years after commissioning. Fig 11 presents Tarbela Storage volume with Diamer Basha dam. Fig 12 presents sediment outflow when Basha is on line from year 2032.

The impact of the Dasu Project developed before Diamer Basha will be dependent on how the sediment is managed in Dasu. If it is allowed to sediment up and no flushing is done, it may delay the sedimenting of Tarbela Reservoir by 10 years. If Dasu is operated to maintain its live storage then this would be reduced to 3 years.

Sediment Flushing Study

The 2 D Modeling of Ghazi Barotha Headpond showed that the flushing should not be routed through the Headpond due to its impact on the Tarbela-Ghazi system. Therefore this excludes the options for Tarbela dam Sediment Flushing Project (TDSFP) on the left bank considered in earlier studies and also from the outlets in the right bank. However sediment shall pass through the outlets when Tarbela becomes run of the river.

The 1D modeling study of Tarbela Reservoir showed that a flushing capacity of 5,000 m^3 /s is required to sustain the storage life of Tarbela and the Tarbela-Ghazi system, although a reduced capacity could slow down the rate of storage loss and/or sediment discharge until, say, Diamer Basha is built.

To achieve an effective flush the reservoir level would need to be drawn down below normal Operating levels to between 400 to 410 m (1312 to 1345ft)and would require the tunnels to be set with inverts at about 380 m (1247 ft). The flush would take place at the start of the high flow period and takes 30 days.

The right abutment flushing route includes tunnels through the elevated land around the right abutment and then a canal. Fig.13 shows plan of proposed flushing facilities. As part of the Environmental Studies a constraint map was prepared to identify the least impact route to discharge 5,000 m^3/s. It will require nine 10 m diameter tunnels for sediment flushing. Using existing nullahs is considered not feasible as the velocities will need to be maintained throughout the waterway to prevent sedimentation and hence blockage of the waterway. The outfall from the canal would need to be placed such that it discharges below the Ghazi Barotha Barrage so that the discharge through the barrage helps to disperse the sediment not carried immediately down the river.

The tunnelling conditions may be expected to be difficult based on both the geology and the experience from the Tarbela Construction. Likewise the intakes,which will require under water construction, will be difficult and this is reflected in the cost estimates of USD 3.1 Billion for 5,000 m /s flush capacity (2.2 Billion for 3,000 m^3 /s).

The 3D modelling of Tarbela Reservoir shows that a guard bund is required between the flushing intakes and the intakes to Tunnels 1 to 4. SMST has investigated the possibility of

using sand filled geo tubes to form the bund and indicative outline costs are of the order of US$.2 Billion.

The main impacts and risks of the Tarbela Dam Sediment Flushing Project (TDSFP) have been as assessed for Option 1.1 (for the 5,000 m^3 /s flush capacity) as being:

Loss of power generation at Tarbela and Ghazi Power Stations during the flushing period and for Tarbela Power Stations loss of power and energy during the drawndown and refilling stages due to reduced head:

Changes to the water outflow regime (it is believed that water wastage should be minimal by adapting the water use schedule);

Increase in annual sediment load in the downstream river by between 18 and 236% annual load). This varies between reaches and years. Also increased sediment inflow into the canals by between 71% and 121% (average annual load). This varies between barrages and assumes that the existing barrage desanding efficiency is maintained. Additional canal maintenance and / or closure would be required during periods of high sediment concentrations;

Increased changes to the aggradation in the river channel by between 1 to 27 MT (average annual change in reaches between Ghazi Barotha and Kotri Barrages);

Disruption and risk to Tarbela operation during construction of the flushing tunnel intakes and guard bund.

The sediment associated problems such as Liquefaction and Abrasion are described as below:

Liquefaction: The seismic and liquefaction studies show that with the foreset face being at its current slope of 2 degrees, a liquefaction slide would only travel a few metres and hence there is little risk of the intakes being blocked as a result of this phenomenon. If the foreset is allowed to reach the intakes (currently an average of 6 Km away) the slope will increase and even relatively small movements may cause the intakes to be blocked. Once the foreset reaches the intakes it is more likely that there will be local instability in the face due to the sediment depositing at slopes that are intransigently too steep or due to sediment being mobilized in the active channel.

Abrasion: If Tarbela is operated so as to draw more sediment out of the reservoir **(Option 0.2),** the turbines will be subject to greater sediment load. The studies carried out for Tarbela 4^{th} extension present a state of current understanding and practice.

The studies carried out for the Tarbela 4^{th} extension conclude that turbines would require repair in 1 to 2 years when there are successive years of high sediment loads,but this could be extended to about 10 years with hard anti erosion coating.

Case Histories: Tarbela is in many respects unique due primarily to its magnitude. The only comparable project found from the literature search is Sanmenxia Reservoir in China where two 11 m diameter tunnels were added and four of the eight power intakes were converted to sediment sluices to keep the reservoir in sediment balance, but even then the history and nature of the project is not comparable. The 35 Bm^3 reservoir on the yellow River is impounded by a 106 m high concrete gravity dam with the power station being integral to the dam. It was completed in 1960 and had lost 40 % of its storage within 4 years.

Dredging: Dredging may be used in a number of ways:

- Reactively to emergency situation where the intakes have blocked;

- Proactively in the area around the intakes to prevent intake blockage situation developing.
- As a means of de-silting the reservoir to the extent that the sediment is in balance;
- As part of the construction of a guard bund.
- Keeping tailrace channel clear.

It is expected that it will take a minimum of 10 years to carry out the necessary EIA, Investigations, design, contract procurement and construction of Tarbela Sediment Flushing project.

Economic Studies of Tarbela Reservoir Flushing

The economic studies have shown that the proposed TDSFP with a capacity of either 5,000 m^3/s or 3,000 m^3/s is not economically as well as financially viable. The key indicators are given in the following Table:-

Indicator	**5,000 m^3/s Flush**	**5,000 m^3/s Flush Costs + 20%**	**3,000 m^3/s Flush**	**5,000 m^3/s Flush Costs + 20%**
IRR	8%	6%	8%	6%
NPV incremental benefits	1,386	1,386	968	968
NPV incremental costs	1,984	2,381	1,444	1,733
Net Incremental benefits	(599)	(996)	(476)	(764)
BCR	0.70	0.58	0.67	0.56

Table 7 Economic Indicators of Tarbela flushing.

The analysis has been based on the CAPEX and OPEX costs of TDSFP from SMST and the energy and water costs derived for the study assessments made under SMST. The analysis assumes that TDSFP is commissioned after 10 years.

Findings and Recommendations

The main findings and recommendations of SMST are as follows:

1. Sediment Flushing

a. The modeling shows that flushing can keep Tarbela Reservoir in sediment balance. It will require a flushing capacity of 5,000 m^3/s and take 30 days a year during which time the reservoir will need to be drawn down. Generation at the Tarbela and Ghazi Power Stations will not be feasible.

b. The flush needs to by pass Ghazi Headpond in order to sustain generation at the Tarbela and Ghazi Power Station.

c. The flush will impact on the downstream river system. Increase the sediment load entering the canals by between 118% and 214% (average annual increase) and changing the bed levels in the river channel. This would necessitate additional sluicing to

clear the canal head regulator pockets. At Chashma there would be head loss into the power station and increased sediment load through the turbines.

d. Keeping the power intakes clear of sediment as a result of flushing will require a guard bund.

e. The most likely TDSFP is a tunnel and canal system on the right bank which clears sediment from the power intake and provides the optimum route past the Ghazi Barotha Barrage Headpond.

f. TDSFP is technically difficult and uneconomic with a negative rate of return and is therefore not recommended.

2. Sediment Management

Assuming it is accepted that TDSFP is not viable, then the options for sediment management for the short and medium to longer term foreseen from the findings of the SMST studies are:

a. Raise the minimum drawdown level year-on-year tracking the rising foreset level upstream of the pivot point. This will result a year-on-year loss of storage of 150 Mm^3 but the impacts on the Tarbela,Ghazi and d/s river systems will be similar to now till Tarbela becomes run of the river.

b. Provide upstream storage to catch the sediment before it reaches Tarbela Reservoir, as would be provided by Diamer Basha for a period of $\pm$ 40 years, and by Dasu to a lesser (short term) extent if it were to be developed before Diamer Basha. Diamer Basha would also provide alternative water storage and enable Tarbela Power Stations to be operated for a longer period of the time at a higher head and cause Tarbela to trap the sediment further away from the intakes.

Once it is known when alternative storage will be available it would be possible to reduce the rate of storage loss in Tarbela Reservoir by allowing the delta to start to encroach on the intakes.

The alternative to upstream sediment trapping and replacement storage would be to provide downstream alternative storage for irrigation and accept that Tarbela is used for the foreseeable future to trap sediment.

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3. HR Wallingford (2013) Sediment Management Study of Tarbela Reservoir. Tarbela Reservoir Modelling.

4. Tarbela Periodic Inspection No. 2 & 5 Reports

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6. Tarbela Hydrology and Sediment Data.

7. Tarbela Annual Sedimentatioin Reports.

Table No. 1: Gauging Station Data Statistics of Indus River

Sr. #	Gauging Station	Inflow/Outflow	Time Period	Avg.Flow (m^3/S)	St. Dev. (m^3/S)	Max. (m^3/S)	Min. (m^3/S)
1.	Shatial		1984-2010	2,127	2,395	16,319	283
2.		Gorband River at Karorar		22	21	271	2
3.	Besham Qila		1981-2010**	2,313	2,542	17,127	341
4.		Brandu River at Daggar	1985-2000	13	18	336	6
5.		Siran River at Phulra	1985-2000	21	30	755	1
6.	Tarbela Outflow		1981-2010	2,364	2,017	14,931	93
7.	Ghazi Barrage U/S		1981-2010*	2,373	1,999	14,928	38
8.	Ghazi Barrage D/S		2004-2010	1,194	1,749	13,327	0
9.		Kabul River at Khairabad	1981-2010	966	809	7,277	83
10.		Barotha Power Complex Outflow	2009-2010	1,245	450	1,745	113
11.		Haro River at Gurriala	1985-2000	31	60	1,725	3
12.		Soan River at Indus	1985-2000	61	143	5,168	4
13.		Kurram River at Thal	1985-2000	24	37	1,606	2
14.	Jinnah Barrage U/S		1981-2010	3,301	2,666	24,269	246
15.	Jinnah Barrage D/S		1981-2010	3,097	2,633	24,241	54

Sr. #	Gauging Station	Inflow/Outflow	Time Period	Avg.Flow (m^3/S)	St. Dev. (m^3/S)	Max. (m^3/S)	Min. (m^3/S)
16.		Touchi River at Tangi Post	1985-2000	12	79	2,322	0
17.	Chashma Barrage U/S		1981-2010	3,342	2,775	28,342	181
18.	Chashma Barrage D/S		1981-2010	3,102	2,765	28,342	0
19.		Tank Zam at Jandola	1985-2000	14	33	487	1
20.		Gomal Zam at K.Murtaza	1985-2000	63	91	1.038	4
21.		Darband Zam at Z.Tower	1985-2000	2	10	635	0
22.	Taunsa Barrage U/S		1981-2010	3,069	2,852	24,356	128
23.	Taunsa Barrage D/S		1981-2010	2.711	2,706	24,356	51
24.		Punjnad at Punjnad D/S	1981-2010	598	1,321	21,075	0
25.	Guddu Barrage U/S		1981-2010	3,268	3,930	33,228	242
26.	Guddu Barrage D/S		1981-2010	2,852	3,757	33,192	37
27.	Sukkur Barrage U/S		1981-2010	2,890	3,832	33,038	11
28.	Sukkur Barrage D/S		1981-2010	1,973	3,638	31,853	28
29.	Kotri Barrage U/S		1981-2010*	1,776	3,274	28,667	25
30	Kotri Barrage D/S		1981-2010	1,193	2,476	26,604	0

Table No. 2 Besham Qila Sediment Data

Year	Tarbela Inflow (Bm^3)	Besham Qila Rating Curve (MT)
1981-1982	67.4	172
1982-1983	59.9	118
1983-1984	81.4	240
1984-1985	66.3	152
1985-1986	71.5	201
1986-1987	76.9	169
1987-1988	91.4	323
1988-1989	72.1	181
1989-1990	88.2	277
1990-1991	80.6	203
1991-1992	74.2	167
1992-1993	61.5	90
1993-1994	90.5	366
1994-1995	69.5	153
1995-1996	75.7	208
1996-1997	61.1	109
1997-1998	74.3	174
1998-1999	86.2	260
1999-2000	68.9	141
2000-2001	62	104
2001-2002	66.8	132
2002-2003	78.8	193
2003-2004	64.5	101
2004-2005	82.4	243
2005-2006	82.9	240
2006-2007	74.6	147
2007-2008	72.7	175
2008-2009	68.7	142
2009-2010	90.9	399
Total Quantity (MT)		**5579**
Average Quantity (MT/yr)		**192**

Table No. 3 Volume of Sediment Deposited in Tarbela Reservoir

Year	Annual Volume (MAF)	Accumulative Volumes (MAF)	Annual Volume (Mm^3)	Accumulative Volume (Mm^3)
1974-79	0.635	0.635	783	783
1979-1980	0.129	0.764	159	942
1980-1981	0.130	0.894	160	1103
1981-1982	0.050	0.944	62	1164
1982-1983	0.083	1.027	102	1267
1983-1984	0.159	1.186	196	1463
1984-1985	0.082	1.268	101	1564
1985-1986	0.089	1.357	110	1674
1986-1987	0.061	1.418	75	1749
1987-1988	0.103	1.521	127	1876
1988-1989	0.075	1.596	92	1868
1989-1990	0.131	1.727	162	2130
1990-1991	0.100	1.827	123	2253
1991-1992	0.075	1.902	92	2346
1992-1993	0.061	1.963	75	2421
1993-1994	0.199	2.162	245	2666
1994-1995	0.093	2.255	115	2281
1995-1996	0.102	2.357	126	2907
1996-1997	0.098	2.455	121	3028
1997-1998	0.084	2.539	104	3131
1998-1999	0.140	2.679	173	3304
1999-2000	0.076	2.755	94	3398
2000-2001	0.099	2.854	122	3520
2001-2002	0.096	2.950	118	3638
2002-2003	0.076	3.026	94	3732
2003-2004	0.072	3.098	89	3821
2004-2005	0.069	3.167	85	3906
2005-2006	0.146	3.313	180	4086
2006-2007	0.123	3.436	152	4238
2007-2008	0.063	3.499	78	4315
2008-2009	0.038	3.537	47	4362
2009-2010	0.197	3.734	243	4605
2010-2011	0.097	3.831	119	4724
2011-2012	0.067	3.0908	82	4806

Table No. 4 SEDIMENT LOAD OF DIFFERENT RIVERS

River	Av. Annual Sediment M.T
Kabul at Nowshera	27.67
Haro at Garriala	1.36
Soan at Dhok Pathan	12.17
Kurram at Thal	3.36
Tochi at Tangi Post	0.81
Tank Zam at Jandola	5.48
Gomal Zam at Kot Murtaza	27.09
Jinnah Barrage	64.23
Chashma Barrage	75.49
Taunsa Barrage	83.91
Sukkur Barrage	98.92
Indus at Partab Bridge	153.7
Indus at Besham Qila	198

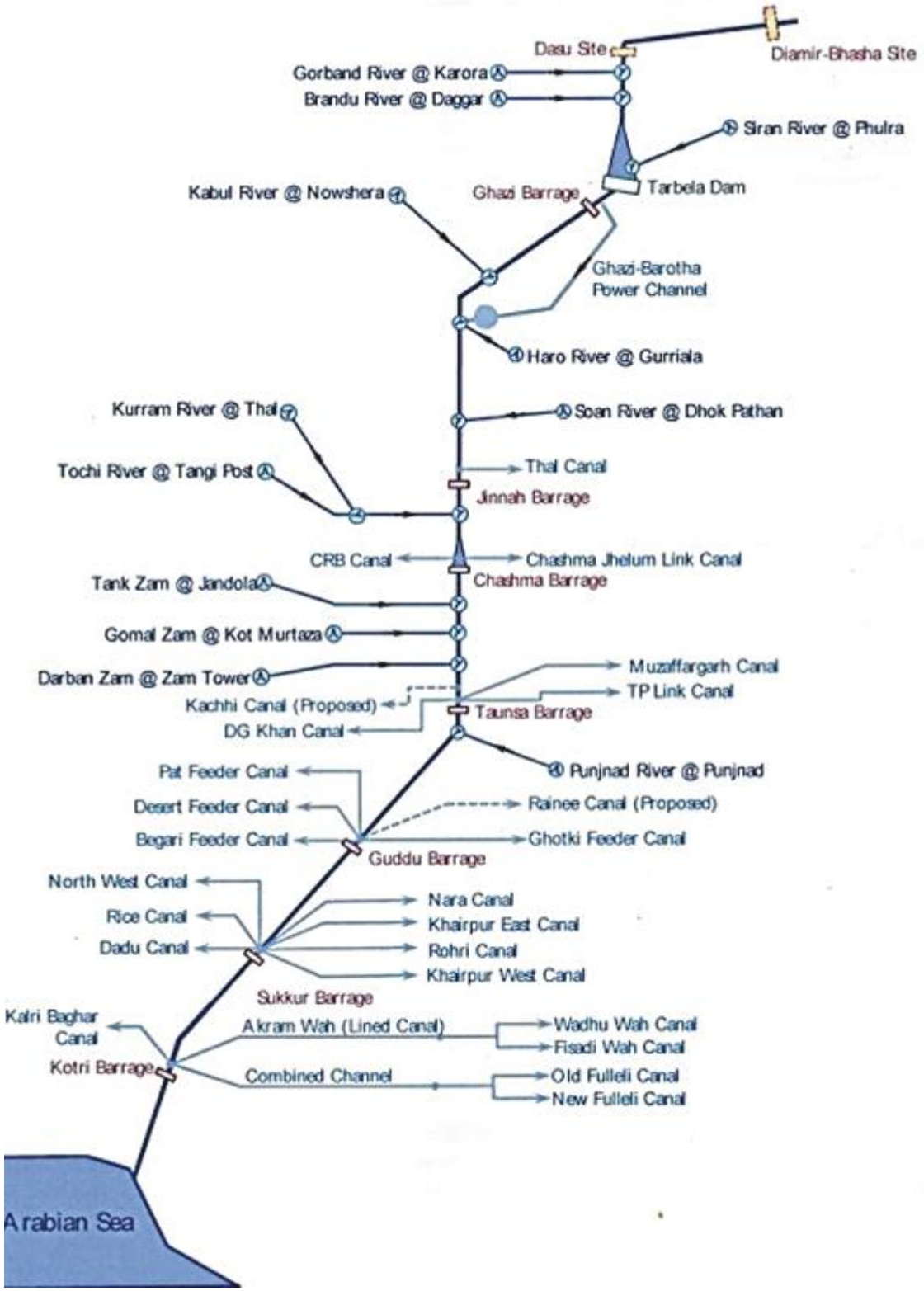


Figure 1: Schematic Sketch of River Indus and its Tributaries with Off-Taking Canals

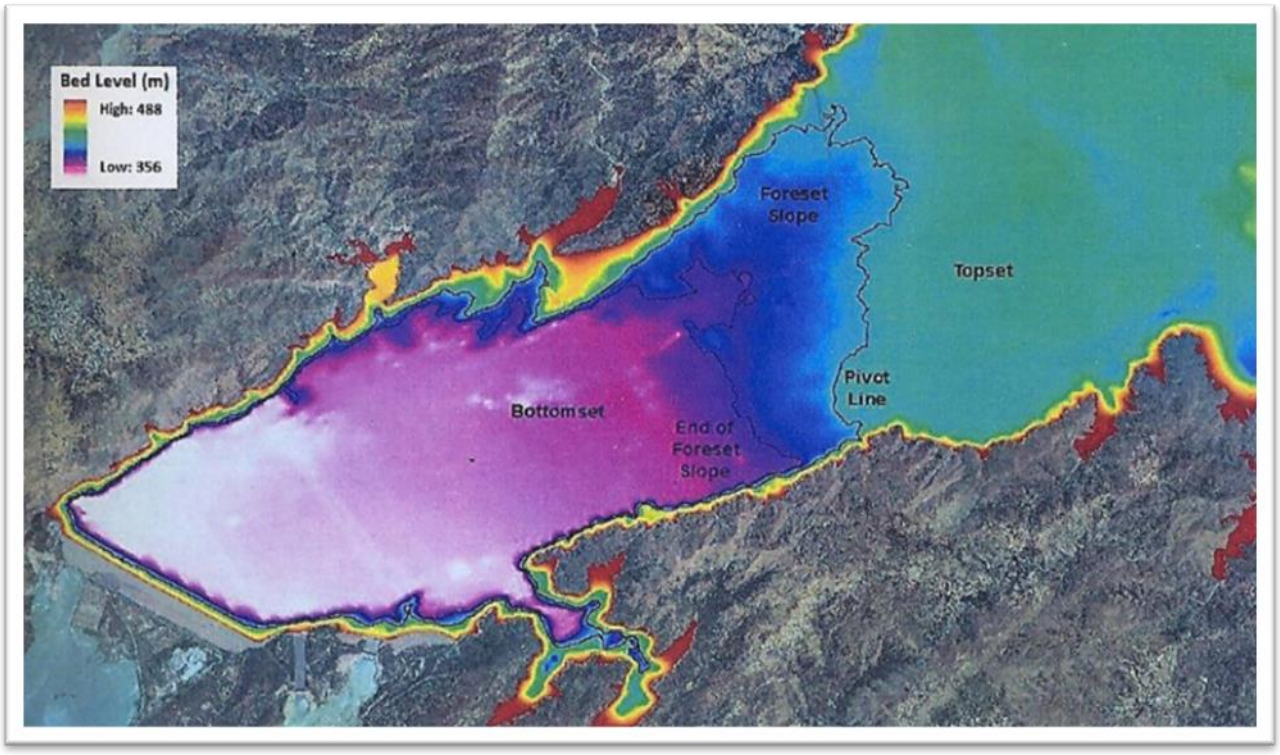


Figure-2: Tarbela Reservoir Area – Contour Plan of Reservoir Bed and Position of Pivot Point

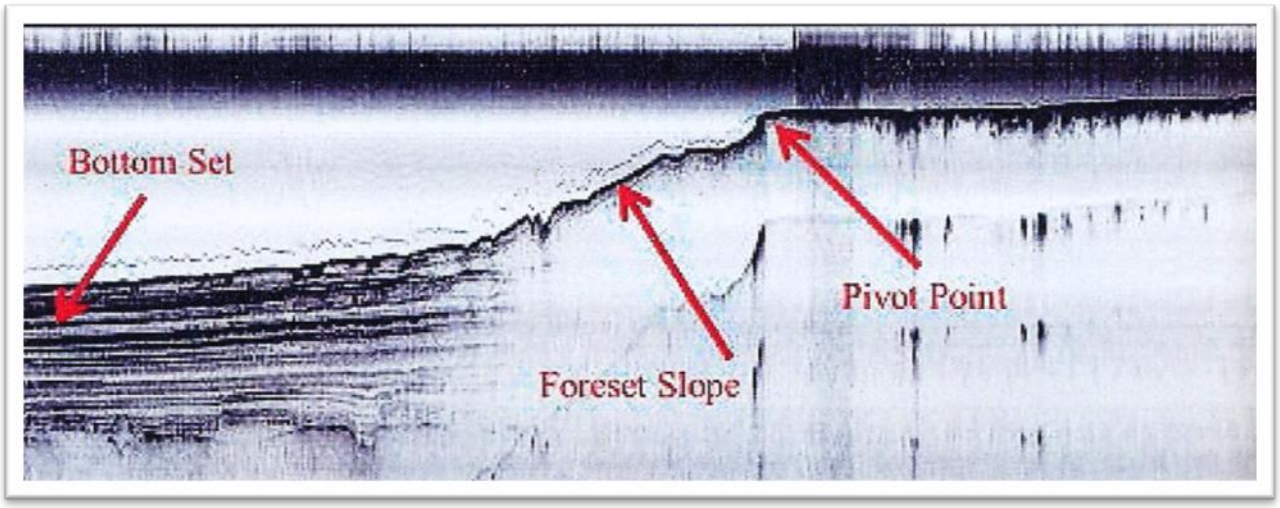
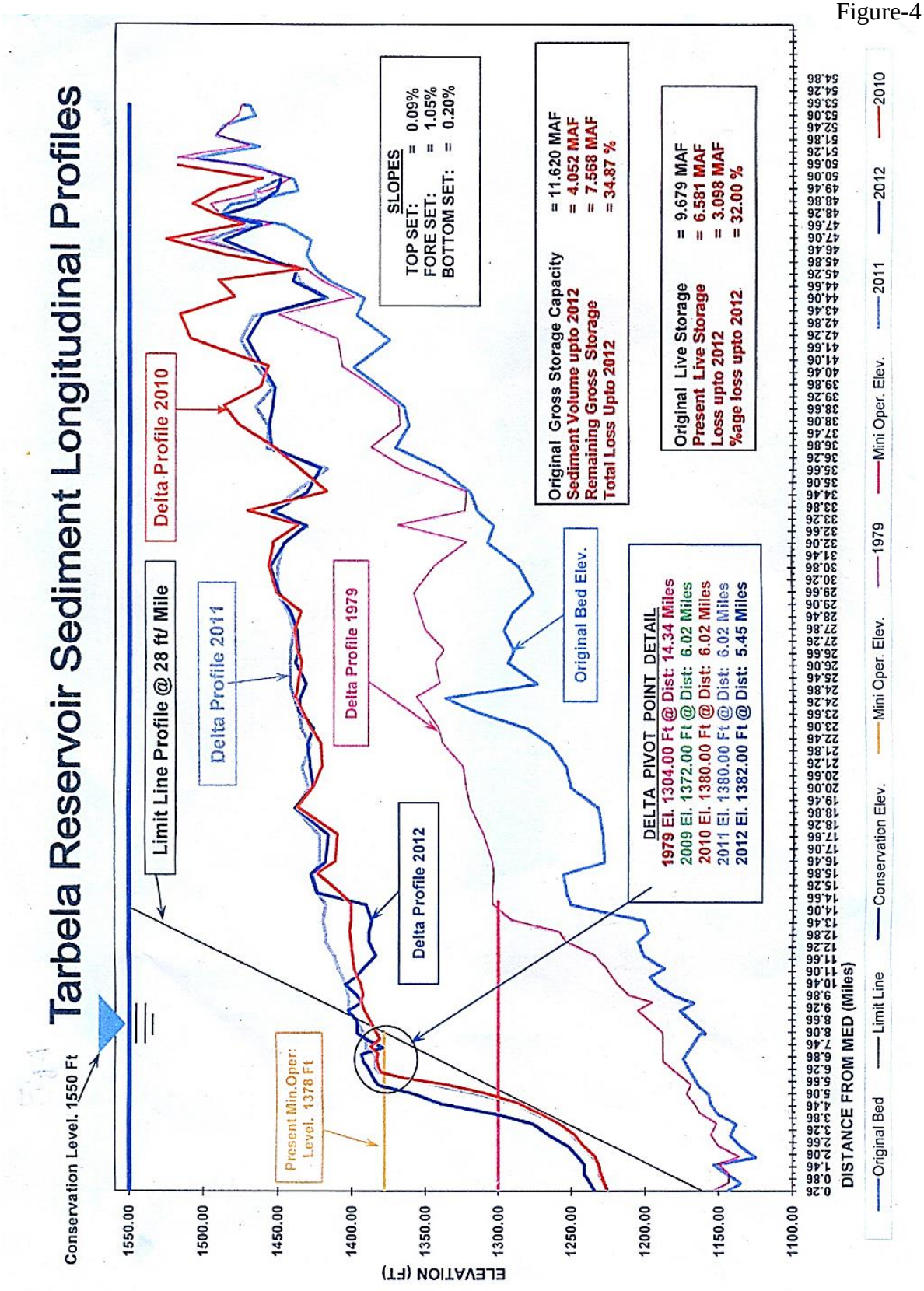


Figure-3: Tarbela Reservoir Delta Area Longitudinal Section

Figure-4


Tarbela Reservoir Sediment Longitudinal Profiles
Conservation Level. 1550 Ft
Limit Line Profile @ 28 ft/ Mile
Delta Profile 2010
Delta Profile 2011
Delta Profile 1979
Delta Profile 2012
Present Min.Oper: Level. 1378 Ft
Original Bed Elev.
SLOPES
TOP SET: = 0.09%
FORE SET: = 1.05%
BOTTOM SET: = 0.20%
Original Gross Storage Capacity = 11.620 MAF
Sediment Volume upto 2012 = 4.052 MAF
Remaining Gross Storage = 7.568 MAF
Total Loss Upto 2012 = 34.87 %
Original Live Storage = 9.679 MAF
Present Live Storage = 6.581 MAF
Loss upto 2012 = 3.098 MAF
%age loss upto 2012 = 32.00 %
DELTA PIVOT POINT DETAIL
1979 El. 1304.00 Ft @ Dist: 14.34 Miles
2009 El. 1372.00 Ft @ Dist: 6.02 Miles
2010 El. 1380.00 Ft @ Dist: 6.02 Miles
2011 El. 1380.00 Ft @ Dist: 6.02 Miles
2012 El. 1382.00 Ft @ Dist: 5.45 Miles
ELEVATION (FT)
DISTANCE FROM MED (Miles)
Original Bed
Limit Line
Conservation Elev.
Mini Oper. Elev.
1979
2011
2012
2010

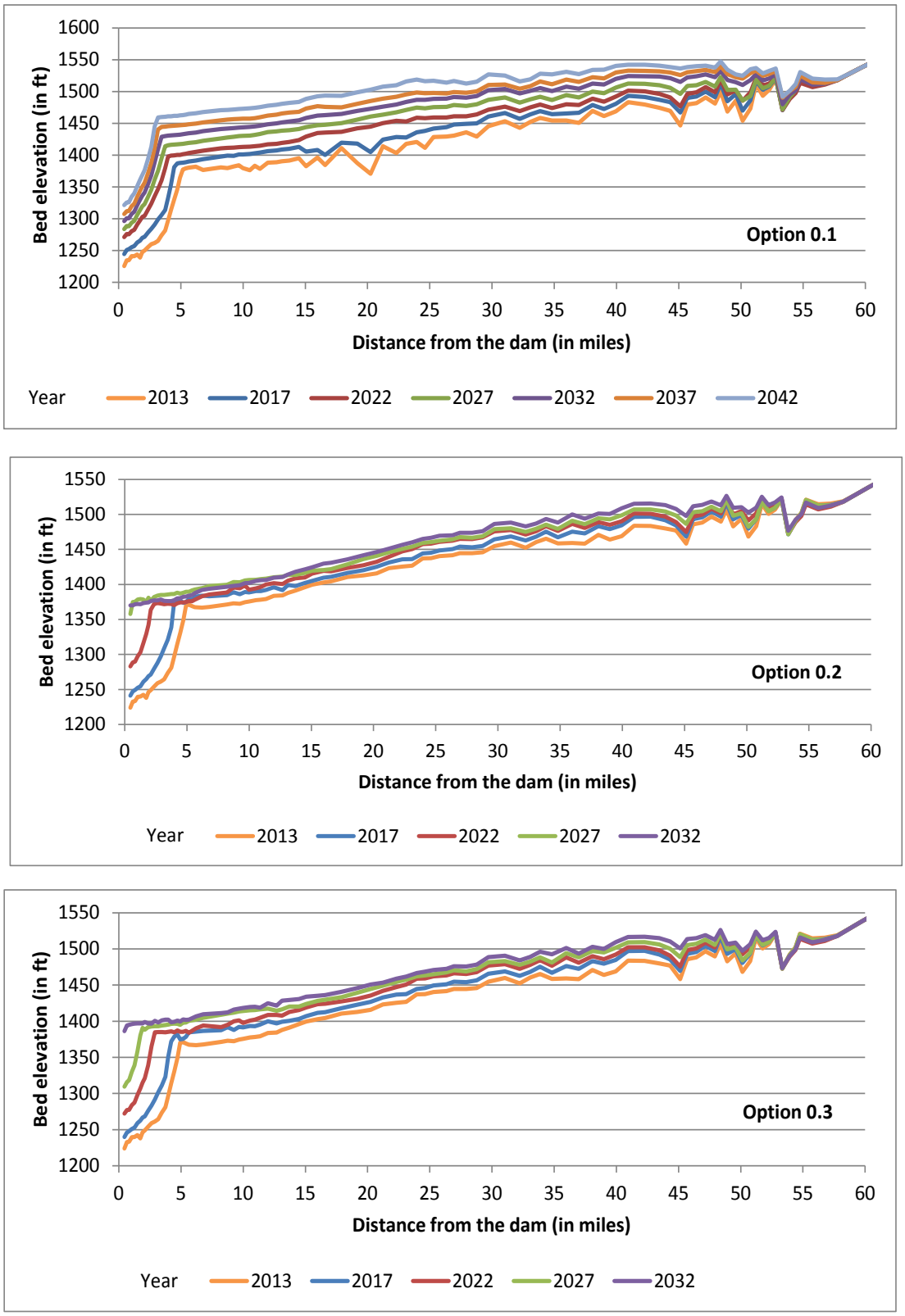


Figure-5: Longitudinal Bed Profiles for the Three Management Options

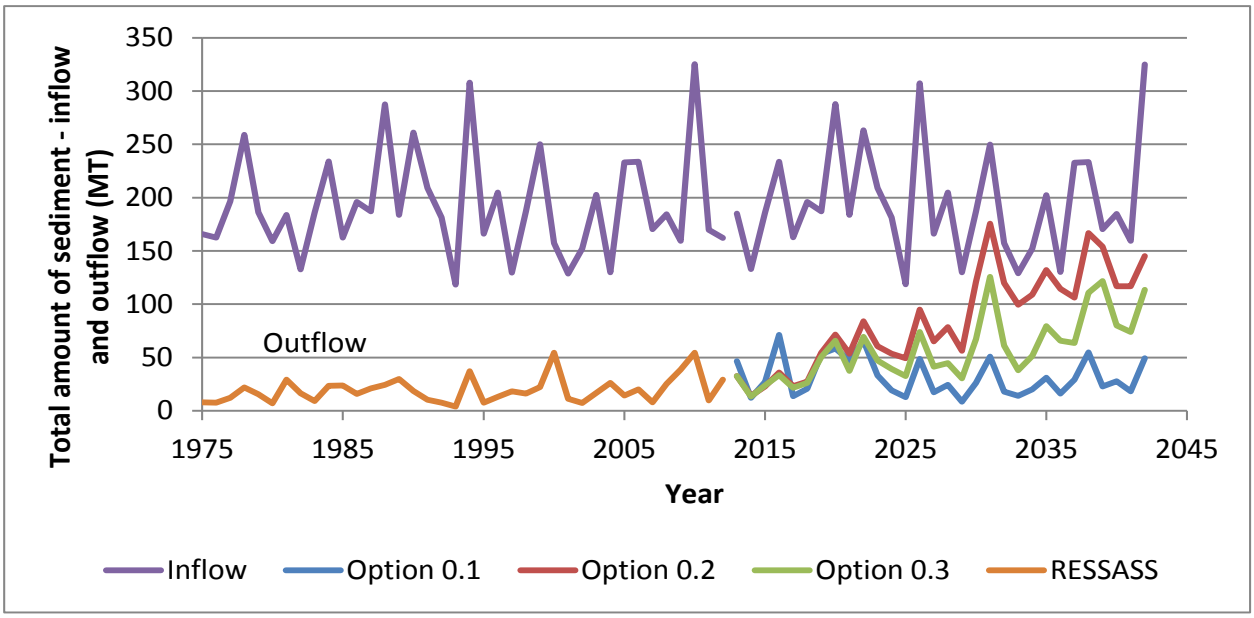


Figure 6: Inflow and Out Flow of Sediment for Three Management Rules

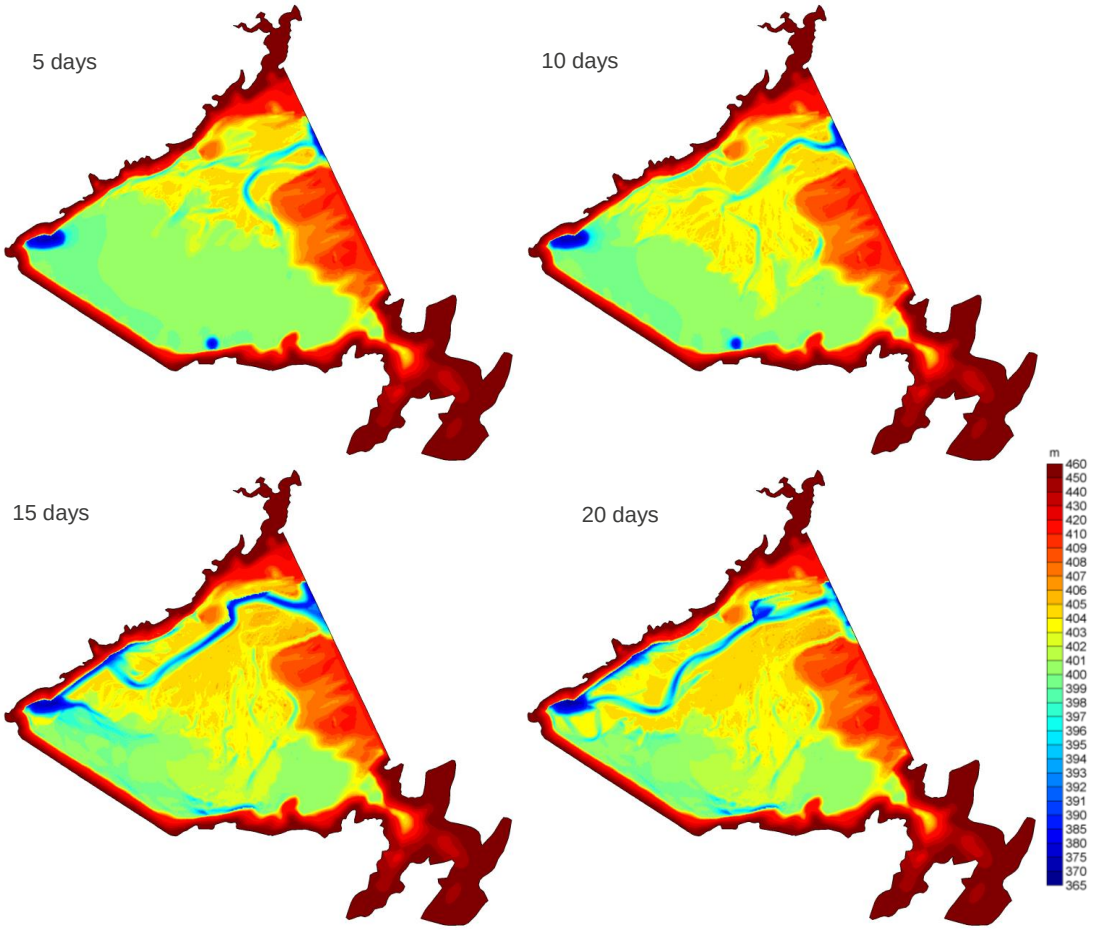


Figure 7: Advancement of Delta towards Intakes during Flushing

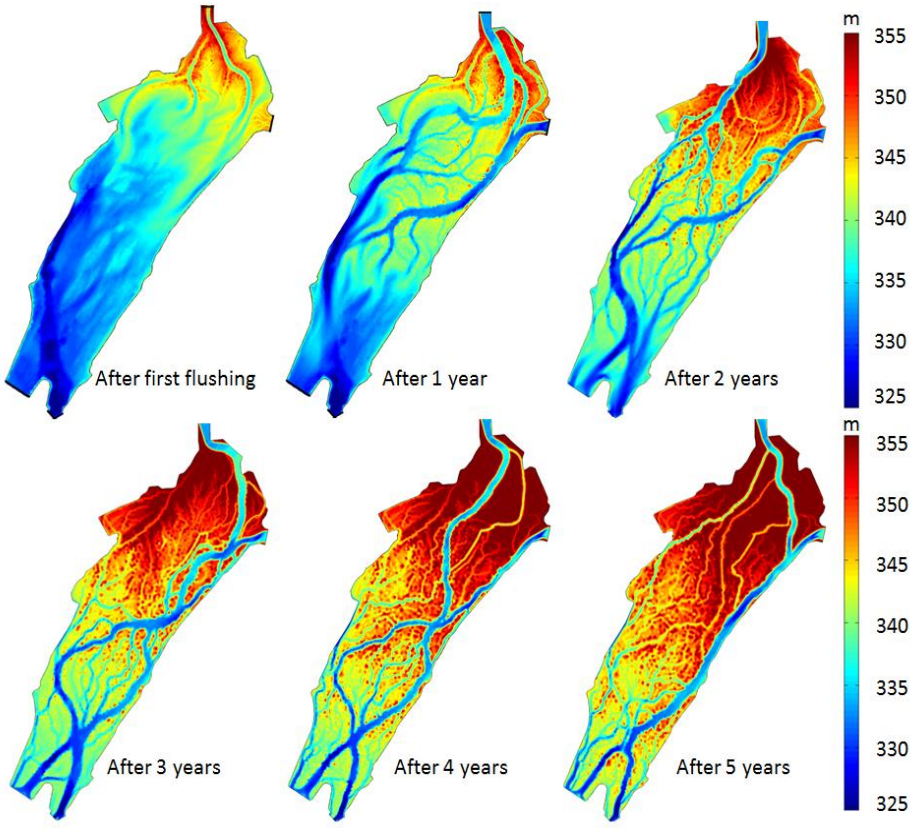


Figure 8: Ghazi Barotha Head Pond with Tarbela Flushing

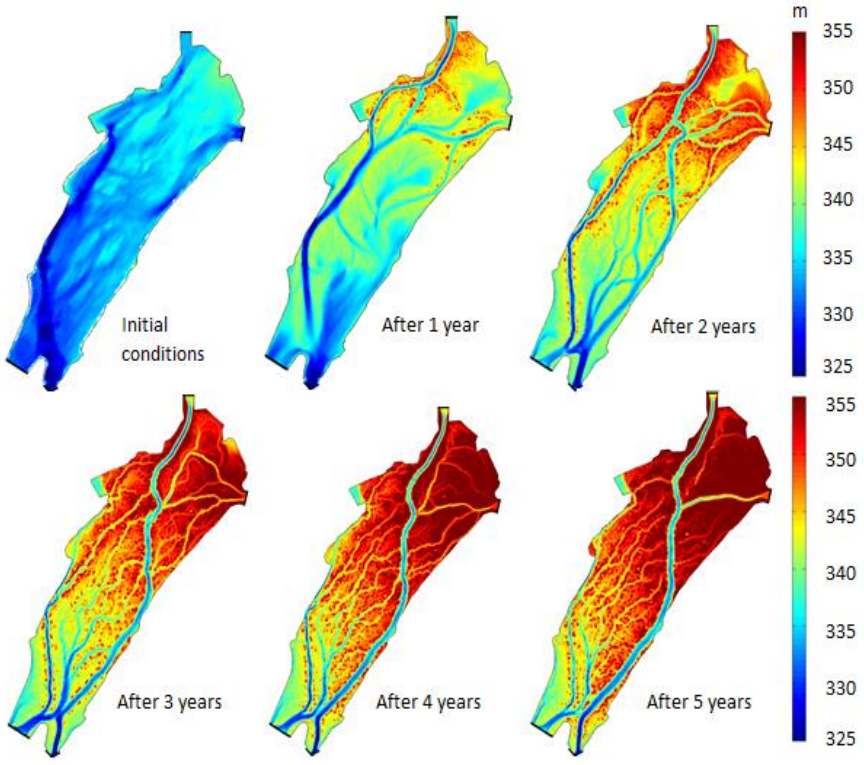


Figure 9: Ghazi Barotha Head Pond with Tarbela Run of River

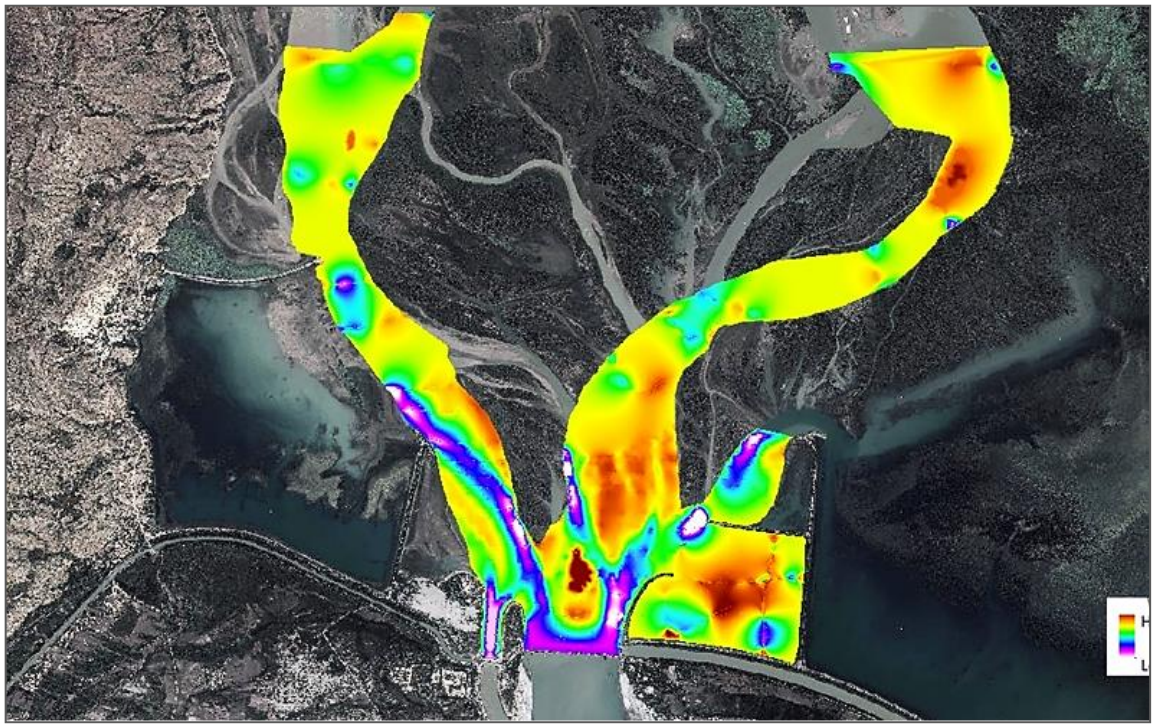


Figure 10: Chashma Reservoir Head Pond Levels with Tarbela Flushing

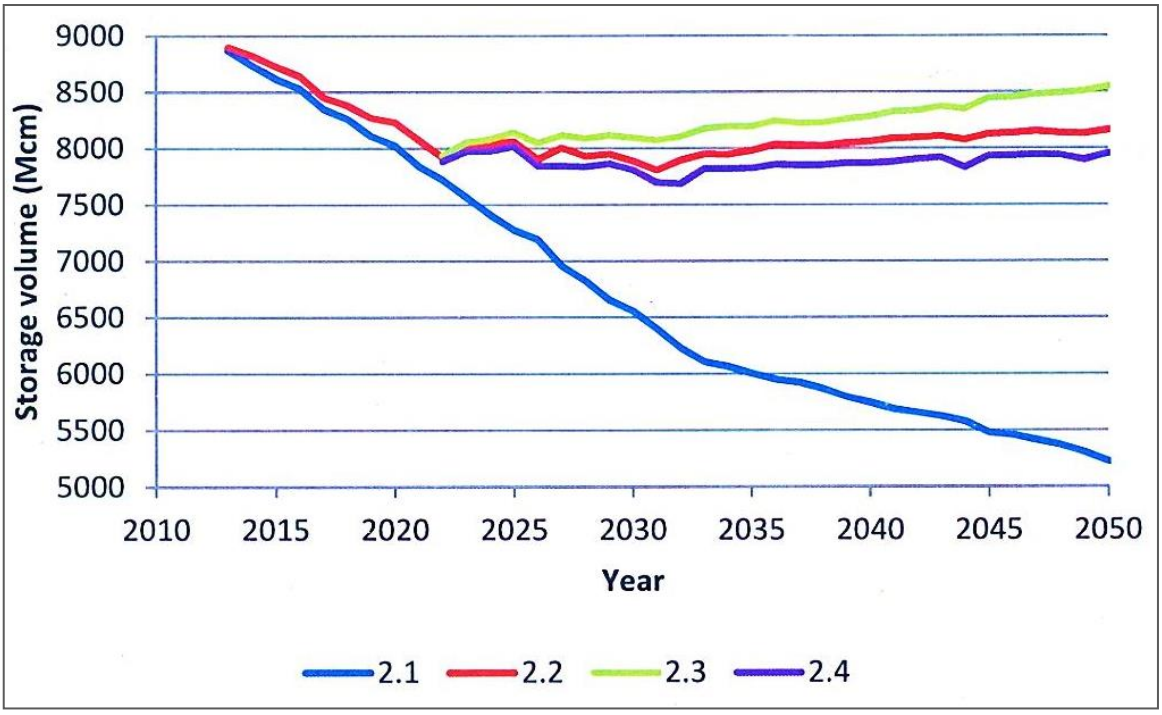


Figure 11: Tarbela Storage volume with Basha Dam

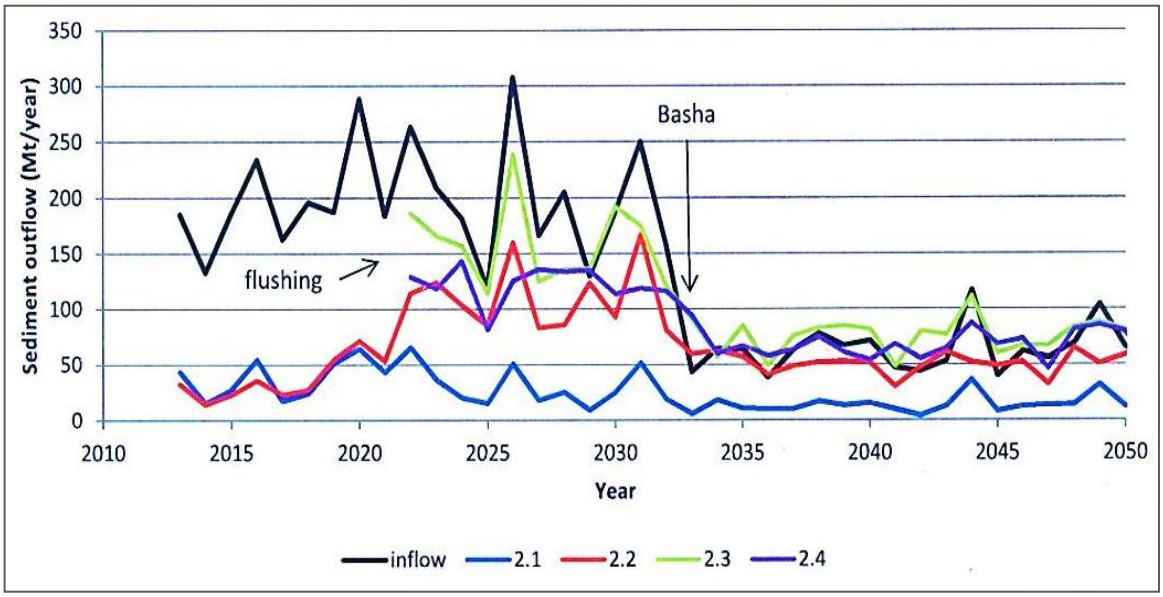


Figure 12: Sediment Outflow for the Tests Including Basha Reservoir from Year 2032



Figure 13: Plan of Proposed Flushing Facilities