SEDIMENTATION MANAGEMENT OF PATRIND HYDRO POWER PROJECT USING OHDS TECHNIQUE

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1. INTRODUCTION

Renewable energy has been in the lime light all around the world due to increased dependency of energy on other sources. Hydropower development is one of the most discussed and developed area amongst renewable sources of energy.

Development of hydropower involves more time and capital which is further influenced by the hydrological conditions. The most critical area of concern in the hydropower development is the sediment management upstream of the reservoir which greatly affects the reservoir operation, storage capacity and its management for which different techniques are adopted worldwide considering the site specific constraints.

Government of Pakistan, through its "Policy for Power Generation Projects" (2002) encouraged private participation in the electricity market. Korea Water Resources Corporation (Kwater) through its special purpose company i.e. Star Hydro Power Limited (SHPL) has developed a run-of-river hydropower project (the "Project") in northern region (near the Himalayan Mountains) of Pakistan having capacity of 150MW on River Kunhar and is successfully operating since November 2017. The watershed area of the project is about 2,400㎢ having average annual sediment load of 4.4Mst.

After detailed studies of the original design of the Project which involved an underground sand trap to settle above 0.2mm particle size it was concluded that the conventional sandtrap structure was not efficient enough also has a huge cost of construction and involved huge slope excavation and stabilization.

Through various studies and modeling a new concept OHDS (Optimal Hybrid DeSander) was considered and was subsequently constructed. This concept consists of a permanent coffer dam approx. 150 m upstream of the main weir structure, a bypass tunnel and a modified pool (natural sand trap between the main weir and coffer dam).

2. PROJECT OUTLINE AND SEDEMENT MANAGEMENT GOALS

2.1 Project outline

The Project is located about 120km northeast of Islamabad, which is capital of Pakistan. Being a run-of-river type Project, water is diverted from Kunhar River through a 2.2 Km headrace tunnel and passed through three units of vertical Francis turbines for power generation located on the right bank of Jehlum River. The specifications of the plant are as follows.

Table 1 : Specifications of the Patrind Hydropower Project

Weir				Intake	Energy Generation		
Catchment Area	Type	Height	Length	Design Discharge	Turbine Type	Installed Capacity	Annual Generation Energy
2,400㎢	CGD	43.5m	167.6m	153.6㎥/s	Vertical Francis	150MW	641.3GWh

Fig. 1 : Bird's-eye View of Patrind Hydropower Project

2.2 Sediment inflow status

Kunhar river is highly sedimentary river with an estimated sediment of 4.4 Mt per year and is directly affected by sedimentation erosion from the Himalayas. During the basic and detailed design stages of the Project, in order to check the amount of sediments flowing into weir, discharge and suspended sediment observation data had been analyzed from 1960 to 2012. The observatory station is located about 12.3 kms upstream of the Project site.

Through regression analysis, sediment rating curve was prepared using the observed discharge and suspended sediment amount.

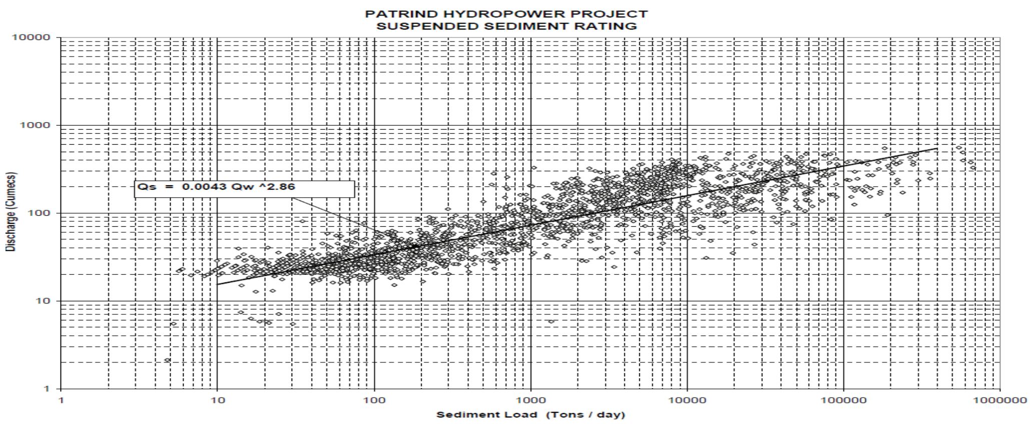

Fig. 2 . Suspended Sediment Rating Curve

3. SAND TRAP DESIGN

3.1 Conventional sand trap and its efficiency

After detailed studies of the original design having an underground sand trap to settle above 0.2mm particle size, it was concluded that the conventional sandtrap structure was not efficient enough resulting in huge cost of construction and huge slope excavation and stabilization.

Table 4 : Specifications of the Sand Trap (Basic Design, 2010)

Type	Design Discharge	Chamber		Flushing Tunnel	
		Section	Length	Type	Section
Open Type	153 m³/s (76.5 m³ × 2 chamber)	23×26.7m	140m	Box Culvert	1.8×2.5m

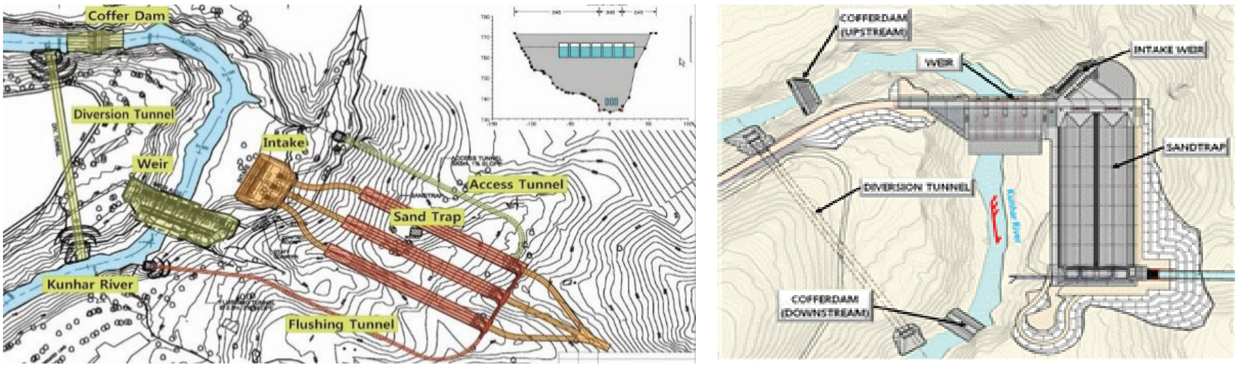

Fig. 3 : Project Layout of the Feasibility Study(left) and Basic Design (right)

Various analyses were done and different scenarios were checked to confirm the appropriateness of the sandtrap design but all the results pointed out that the reservoir is likely to be filled in not more than five years which led to adoption of alternative sediment management techniques.

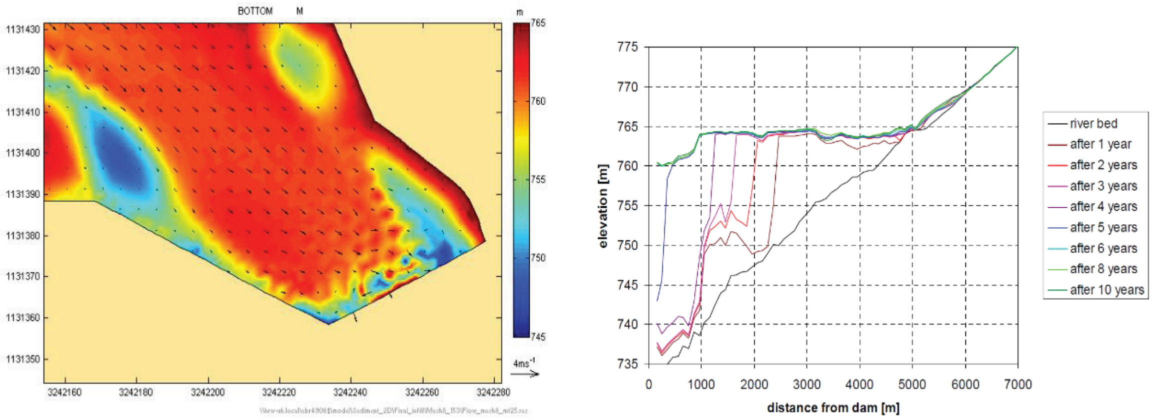

Fig. 4 : Bed Evolution During Deposition(left) and Deposition after 48days ($Q=153m^3/s$) (right)

3.2 OHDS Technique

Mr. Alam in 2014 suggested to consider the flows exceeding the capacity of the intake ($153.6m^3/s$) diverting through a by-pass tunnel. The area between coffer dam and weir structure is termed as Modified Pool (MP) acting as a natural sand trap and its efficiency should be higher than that of the artificial sand traps.

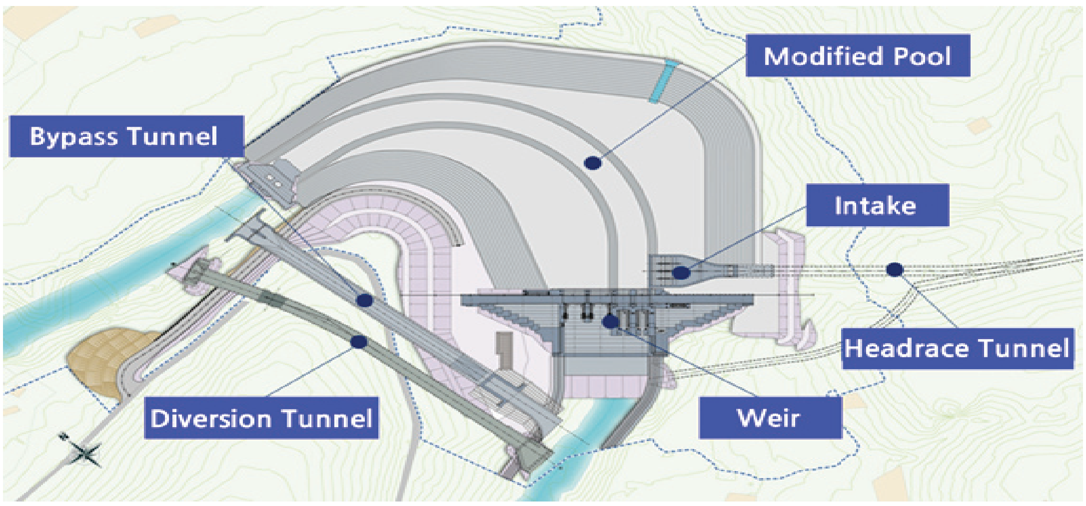

Fig. 5 : Layout of the Weir Site(Detail design, 2015)

3.3 Physical Model

Reservoir flushing test was carried out through a Physical Model established at ETH Zurich Switzerland to find the optimum condition of sediment removal. The performance of the two flushing tests (Q = 150㎥/s and 200 ㎥/s) were very similar, though the flushed out sediment volume was about 10% higher for Q = 200 ㎥/s.

Table 7 : Volume Balance of Flushed Deposits in the MP for Load Case

Load case	MP volume (m^3)	Initial deposit volume (m^3)	Erosion		Residue	
			Volume (m^3)	Percentage of eroded volume	Residual deposits (m^3)	Residual MP volume
Q 150m³/s, 1day flushing	687,000	200,000 (100%)	88,000	44%	112,000	84%
Q 200m³/s, 1day flushing			96,500	48%	103,500	85%

The Initial Condition(left) and Hydraulic Flushing of Built up deposits with 150㎥/s after 14 Hours of Flushing Through the Fully Opened Underway Spillway Gate

4. IMPLEMENTATION OF NUMERCAL AND PHYSICAL MODEL RECOMMENDATIONS

All the studies carried out earlier recommended that at least 10 days of flushing will be necessary every year to maintain reservoir storage. After two years of operations, the flushing activity has been carried out in high flow season i.e. July 2019. The main reason of this activity was to maintain the reservoir storage capacity intact and confirm that adequacy of the new concept.

Further deliberations were made to optimize the flushing duration as during the high flow season, the power purchaser does not allow the plant to go offline. The flushing activity was conducted from 23rd to 30 July 2019. For comparison of the flushing activity a pre-flushing survey (bathymetric survey) was conducted to check the storage capacity and the same was done after the 6 days of flushing (5 days for reservoir and 1 day for modified pool).

4.1 Bathymetric survey

Since the Project is in operations from November 2017, the flushing activity was not conducted in its first high flow season keeping in view the results of bathymetric survey being conducted every quarter after November 2017. This survey is being done in order to have update on the river topography under the reservoir and natural sand trap.

4.1.1 *Methodology of bathymetric survey*

Reference cross sections are taken from the survey which was carried out before the impounding of the reservoir. New cross sections obtained through a bathymetric survey using echo sounder are compared with these reference cross sections to calculate the updated capacity of the modified pool. There are 37 reference cross sections which are taken at almost 100 meters interval throughout the reservoir area.

While comparing the cross sections to check the updated capacity of the reservoir, one thing should be kept in mind that every time we should follow the same cross section to obtain the data from echo sounder.

4.1.2 *Bathymetric survey prior to flushing activity*

in order to assess and analyze the results of flushing activity, a bathymetric survey was conducted before the flushing activity and the results of the survey showed that approx. 45% volume of the reservoir has been filled up with the sediment. The survey indicated that majority of the deposition is between cross section 1300 to 2800 which means not very close to the bypass tunnel.

4.2 Flushing activity

In accordance with HR Wallingford’s report, the main parameters of the flushing operation are as follows:

- Discharge for flushing
- Drawdown level
- Duration and frequency of flushing

4.2.1 *Discharge for flushing*

The results of the sediment modelling indicate that the optimum discharge/flow required for flushing is between 150 and 200 m^3/s.

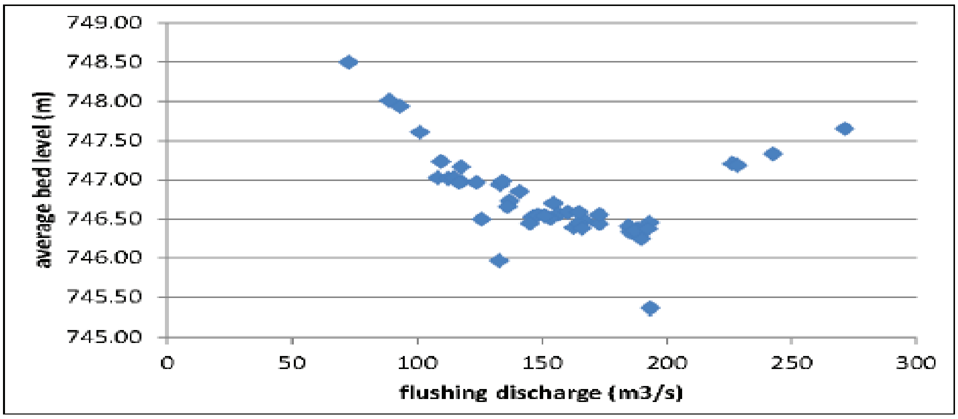

Fig. 6 : Required Discharge for Flushing

4.2.2 *Drawdown level*

During flushing, the drawdown water level in reservoir and modified pool will be set by the volume of inflow, the discharge capacity of bypass tunnel and the underflow spillway.

The following shows the drawdown levels compared to the inflow rates.

Table 8 : Drawdown level of Reservoir and Modified Pool during flushing

Inflow (m3/sec)	Drawdown Level (El. m)			
	Flushing of modified Pool		Flushing of Reservoir	
	Reservoir	Modified Pool	Reservoir	Modified Pool
150	756.37	748.41	749.54	745.00
200	756.63	749.13	751.57	745.00

4.2.3 *Duration and frequency of flushing*

Regular flushing of the reservoir and modified pool is required to maintain a suitable storage capacity. In accordance with the HR Wallingford report flushing should be carried out annually in August. It should consist of 5 days of flushing via the bypass tunnel (For the reservoir) followed by 1 day of flushing via the underflow gates (For the modified pool).

When the inflow exceeds 800 m3/s and water is prevented from entering the HRT (Head Race Tunnel) by fully opening all gates of the spillways and bypass tunnel. It leads to draw down the water level of the reservoir and modified pool and to minimize the sediment deposition during high frequency flood. The sediment will be naturally flushed out for the descending time after the peak flow, which may contribute to maintain the long-term active storage volume.

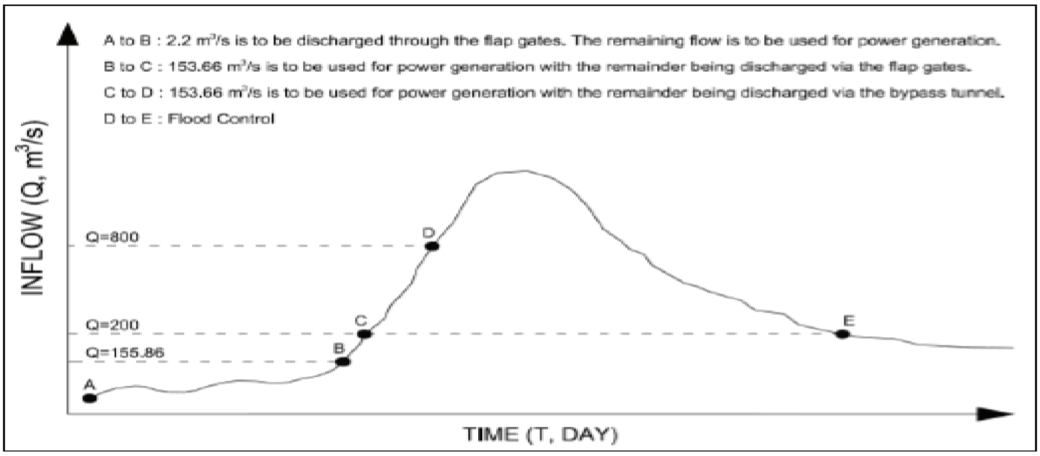

Fig. 7 : Duration and Frequency of Flushing Operation

4.3 flushing methodology

At the initial test impounding, the limit condition of increasing and draw down of water level was set up 5 m per day. In operation stage, however during flushing period draw down and impounding can be carried out continuously as suggested in the O&M manual.

The detail step is as following;

(a) In case of 150 ~ 200 m3/sec, flushing procedure could be descripted below.

(i) Drawdown of the Modified Pool Water Level

I Gate Operation: Fully open the underflow radial gate

II Water Level: EL.765.00 m → EL.748.41 ~ 749.13 m

III Required Time: 3.9 ~ 5.3 hour (The time of full drawdown may be changeable due to the river flow from the Kunhar river.)

IV Open the gate of the underflow spillway according to the gate operation sequence. Flushing is being started from the gate opening of the underflow spillway. (Allowable maximum gate opening is 30 cm at one time. However, it is recommended to adjust the gate opening so that the water level drop rate does not exceed 10cm at 1 minute in the Modified Pool.).

(ii) Flushing for the Modified Pool: Required time 24 hours with the full opening gate of the underflow spillway

(iii) Drawdown of the Reservoir Water Level

V Gate Operation: Fully open the bypass tunnel gate

VI Water Level: EL.756.37 ~ 756.63 m → EL.749.54 ~ 751.57 m

VII Required Time: 4.0 ~ 4.8 hour (The time of full drawdown may be changeable due to the river flow from the Kunhar river.)

VIII Open the gate of the bypass tunnel according to the gate operation sequence. Flushing is being started from the gate opening of the bypass tunnel gate. (Allowable maximum gate opening is 30 cm at one time. However, it is recommended to adjust the gate opening so that the water level drop rate does not exceed 10cm at 1 minute in the Reservoir.).

(iv) Flushing for the reservoir: Required time 97.6 ~ 102.3 hours with the full opening gate of the bypass tunnel

(v) Impounding until EL.765 m for 6.2 ~ 8.2 hours (By closing all gates)

(vi) Stabilizing time for 6 hours to prevent the resuspension of the sediment in the modified pool by the gate operation of bypass tunnel

Total required flushing duration for the reservoir and the modified pool is 6 days including the time for the drawdown and impounding of the reservoir and the modified pool.

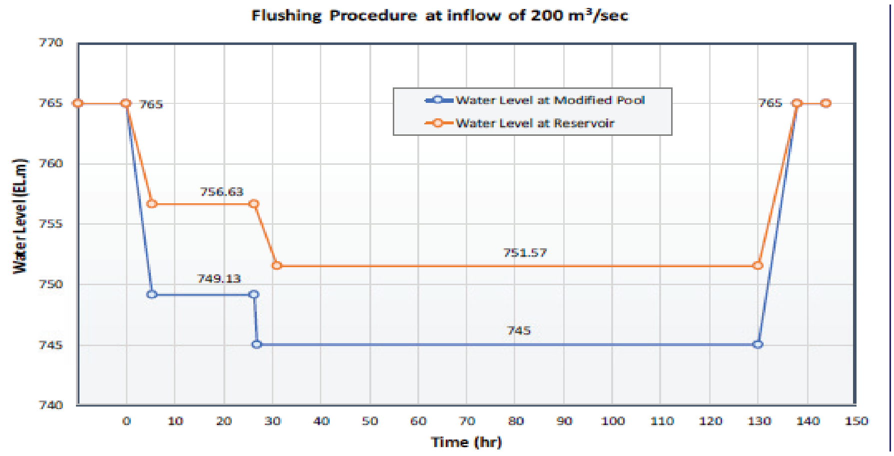

Fig 8 : Flushing procedure

Due to the variation of inflow from the Kunhar river, required time should be adjusted for the condition of inflow. However, total required flushing duration for the reservoir and modified pool need approximately 6 days according to the sedimentation study carried by HR Wallingford.

5. FLUSHING RESULTS

In accordance with the recommendations laid down in numerical and physical models of the Project, the very first flushing activity has been conducted in the month of July 23 to 30, 2019.

The results confirmed the efficiency of flushing activity was similar to the earlier studies. The storage capacity was increased by 30% as before the flushing the filled volume was 45% and after flushing the filled volume reduced to 15%.

Fig. 9 : Flushing and sampling

The flushing activity showed extremely positive results as the expected removal of sediments in physical model was approx. 10% however the actual results showed the removal of filled material approx. 30%.

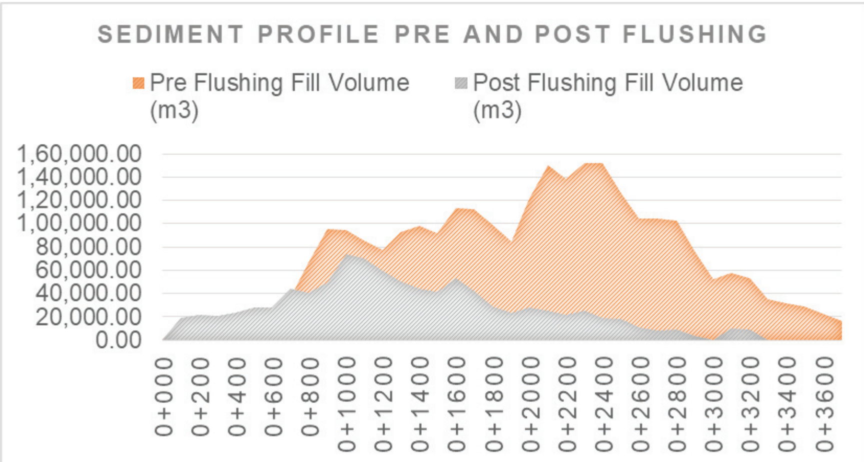

Fig. 10 : Sediment Profile- Pre and Post Flushing

Through the successful flushing activity, majority of the material has been flushed out which confirms that the changed design i.e. replacement of sandtrap with new design is a better solution for two reasons.

Trapping of the material larger than 0.2mm and keeping the reservoir storage capacity intact through effective and efficient flushing.

With the conventional sandtrap only 0.2mm material was to be restricted from entering in to the headrace tunnel however, the removal of larger particles from the reservoir remained a bigger challenge but with this new concept both the objectives are met successfully.

The comparison of bed profile at different times shows the behavior of sediment before and after the project construction and pre and post flushing time.

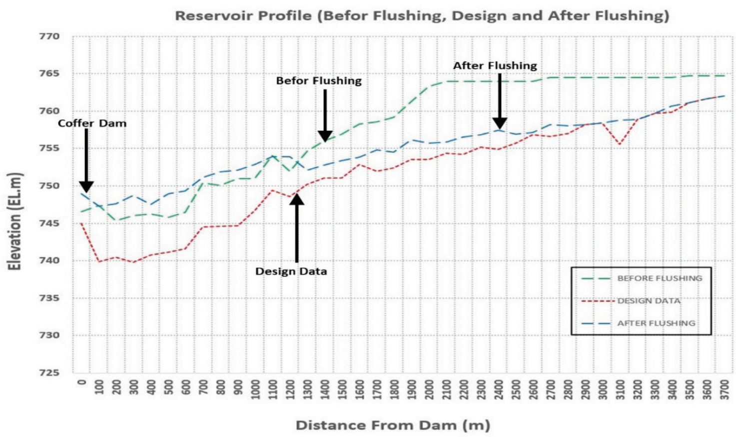

Fig. 11 : River Bed Profile- Pre and Post Flushing

From the above graph it can be seen that through flushing, the sediment has been removed from the upstream area and some of which is deposited near the coffer dam and removal of the same can be confirmed after second year flushing which means the flushing time and duration needs to be optimized for better results in the future as well.

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