APPLICATION OF A 1D NUMERICAL MODEL FOR SEDIMENT MANAGEMENT IN DASU HYDROPOWER PROJECT

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ABSTRACT

A one dimensional numerical model for the sediment study of the Dasu hydropower project (HPP), before constructing the Bhasha Diamer dam, is presented in this paper. Several formulae were used for sediment simulations under no flushing condition, maintaining reservoir water level at a full supply level (FSL) of 950 m asl. The preliminary assessment for both flushing methods, pressure flow flushing and free flow flushing was carried out. The validity of the model was checked with the Brune´s formula. The simulation result showed that without flushing, low level outlets and power intakes would be filled with the sediments between, 20-25 years. It was also observed that free low flushing, after minimum 15 years of dam commissioning, is more efficient compared to pressure flow flushing. It is recommended that without construction on any upstream reservoir, sedimentation is a severe problem for the Dasu HPP or any downstream run-of-river power plant.

Keywords: Reservoir sedimentation, sediment management, Dasu dam, HEC-RAS

1. Introduction

Sedimentation is one of the most challenging carry-over problems in hydraulic engineering (McCully, 1996). On a worldwide scale, dam reservoirs silt up at a rate of about 1% of their useful storage volume every year. With the same trend 25% of world reservoirs will be abolished in the coming 25 to 50 years (WCD, 2000). Reservoir sedimentation causes various severe problems such as (1) decrease of active volume leading to both loss of energy production and water available for water supply and irrigation; (2) decrease of the retention volume in case of flood events; (3) endangerment of operating safety due to blockage of the outlet structures; and (4) increased turbine abrasion due to increasing specific suspended load concentration (Sumi *et al*., 2009). Similarly, Tarbela and Mangla reservoirs in Pakistan, are losing their storage capacities at the rate of 0.132 bm^3/yr and 0.038 bm^3/yr, respectively (Haq and Abbas, 2007). Same may happen with the Dasu hydroelectric power project (Pakistan) which has reservoir life of only 30 years, without flushing, due to sedimentation, along with 40% reduction in power generation due to ingress of sediments into the power inlets (DHC, 2013). Warsak dam (Pakistan) also silted up just after thirty years of operation (Sabir *et al*., 2013). It is not possible to completely overcome the sedimentation problem but it can be reduced by flushing the reservoir regularly (Olsen, 1999). Venting of turbidity currents, efficiency also very much influenced by timing of gate opening and there arrangement in the dam body (Morris and Fan 1997).

The sedimentation problem is more sever for Pakistan. The country is losing its existing storage capacities of the reservoirs due to sedimentation. This problem is affecting not only the water availability for agriculture but also the power generation in which it already faces crisis. The aim of this paper is to simulate the sedimentation patterns in the reservoir Dasu (1) without flushing, (2) under pressure flow flushing and free flow flushing, and (3) impact of sedimentation on downstream (d/s) run-of-river hydropower projects without any upstream (u/s) reservoir.

2. Site description

The Dasu Hydropower Project is located in the Indus River Basin, about 350 km north from the capital Islamabad, Pakistan. The proposed damsite is also 74 km downstream of the Diamer Bhasha damsite and 241 km upstream of the Tarbela dam, along the same river. The elevation at the damsite is 764 m asl. There are several tributaries between the Bhasha dam and the Dasu HHP and of these, the prominent ones are the Daral River, Tangir River and Kandia River. These tributaries generally bring snowmelt flow to the Indus River with some fine to coarse sand. The catchment of the Indus River at the damsite is 158,800 km^2. The mean annual runoff at the damsite is 2,116 m^3/s and the lowest flow is 291 m^3/s. Total annual flows at Dasu is 66.7 bm^3 and 90% of these flows come from melting of snow and glaciers. Hence nearly 80% of flows occur in summer months of June to September while October to May is known as the low flow season. Gross storage capacity of reservoir at elevation of 950 m asl is about 1.41 bm^3 and operational storage capacity is 0.82 bm^3.

3. Methodology

3.1. HEC-RAS program system

The Hydrologic Engineering Centre-River Analysis System (HEC-RAS) is a one-dimensional software, which is designed to perform steady flow water surface profile computations through natural rivers and full networks of natural and engineered channels, unsteady flow simulations, movable boundary sediment transport computations, and water quality analysis. A key element is that all these components will use a common geometric data representation and hydraulic computation routines. Sediment transport simulations are based on the calculations of one-dimensional movable material from the river bed causing scour or deposition over a certain modeling period of time. Generally, sediment transport through rivers, streams and channels occurs through two modes which depend on parameters such as the particle size, water velocity, and bed slope. The two modes are known as bed load and suspended load. The basic principle of evaluating sediment transport capacity within HEC-RAS is by computing sediment capacity associated with each cross section as a control volume and for all grain sizes in that particular case. For making such calculations, HEC-RAS requires boundary conditions for each type of data. These boundary conditions are required to obtain the solution to the set of differential equations describing the problem over the domain of interest. In HEC-RAS, there are several boundary conditions available for steady flow and sediments analysis computations. Boundary conditions can be either external specified at the ends of the network system (upstream or downstream) or internal used for connections to junctions. The background to the computational methods and equations used for modeling sediment transport can be found in Brunner & HEC (2010).

3.2. Model setup

Based on observed data, a rating curve of suspended sediment load per day Q_s (tons/day) was developed (Eqs.1 & 2), and used as the upper boundary condition of the Dasu reservoir.

$$Q_s=4.99\times10^{-14}Q^4, \text{ for } Q<448m^3/s \tag{1}$$

$$Q_s=7.61\times10^{-8}Q^{2.52}, \text{ for } Q>448m^3/s \tag{2}$$

Where Q_s = suspended sediment load with respect to flow discharge Q. Furthermore, bed load was also added as 10% of the suspended load. The sampling for the river bed material within the Dasu reservoir was carried out (Table 1) and used as initial grain size distribution in the model.
Daily inflow discharge over 47 years from 1962 to 2008 were given as upper boundary conditions and reservoir water levels (RWL) as downstream boundary conditions on daily basis. For the sediment simulation and management study in the Tarbela dam in 1998, the Ackers-White transport formula has been intensively adopted in view of much sand fraction than finer materials. Wallingford (2012) also suggested the use of the Ackers-White formula, for total load transport capacity of sand-sized fraction is appropriate tool. Hence, in the present study this formula is used again.

In general pressurized and free flow flushing are used for venting of sediments from the dam. Hydraulic features of pressure flushing includes (i) less velocity in reservoir and less tractive force along the river bed due to high water depth (ii) development of scour cone around inlet of the Low Level Outlet (LLO) due to rapid flow towards LLO inlet in radial direction and (iii) higher trapped sediment in the reservoir due to less flushing efficiency. Reversely hydraulic features of free flow flushing includes (i) higher velocity in the reservoir and higher tractive force along river bed due to shallow water depth and (ii) less trapped sediment in the reservoir due to high flushing efficiency. In order to evaluate applicability of both flushing methods to the Dasu reservoir, the flushing simulation by using HEC-RAS is carried out.

Table 1: Gradation of river bed material in Indus River.

Size (mm)	3.5 km d/s of damsite (% finer)	56 km u/s of damsite at Shatial Bridge (% finer)
0.075	2.9	2.7
0.16	10.2	10.4
0.30	51.3	52.6
0.60	99.5	100
1.20	100	-

4. Results and discussions

To assess and clarify the accuracy of transport formula selected, the preliminary simulation sedimentation study was carried out by using the Ackers-White, Laursen-Copeland and Yang formulas under no flushing conditions, maintaining RWL at a FSL of 950 m asl. Up-to 17 years, there was not much difference in the results of both formulas, such as reduction of storage volume, annual sediment inflow and outflow, trapped efficiency and accumulated sediment volume in the reservoir. However, after 17 years the accumulated sediment volumes by the Laursen-Copeland formula and the Yang formula showed the higher amounts than Ackers-White due to change of profile delta. It was also justified that the Ackers-White formula gives safer results than that of the Laursen-Copeland and Yang's formulas. Table 3 shows the calculated results of annual sediment inflow, outflow and trapped sediment in the reservoir during no flushing. It was observed that the trapped sediment volume using the HEC-RAS model (58% of sediment inflow) was well coincided with the trap efficiency obtained by Brune's curve (61%).

In order to grasp sedimentation in the reservoir for certain operation period, the scour and deposition were analyzed using computer simulation basis that the reservoir water level was maintained at a FSL of 950 m asl. without flushing operation. The results suggested the following points (Figure 1): (1) From the longitudinal profiles of sedimentation delta in each 5-year interval, it was expected that the inlets for LLOs and power intake would be filled with the sediment between 20-25 years. (2) At 15 years elapsed period after Commercial Operation Date (COD) of Phase-1, the foot of sedimentation delta was developed up to 780 m asl. at about 9 km upstream of the dam and its top was accumulated up to 910 m asl. satisfying the stable slope of 5.3 m/km shown in the guideline of the Tarbela reservoir. (3) It was likely that the sedimentation delta will rapidly approach to the dam exceeding the stable slope. This might bring the sudden collapse of delta and will result in the blockage of LLO inlet. The inlet facilities for LLO and power intake might be filled with the sediment within 25 years after commissioning of Phase-1.

Every year flushing since impounding of reservoir in the month of June at low level outlets EL. 830 m asl. and LLOs discharge capacity of 6,600 m^3/s under free flow flushing suggests the following results (Figure 2): (1) In case that the one month flushing is started immediately after the impounding, the reservoir life is extended to 40 years. (2) Drawdown flushing in the month of June will allow filling of the reservoir immediately, after termination of flushing, in the following months of high flows during the monsoon season. Rapidly filling the reservoir in the following months will also provide greater opportunity of power generation in the rest monsoon period.

The preliminary assessment for both flushing methods, pressure flow flushing and free flow flushing were checked and clarified by the tractive force and critical friction velocity based on the backwater calculation. Under the pressure flow flushing having discharges varying from 1,000 to 6,000 m^3/s, maintaining RWL at FSL. 950 m asl., whole wash loads below 0.0625 mm were mobilized and trapped in the reservoir section over 15 km u/s of dam. Part of wash loads was expected to be flushed out through LLOs and turbine under pressure flow. The velocity in the reservoir was ranged from 0.02 to 0.14 m/s near the damsite. Under the free flow flushing having discharges of 6,000 m^3/s, and RWL at 853.92 m asl., the suspended loads with 0.2 to 0.6 mm were mobilized and trapped in the reservoir section over 15 km u/s of dam. Particles below 0.2 mm were flushed out through LLOs during flushing operations under the free flow. The velocity in the reservoir was ranged from 0.39 to 0.44 m/s near the damsite.

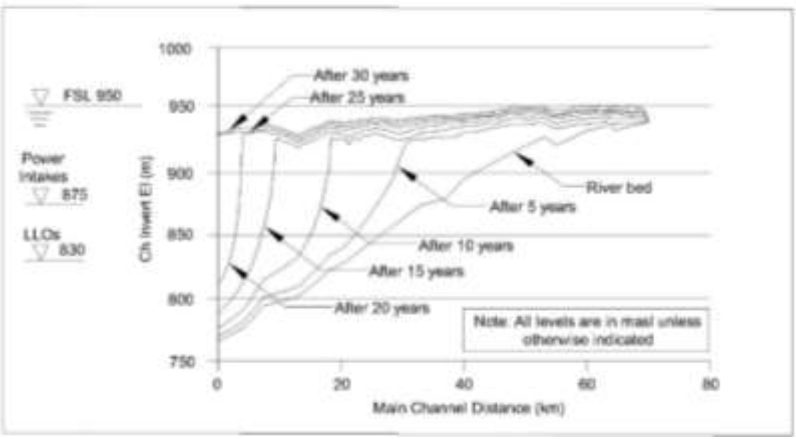

Figure 1: Sediment profile by maintaining RWL at FWL (no flushing).

5. Conclusion

It is evident that the period of non-flushing operation for the Dasu reservoir should be limited to 15 years if it is at the status of “Pre-Bhasha”. This operation would contribute not only for the maximization of annual energy during construction phases of the Dasu project but also for the mitigation of annual sediment inflow to the Tarbela reservoir and the extension of the reservoir life for the Tarbela project. If “Post-Bhasha” is achieved, the flushing operation is not required further than 30 years since the Bhasha dam has enough storage capacity.

From the above initial flushing operation study, it is concluded that the free flow flushing is more appropriate and expected to show higher efficiency of sediment evacuation due to shallow water level near the dam. It is further concluded that an upstream reservoir is necessary for sustainable operation of run-of-river hydropower project on the Indus River in Pakistan.

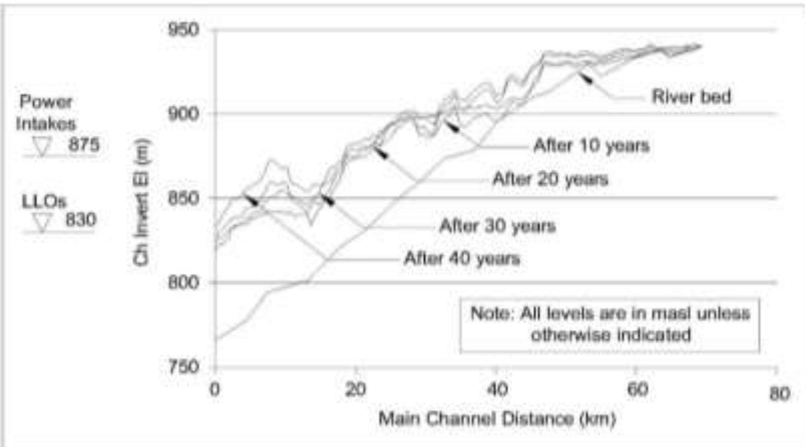

Figure 2: Sediment profile under free flow flushing.

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