# ONE-DIMENSIONAL SEDIMENT MODELLING FOR CHUZACHEN AND DEVSARI HYDROELECTRIC POWER PROJECTS TO CHECK THE FEASIBILITY OF THE RESERVOIRS' USAGE AS PSEUDO-DESANDERS

P. Machhkhand[1]

When a river enters any reservoir, the flow velocity decreases, and the sediment load begins to deposit. The deposition is more rapid at the head of the reservoir. The bed load and the coarse fraction of the suspended load are deposited immediately to form delta deposits, while finer sediment particles with lower settling velocities are transported further into the reservoir. The proportion of the total sediment yield that is deposited in the reservoir depends on a number of factors, of which the reservoir capacity, the concentrations, and the inflow magnitude are vital. In hydroelectric projects, if where and how much sediment will be deposited in a reservoir is primarily assessed, the requirement of desander for any such project can be scientifically justified. The decision on requirement of desander, merely, based on which and how many particles of a certain diameter of the suspended load will enter into the water conveyance system, and will affect the maintenance cost of the turbine runners may lead to addition of project cost.

With the one-dimensional sediment modelling approach, the case studies of reservoirs, viz., Rangpo, Rongli, and Devsari have been modelled. The Rangpo and the Rongli Reservoir together constitute to form Chuzachen Hydroelectric Project, whereas the Devsari Reservoir forms Devsari Hydroelectric Project. The hydrological years for the corresponding projects have been established to analyze the mean flow representation of each project by volumetric balance. The relation between the observed concentration and inflow inputs has been derived. The hydraulic modelling software SHARC-DOSSBAS has been used to simulate the models with various scenarios. Discussions on the simulated results of the said models have been advocated to conclude the usage of reservoirs for sediment settlement instead of desanders.

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1 Senior Manager, Hydropower and Water Resources, Lahmeyer International (India) Pvt Ltd, Gurgaon 122002, India, Email: pradyumna19@gmail.com (Member, IAHR).

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**Abstract:** When a river enters any reservoir, the flow velocity decreases, and the sediment load begins to deposit. The deposition is more rapid at the head of the reservoir. The bed load and the coarse fraction of the suspended load are deposited immediately to form delta deposits, while finer sediment particles with lower settling velocities are transported further into the reservoir. The proportion of the total sediment yield that is deposited in the reservoir depends on a number of factors, of which the reservoir capacity, the concentrations, and the inflow magnitude are vital. In hydroelectric projects (HEPs), if where and how much sediment will be deposited in a reservoir is primarily assessed, the requirement of desander for any such project can be scientifically justified. The decision on requirement of desander, merely, based on which and how many particles of a certain diameter of the suspended load will enter into the water conveyance system, and will affect the maintenance cost of the turbine runners may lead to addition of project cost.

With the one-dimensional sediment modelling approach, the case studies of reservoirs, viz., Rangpo, Rongli, and Devsari have been modelled. The Rangpo and the Rongli Reservoir together constitute to form Chuzachen HEP, whereas the Devsari Reservoir forms Devsari HEP. The hydrological years for the corresponding projects have been established to analyze the mean flow representation of each project by volumetric balance. The relation between the observed concentration and inflow inputs has been derived. The hydraulic modelling software SHARC-DOSSBAS has been used to simulate the models with various scenarios. Discussions on the simulated results of the said models have been advocated to conclude the usage of reservoirs for sediment settlement instead of desanders.

**Keywords**: HEPs; concentrations; Chuzachen; Devsari; SHARC-DOSSBAS

## INTRODUCTION

In HEPs, it is quite possible to observe that the feasibility of reservoir to withstand the sediment depositions is secondarily assessed. It is customary to propose desanders in such projects; though they are not required in many cases. The primary function of a desander is to trap the incoming concentrations of sediments; and so do the reservoirs, thereby protecting the turbine runners from particle intrusions, and maintaining the smooth functioning of water conductor system. However, whether the desanders are essentially required or not could be assessed by a deep prognosis of

1 Senior Manager, Hydropower and Water Resources, Lahmeyer International (India) Pvt Ltd, Gurgaon 122002, India, Email: pmachhkhand@lahmeyer.in; pradyumna19@gmail.com (Member, IAHR).

the subject. In this paper, the endeavour has been to strengthen scientific support to the utility of dam/barrage reservoirs for sediment management procedures in HEPs. Examples of work dealing with sediment modelling in reservoirs of hydropower projects have been showcased to stimulate the cognition of potential usage of the reservoirs for sediment management to improve the sustainability of the projects.

Models have been developed representing the reservoirs of Devsari HEP and Chuzachen HEP. As the methodologies adopted for Rangpo and Rongli are similar, only the sediment modelling of Rangpo Resevoir as a part of Chuzachen HEP has been presented in this paper. However, the pre-processing of input parameters has been discussed for all the three cases. Hydrological inferences have been drawn to understand the flow and the sediment pattern in the catchments followed by optimization of sediment yields. The phenomenon of sediment deposition and sediment flushing has been illustrated, thereby indicating possible sediment processes, which hold significant stand on whether the reservoirs would withstand the sediment deposition with due cycle of flushing.

The contents of this paper are purely scientific and it is based on hydraulic modeling studies carried out by the author during various stages of the projects. Therefore, the basic information of the projects refers to the values adopted during project works while carrying out the studies and it, by no means, challenges the current state or changed data of the projects. The aim of this paper is to project the methodologies that led to conclude the efficient usage of reservoirs for sediment management works.

**Background Information**

Devsari HEP is located on Pinder River in Chamoli district of Uttarakhand State of India. It consists of 35m high dam from river bed which provides the reservoir to cater the diurnal pondage required to operate the plant in peak hours. The extent of reservoir from dam is about 4.8km. The design discharge of Devsari intake is 120.76 $m^3$/sec, whereas the total storage of Devsari Reservoir is 9.026 $Mm^3$.

The Chuzachen HEP is located in the East District of Sikkim on the rivers, Rangpo and Rongli. The Rongli River is a tributary of Rangpo River, whereas the Rangpo River is a major tributary of Teesta River. The reservoirs of Rangpo Dam (48m high from foundation level) and Rongli Dam (41m high from foundation level) have storage capacities of 360400 $m^3$ and 199400 $m^3$, respectively. At lower end of the project, the head race tunnels from the intakes of these two reservoirs are linked to form a common head race tunnel of Chuzachen HEP. The design discharges of Rangpo Intake and Rongli Intake are 21.5 $m^3$/sec and 18$m^3$/sec, respectively.

**Data Availability**

- reservoirs' geometrical inputs,
- hydrological year (June to May) average flow series of Devsari, Rangpo, and Rongli HEPs,
- hydrological year(June to May) sediment concentration series in parts per million (ppm) of Devsari HEP,
- observed sediment concentration series of Rangpo and Rongli Rivers in ppm.

## RESERVOIR SEDIMENTATION 1-DIMENSIONAL MODELLING

Models can be conceptual, logical, mathematical, and physical or of other types but, in all instances, they are an abstraction or simplification of a prototype system. In reservoir sedimentation, empirical methods by (Hazen, 1904), (Vetter, 1940) and (Camp, 1946) have been of use for determining the sediment trap efficiency. However, these methods cover only the settling phase of a reservoir operation and are limited in their applicability. The major factors which are not included in the empirical methods are:

- the sediment transporting capacity of flow in a settling reach,
- the change in conditions as reservoir fills with sediment,
- the effect of variation in flow depth down a basin or reservoir,
- and the additional turbulence caused by inlet condition to a basin or reservoir.

Therefore, it is very important to model the reservoir behaviour with at least a one-dimensional numerical model, which not only simulates the deposition of sediment in a reservoir but also simulates the sluicing of sediments. The turbulence in the reservoir initiates at the entry, thereby topset and foreset depositions. The effect of turbulence in sediment movement and mass deposition can be modelled by applying one-dimensional models. They have significant advantage over others as they do not require grids to approximate cross-sections, and they require relatively less field data to set up. On the other hand, the two- and three- dimensional models offer a detailed view of the hydrodynamics of reservoir system, but at the cost of a longer computational time and substantial amount of field data to capture complexities of two- or three-dimensional flow. In this study, the availability and accessibility of data has been found to be limited and therefore, suitably, one-dimensional approach has been attempted.

### Model Description (Atkinson, 1992)

In the presented case studies, the sedimentation modelling has been carried out using the DOSSBAS (Design of Sluiced Settling Basins) tool of the SHARC software developed by HR Wallingford. SHARC is a suite of integrated programs designed to assist in the identification and solution of sediment problems at intakes in rivers and canal systems. DOSSBAS is designed to model sediment deposition basins and has the capability of modelling regular and non-regular basins. DOSSBAS comprises two suites of models namely, Deposition Model and Sluicing Model.

*Deposition model*

In the deposition model, the sediment quantities passing through the reservoirs are predicted. It also predicts the deposition pattern of the sediment. The deposition model is primarily used to model the sediment deposition in settling basin or reservoir which is; typically a canal with enlarged cross-sections causing the flow velocity to be reduced, and so sediment is deposited.

In the presented cases, the basin concept is altered with reservoir by approximating the geometry of the cross-sections at intake and at upstream adjusting the side slope, thereby making the reservoir hydraulically equivalent to the basin. In this text, any term basin is referred as reservoir. The deposition model splits the reservoir into short sub-reaches and the filling period into short time steps; within each time steps steady conditions are assumed. The discharge and bed levels at the start of the time step are used for backwater calculation to obtain the water levels in the basin from a known water level at the downstream end for each individual time. The turbulence in the model is generated by three sources: the gradually expanding flow in a reservoir, friction at bed and inlet conditions.

The sand entering the reservoir is split into 10 equal size fractions; the concentrations of each fraction are then traced down the basin or reservoir. Concentrations are calculated at 10 heights above the bed at each section in the reservoir. Within a sub-reach, the concentration change between one section and the next downstream section is computed from a turbulent diffusion equation, which is derived from the basic equation of turbulence on sediment concentrations (Dobbins, 1944) given by,

$$u\frac{\partial C_j}{\partial x} = \in_y \frac{\partial^2 C_j}{\partial y^2} + \left(V_{sj} + \frac{\partial \in_y}{\partial y}\right)\frac{\partial C_j}{\partial y} + \in_x \frac{\partial^2 C_j}{\partial x^2} \qquad (1)$$

where, $u$ = flow velocity at height y above the bed (m/sec),
$y$ = height above bed (m),
$C_j$ = sediment concentration at height ($y$) above bed for size fraction( $j$),
$x$ = distance co-ordinate along channel (m),
$\in_y$ = sediment diffusion coefficient in $y$-direction ($m^2$/sec) ,
$\in_x$ = sediment diffusion coefficient in $x$-direction ($m^2$/sec), and
$V_{sj}$ = settling velocity (formula by Gibbs et al, 1971) of sediment for the sediment size fraction ($j$) (m/sec).

The basic assumptions in deriving the Equation (1) are:

- the flow is steady,
- the velocities and concentrations are constant across the width of the channel,
- and the concentrations in one size fraction do not affect other size fractions.

By further assuming that the diffusion in $x$-direction is insignificant (Dobbins, 1944) and the diffusion co-effcient $\in_y$ is equal to the eddy diffusivity, $\in_s$, which is expressed as,

$$\in_s = \frac{hu_*}{15} + v_{ti} e^{-x/x_a} + v_{te} \qquad (2)$$

the simplified form of Equation (1) is given by,

$$u\frac{\partial C_j}{\partial x} = \in_s \frac{\partial^2 C_j}{\partial y^2} + V_{sj}\frac{\partial C_j}{\partial y} \qquad (3)$$

where $h$ = depth of flow (m),
$u_*$ = shear velocity (m/sec),
$x$ = distance from inlet,
$x_a$ = adaption length,

$\nu_{ti}$ =initial extra turbulence at the distance *x*, and

$\nu_{te}$ = kinematic turbulent viscosity.

The input to the computation includes turbulent viscosity, settling velocity and the concentration at the bed. The sediment concentration at bed is itself calculated, for each size fraction from the grain size, the proportion of the bed material which consists of that fraction and the hydraulic conditions in that sub-reach of the basin or reservoir.

With the known concentrations and transport rates, the rate of sediment deposition in each sub-reach of the basin can be calculated using the concept of continuity. The proportions of each fraction within the total rate of sediment deposition are used to derive the size grading of the depositing material in each sub-reach. The bed level rise at each sub-reach is due to the total rate of deposition the density of settled sediment. The new bed levels are then induced as an input to the subsequent time step. At each time step the concentrations of each fraction leaving the reservoir are used to determine both the total concentration leaving the basin and its size grading.

*Sluicing model*

The predictions of the sediment deposition model are input to the sluicing model. The sluicing model requires the initial bed levels, sediment sizes and densities to predict the flushing performance. This information is stored by the deposition model as the simulations proceeds except the silt sizes. Only sand sizes are stored because the sluicing model simulates only sand movements. It is assumed that any silt in the exposed bed material is sluiced instantly and so only the sand transport controls the sluicing rates.

The sluicing model has the same structure as that of deposition model. The basin or reservoir is split into sub-reaches and time into time steps. For each time step the water levels, and hence the velocities and friction slopes are calculated. The sediment transport capacity is also estimated from the above in each sub-reach of the basin. Sand concentrations can then be traced down a basin from low concentrations entering the basin to high concentrations at the outlet. Changes in concentration from one sub-reach to the next are used to compute change in bed level for the time step, then the subsequent time step follow up. The cycle is continued until the reservoir is empty. As the diffusion is not a dominant process in sluicing, the sluicing is modelled using the equation,

$$X_{out} = X_T - (X_T - X_{in})e^{-x/x_a} \tag{4}$$

where $X_{in}$ =concentration entering the reach,

$X_{out}$ =sand concentration leaving a sub-reach, and

$X_T$ = transporting capacity.

The elapsed time is the time to flush during flushing operation in reservoir sedimentation modelling.

## MODELLING SCHEME

With known objectives, the procedures to be followed while modelling the sediments can be schematically aligned and framed based on the input and output details of the model. The input to the models are inferences drawn from the pre-processing of available discharge and sediment concentration data, which also includes the optimization of these data based on annual sediment yield. However, the outputs are generated twice; one for deposition model and the other for sluicing model. As a preliminary understanding, a modelling scheme has been developed, which is valid for all the said case studies. The scheme has been displayed below:

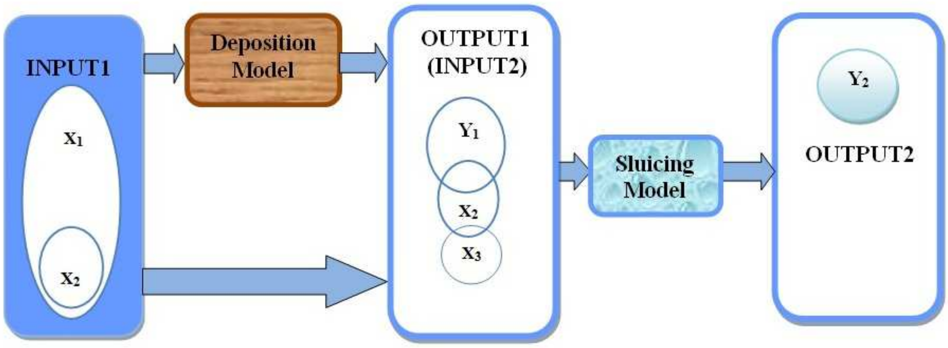


**Fig. 1. Modelling scheme of reservoir sediment management plan**

In Fig.1, $\mathbf{X_1}$ is the set of input parameters, viz., reservoir geometry, Manning's roughness, sand and silt concentrations, specific gravity values for sand and for silt, settled densities for sand and for silt, temperature, discharge, run time, the particle size distributions, the settling velocities, and the downstream water level. $\mathbf{X_2}$ is the set of parameters that includes the temperature, and the sand concentrations to be applied in both deposition and sluicing model. The input parameters for deposition model can be expressed as, $(\mathbf{X_1} \cup \mathbf{X_2})$. The set $\mathbf{X_3}$ is composed of additional parameters such as, flushing/sluicing discharge, the water level at the time of sluicing, and the duration of sluicing. $\mathbf{Y_1}$ is the set of longitudinal bed profiles, which are results of deposition models. The input parameters for sluicing model can be expressed as, $(\mathbf{Y_2} \cup \mathbf{X_2} \cup \mathbf{X_3})$. The set $\mathbf{Y_2}$ comprises results of sluicing models in terms of elapsed time for flushing out the sediments and change in bed profiles at different time.

## DATA ORGANIZATION

The observed discharge and concentration data as well as the hydrological year flow series are essentially required to be processed for their utilities in the model. It is recognized that for a particular discharge and corresponding concentration, the time to run in the model is needed to be specified and therefore, it enhances the pre-processing of data.

### Pre-processing of Available Data

The following points indicate the step by step pre-processing of the available data

1. The concept applied for preparing the input data reconciles with the principle of hydrological arrangements of flow data, which is typically a 10-daily format. Therefore, in the case of Devsari HEP, the 10-daily average suspended sediment concentration values have been derived from the daily available sediment data.
2. In the case of Chuzachen HEP, only the available monsoon concentrations have been processed by interpolation and extrapolation to determine the concentrations of various discharges of Rangpo and Rongli Rivers.

3. The hydrological year mean flow duration curves have divided into three and four divisions for Devsari HEP and for Chuzachen HEP (Rangpo and Rongli Reservoirs), respectively.
4. Each division dictates the duration of model run for the mean discharge of that particular division.
5. The basis of mean discharge for each division is volumetric as indicated in the figures below:

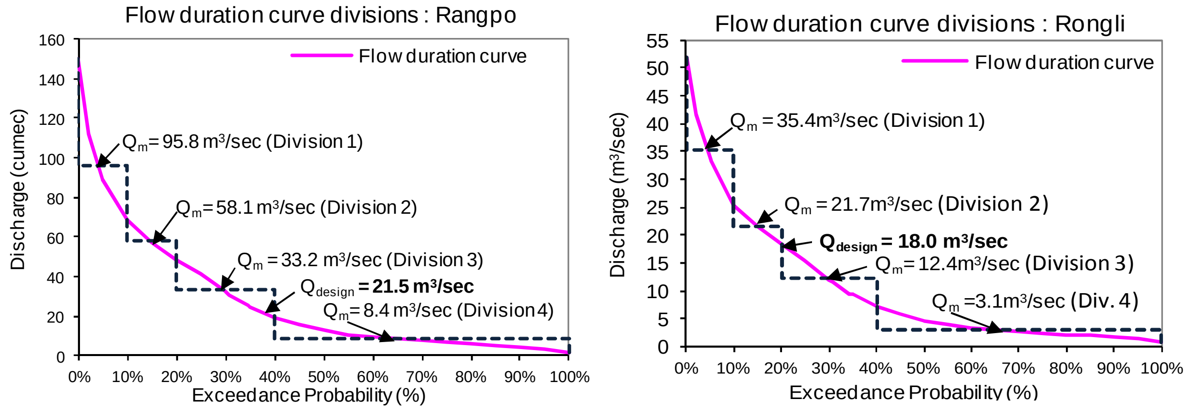


**Fig. 2. Flow duration curves of Rangpo and Rongli Reservoirs**

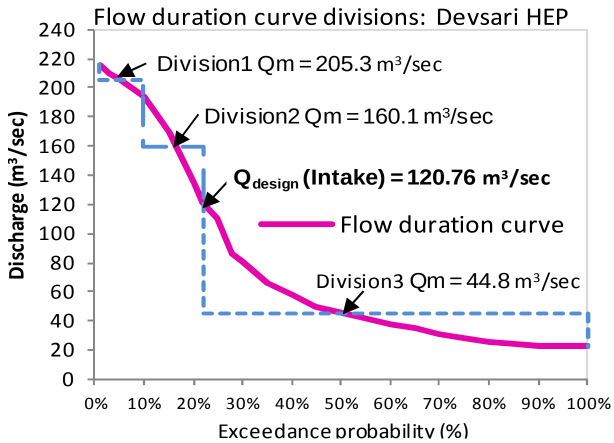


**Fig. 3. Flow duration curves of Devsari Reservoir**

The adopted duration for each division is data driven and the classification can be well observed from the flow duration curves. Therefore, it is a flexible assessment to apply suitable logic here. The average discharge and average concentration data have been computed based on the hydrological year flow duration series of Devsari, Rangpo, and Rongli Reservoirs. The same have been tabulated below:

**Table 1. Pre-processed average discharge and mean concentrations**

| Divisions | Devsari | | Rangpo | | Rongli | |
|---|---|---|---|---|---|---|
| | $Q_m$ | Mean conc. | $Q_m$ | Mean conc. | $Q_m$ | Mean conc. |
| | $m^3/s$ | *ppm* | $m^3/s$ | *ppm* | $m^3/s$ | *ppm* |
| 1 | 205.3 | 511 | 95.8 | 707 | 35.4 | 396 |
| 2 | 160.1 | 436 | 58.1 | 389 | 21.7 | 163 |
| 3 | 44.8 | 192 | 33.2 | 187 | 12.4 | 93 |
| 4 | - | - | 8.4 | 47 | 3.1 | 23 |

**Optimization of Input Parameters**

*Devsari HEP*

The mean concentration values are derived from non-linear power fit curve equation as displayed below:

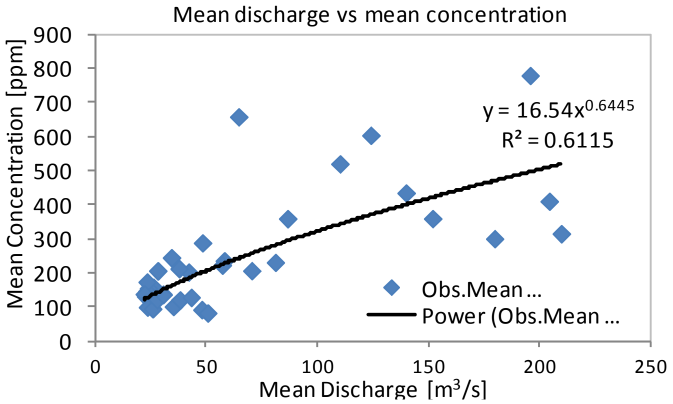


**Fig. 4. Flow duration curves of Devsari Reservoir**

However, a substantial difference between the average annual load and the previously studied average yearly mean sediment load has been observed. Since the recorded length of mean concentration data is three years, it might be one of the reasons for poor result. Therefore, it is essential to put weights against the derived concentrations and optimize them for each division so that the yearly sediment yield is nearly conserved. Mathematically, for each division, it can be expressed as,

$$C_m = \frac{1}{\alpha}\left[16.54x^{0.6445}\right] \tag{5}$$

where $C_m$ = divisional mean concentration (ppm),

$\alpha$ = weight, such that $[0 < \alpha \leq 1]$, and

$x$ = divisional mean discharge ($m^3$/sec).

The mean concentration values of each division have been optimized applying the above equation; it also suffices the average yearly sediment yield at Devsari HEP.

**Table 2. Average discharge and mean concentrations**

| Divisions | $Q_m$ | Adopted mean concentration |
|---|---|---|
| | *m³/s* | *ppm* |
| 1 | 205.3 | 665 |
| 2 | 160.1 | 566 |
| 3 | 44.8 | 249 |

The divisional discharge of the above table is input to the reservoir sedimentation one-dimensional numerical modelling.

*Chuzachen HEP*

In the case of Chuzachen HEP, due to limited accessibility of data, the obsereved concentration data has been confined to interpolation and extrapolation of data. Further, it has been observed that by adopting the values listed against Rangpo in **Table 1**, the annual sediment volume of Rangpo is about 70% the capacity of the Reservoir, and therefore, it is quite conservative to adopt the same values. In the case of Rongli, the annual sediment volume of Rongli has been estimated to be about 25% the capacity of the Rongli Reservoir.

## MODEL SET UP

In the DOSSBAS model, initially, the deposition of sediment is modelled. The input parameters in the deposition model are classified into three components; the basin geometry, flow and concentration data and sediment properties including the sizes of sediment and settling velocity. The reservoir has been modelled as wedge shaped channel with 10 cross-sections from upstream of the reservoir till intake along the river with constant side slopes equivalent to average side slopes in the reservoir.

The bed gradation curves for the Rangpo and Devsari have been applied in the models and the same have been displayed below:

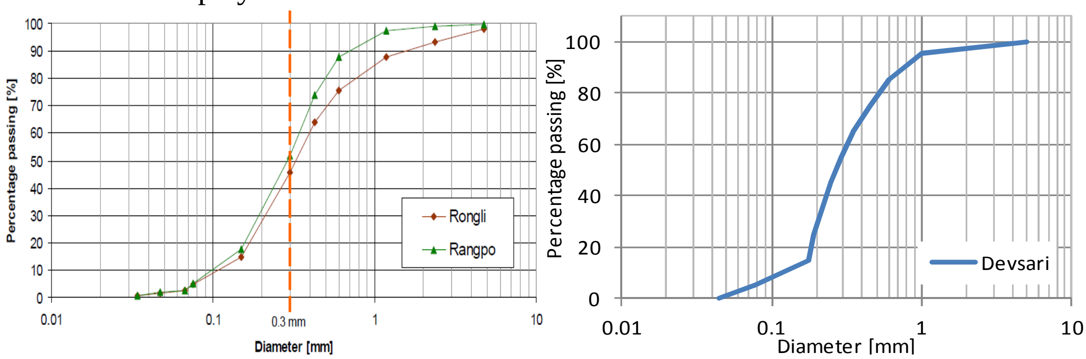


**Fig. 5. Bed gradation curves**

The minimum river bed profile has been kept constant for all the divisions assuming that after completion of each cycle of the divisions, the concentrated particles are to be flushed to regain the pseudo-original bed profile. Due to steep gradient of the river, it is prudent that the reservoir would witness the transport of large quantities of sediment. The suspended sediment can be monitored through sediment sampling techniques, whereas the variation in bedload is difficult to estimate. Hence, this is normally estimated as a fraction of suspended sediment. In the absence of any regional data, the following table indicates the ranges that can be used to estimate bedload.

**Table 3: Bedload estimation from suspended sediment concentrations for sand-bed rivers** (*USBR, 'Design of Small Dams', 3rd edition, 1987*)

| Suspended load (mg/l) | Percentage bedload in terms of measured suspended sediment load |
|---|---|
| Less than 1,000 | 25 – 150% |
| 1,000 - 7,500 | 10 – 35% |
| More than 7,500 | 5 – 15% |

The input parameters that have been used in DOSSBAS of the models for Devsari and Rangpo Reservoirs sediment modelling have been summarized in the following tables:

**Table 4. Basic input parameters for Devsari in DOSSBAS**

| Divisions | Flow | Sediment concentration | | Deposition cycle time | | Flushing discharge |
|---|---|---|---|---|---|---|
| | | Silt | Sand | | | |
| | *$m^3$/sec* | *ppm* | *ppm* | *Days* | *Hours* | *$m^3$/sec* |
| 1 | 205.3 | 465 | 199 | 37 | 876 | 205.3 |
| 2 | 160.1 | 397 | 170 | 44 | 1051 | 160.1 |
| 3 | 44.4 | 174 | 74 | 285 | 6833 | 44.4 |

**Table 5. Basic input parameters for Rangpo in DOSSBAS**

| Divisions | Flow | Sediment Concentration | | Deposition cycle time | | Flushing discharge |
|---|---|---|---|---|---|---|
| | | Silt | Sand | | | |
| | *$m^3$/sec* | *ppm* | *ppm* | *Days* | *Hours* | *$m^3$/sec* |
| 1 | 95.8 | 495 | 212 | 37 | 876 | 74.3 |
| 2 | 58.1 | 273 | 117 | 37 | 876 | 36.6 |
| 3 | 33.2 | 131 | 56 | 73 | 1752 | 11.7 |
| 4 | 8.4 | 33 | 14 | 219 | 5256 | NA |

## RESULTS AND DISCUSSIONS

The results of hydraulic modelling of sediments for both cases, Devsari HEP and Chuzachen HEP have been discussed and presented below:

**Devsari HEP**

*Devsari deposition model results*

The simulated result of sediment deposition model of Devsari Reservoir for peak season (Division1) has been displayed in the figure below; followed by the tabulated output details.

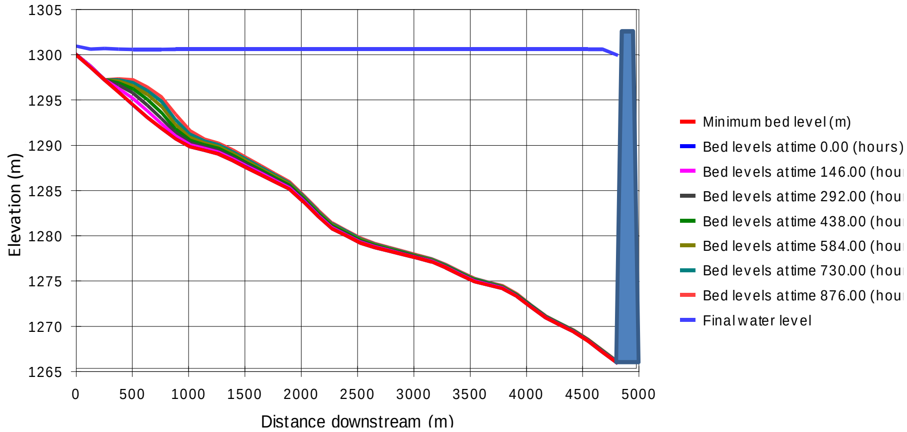


**Fig. 6. Plot of bed profiles down the Devsari Reservoir**

**Table 6. Deposition model (at the end of deposition cycle)**

| Divisions | Sediment Volume | | Outflow Sediment | | Trap Efficiency | | Reservoir Storage | |
|---|---|---|---|---|---|---|---|---|
| | Silt | Sand | Silt | Sand | Silt | Sand | Before run | After run |
| | *$Mm^3$* | *$Mm^3$* | *PPM* | *PPM* | *%* | *%* | *$Mm^3$* | *$Mm^3$* |
| 1 | 0.1 | 0.1 | 215 | 0 | 53.7 | 100.0 | 9.1 | 8.9 |
| 2 | 0.1 | 0.1 | 164 | 0 | 58.6 | 100.0 | 9.1 | 8.9 |
| 3 | 0.1 | 0.1 | 35 | 0 | 79.8 | 100.0 | 9.1 | 9.0 |

The deposition model results show the overall increase in bed level. This bed level rise is due to the total rate of deposition as well as the density of settled sediment. The sand sized sediment takes the lowest level where as, the silt is exposed over the bed when the deposition cycle is completed.

The sediment particles whether to be in suspension or not, after deposition cycle, relate to silt only because the sand trap efficiency of the reservoir is about 100% throughout the average hydrological year. Therefore, any sediment that is likely to escape into the water conductor system is, predominately, silt. The threshold for distinction between silt and sand in the model is 63 microns, where the grains with size lesser than the threshold are silt or else sand. The sediment modeling results also illustrate the sediment outflow in terms of sand and silt concentrations, which are likely to enter the intake. In all the divisions, the outflow sediment values are quite significant primarily with silt, whereas the sand concentration values are negligible. The decrease in storage is temporary till the flushing cycle is on.

*Devsari sluicing model results*

The simulated result of sediment sluicing model of Devsari Reservoir has been displayed for peak season (Division1) in the figure below; followed by the tabulated output details. The design discharge adopted for diversion works is 21.5m$^3$/sec and the discharge available for the flushing/sluicing is determined from the inflow and the flow diverted.

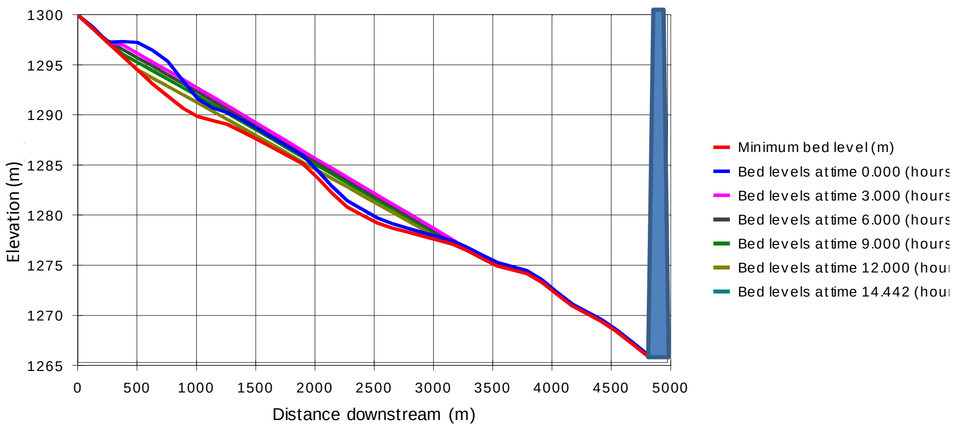


**Fig. 7. Plot of Devsari sluicing model output**

**Table 7. Sluicing model (at the end of flushing cycle)**

| **Divisions** | **Volume removed** | | | **Elapsed time for flushing** |
|---|---|---|---|---|
| | **Silt** | **Sand** | **Total sediment** | |
| | *Mm³* | *Mm³* | *Mm³* | *Hours* |
| 1 | 0.1 | 0.1 | 0.2 | 14.44 |
| 2 | 0.1 | 0.1 | 0.2 | 28.59 |
| 3 | NA | | | |

The elapsed time for flushing is 14.44 hours during the peak seasons to regain the actual profile of the reservoir.

**Rangpo Reservoir (Chuzachen HEP)**

*Rangpo deposition model results*

The simulated result of sediment deposition model of Devsari Reservoir has been displayed for peak season (Division1) in the figure below; followed by the tabulated output details.

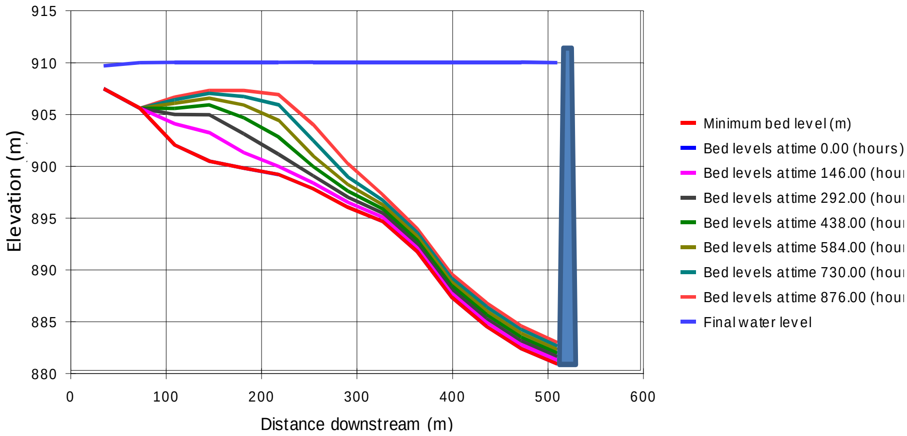


**Fig. 8. Plot of bed profiles down the Rangpo Reservoir**

**Table 8. Deposition model (at the end of deposition cycle)**

| Divisions | Sediment Volume | | Outflow Sediment | | Trap Efficiency | | Reservoir Storage | |
|---|---|---|---|---|---|---|---|---|
| | Silt | Sand | Silt | Sand | Silt | Sand | Before run | After run |
| | *Mm³* | *Mm³* | *PPM* | *PPM* | *%* | *%* | *Mm³* | *Mm³* |
| 1 | 0.013 | 0.045 | 350.0 | 5.0 | 12.6 | 97.5 | 0.36 | 0.31 |
| 2 | 0.009 | 0.015 | 217.0 | 1.0 | 20.4 | 99.3 | 0.36 | 0.34 |
| 3 | 0.007 | 0.008 | 89.0 | 0.0 | 31.7 | 100.0 | 0.36 | 0.35 |
| 4 | 0.003 | 0.002 | 14.0 | 0.0 | 58.8 | 100.0 | 0.36 | 0.36 |

The deposition volume with respect to the storage of the reservoir is higher in this case. However, the sand trap efficiency of the Rangpo Reservoir ranges from 97.5 to 100% throughout the average hydrological year, which indicates that the reservoir can be utilized for better planning of sediment flushing.

*Rangpo sluicing model results*

The simulated result of sediment sluicing model of Rangpo Reservoir has been displayed for peak season (Division1) in the figure below; followed by the tabulated output details.

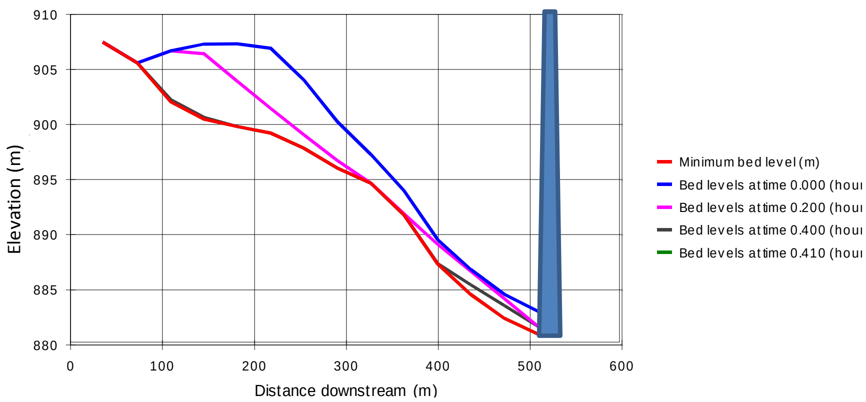


**Fig. 9. Plot of Rangpo sluicing model output**

**Table 9. Sluicing model (at the end of flushing cycle)**

| Divisions | Volume removed | | | Elapsed time for flushing |
|---|---|---|---|---|
| | **Silt** | **Sand** | **Total sediment** | |
| | *Mm*$^3$ | *Mm*$^3$ | *Mm*$^3$ | *Hours* |
| 1 | 0.014 | 0.043 | 0.06 | 0.41 |
| 2 | 0.009 | 0.015 | 0.02 | 0.35 |
| 3 | 0.005 | 0.008 | 0.01 | 0.79 |
| 4 | NA | | | |

The live storage of the reservoir is 0.36Mm$^3$. The flushing discharge that has been used in sluicing model has been derived from the adopted mean inflow for each division and the flow diverted towards intake. The simulation of model illustrates that with a deposition cycle of 876 hours in the peak season, the storage of the reservoir gets reduced by 14%, temporarily till flushing. The elapsed time for flushing is 0.41 hour during the peak seasons to restore the reservoir original capacity.

The results of the model studies in terms of adequacy of the reservoir have been validated by evaluating the flow through velocity and the required lengths of both the reservoirs as illustrated below:

**Table 10. Velocities and required lengths of Devsari and Rangpo Reservoirs**

| | **Devsari** | **Rangpo** | Units |
|---|---|---|---|
| Full reservoir level (FRL) = | 1300 | 910 | MASL |
| Minimum drawdown level(MDDL) = | 1295 | 893 | MASL |
| Division1 average discharge (Qa) = | 205 | 90 | m$^3$/sec |
| The approximate average area of flow (A) = | 4700 | 1978 | m$^2$ |
| The corresponding flow through velocity (V) = Qa/A = | 0.044 | 0.046 | m/sec |
| Mean flow through velocity for 0.2mm particle to settle down, v' = | 0.2 | 0.2 | m/sec |
| Settling velocity of 0.2mm particle, w = | 0.022 | 0.022 | m/sec |
| Length of reservoir required to settle 0.2mm particle, L*= v'/w x ( FRL-MDDL) = | 45.5 | 154.5 | m |
| Mid-Length from dam axis of reservoir, L = | 2500 | 254 | m |

From the above analysis, it can be inferred that average flow through velocities in the Devsari Reservoir (V = 0.044 m/sec) and in the Rangpo Reservoir (v = 0.046 m/sec) are less than the mean flow through velocity (v'= 0.2 m/sec) for 0.2 mm particle. Also, the required lengths of the reservoirs are quite less than the considered length of the reservoirs. Therefore, it may be substantiated that the lengths of the reservoirs from the dam axis to the middle of the reservoir extents are adequate enough for 0.2 mm particles to get settled in the reservoir.

## CONCLUSIONS

From the presented results of the 1-dimensional numerical modeling, following may be concluded:

i. It can be safely inferred from the model results that the sediment grain size of 0.2mm and greater than 0.2mm shall be settling down in the reservoirs.
ii. If periodical flushing operations are realized during the whole life of the reservoir, the entrance sill of the intake will not be affected by the deposited sediments; as it is already being witnessed in the model studies.

The aforesaid points are not only the indicators of the case studies' results, but also they indicate the capability of 1-dimensional numerical modelling of reservoir sediment, which helps in decision making process while proposing sediment management plans in HEPs. However, the model studies have potential scopes to enhance the analysis; the sensitivity analysis of the models is one of them. Further, the optimization of bed gradation may be studied from many samples of the reservoirs, and then be applied to the models.

It would be in the interest of HEPs, if the utility of the desanders decelerates before placing the them in the planning stages, thereby encouraging physically-based hydraulic modelling study of the sediments in the interim to assess whether the reservoirs are self-sufficient for managing the sediment processes or not. The case studies of this paper offer supporting results to the usage of reservoirs for sediment management, but since the rapidification of desanders are commonly observed in HEPs; despite the reservoirs being gigantic in size, the term "pseudo-desanders", used in the title of the paper, for reservoirs reasonably suits the context.

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