Sediment Management Practices in NHPC's Power Stations

Balraj Joshi, Keshav Deshmukh, Rajeev Baboota, Rajeev Sachdeva and Manjusha Mishra
NHPC Limited, a Government of India Undertaking

ABSTRACT:

The problem of sedimentation is extremely serious for the dams positioned on Himalayan Rivers as they carry huge sediment load. More than 80% of annual sediment inflow comes during the monsoon. Efficient sediment management is therefore required in monsoon season to protect the economic life of the reservoirs. NHPC Limited, a Government of India Enterprise in India is maintaining 20 power stations in Himalayan region and has been successful in maintaining gross/live capacity of reservoirs of these power stations satisfactorily by adopting different site/project specific techniques of sediment management.

Drawdown flushing in small reservoirs along-with sluicing in large/medium size reservoirs, are most adopted techniques in NHPC for sediment management in reservoir. Desilting basins/chambers have been provided in most of the power stations to allow settlement and removal of significant portion of the coarse sediment entering into the intake, thereby reducing the impact of big size sediments into turbine and other parts. Silt excluders/silt ejectors have also been provided in some of the projects of NHPC. Site specific reservoir operation and flushing guidelines, prepared for every power station, have been proven to be very helpful in preserving the reservoir capacity and ensuring smooth running of power plant.

1 INTRODUCTION

It is a well know fact that sedimentation poses a significant threat to the long life, efficacy, and sustainable operations of both storage and run-off the river projects as enumerated below;

- Loss of storage capacity : It has a serious impact on water resources development by reducing water supply, hydropower production, the supply of irrigation water, and the effectiveness of flood control schemes.
- Growth of the delta deposits at the upstream end of the reservoir cause increased flooding in the backwater upstream.
- Abrasion of turbines, spillway and other dam/WCS components, decrease in efficiency of a turbine and can require expensive repairs.
- Apart from loss in energy generation, the shutdown of hydropower stations to avoid operating under such conditions leads to loss of peaking availability.
- Sedimentation at or near the dam face may tend to block the outlets causing difficulties in operation of the gates.

It is predicted that there shall be around 50% loss in the existing reservoir storage by year 2050 and almost all the storage shall be lost in 200-300 years. Concern over the long term viability and sustainable use of reservoirs has led to worldwide efforts to evaluate and develop techniques to minimize the impacts of reservoir sedimentation on the life of reservoir as also on the life of water conductor system and turbines. The World Bank in its RESCON (Reservoir Conservation) approach, call for adoption of "life cycle management" approach for designing dam. The RESCON approach is based on the following two messages:

- Whereas the last century was concerned with reservoir development, the 21st century will need to focus on sediment management; the objective will be to convert today's inventory of non-sustainable reservoirs into sustainable infrastructures for future generations.
- The scientific community at large should work to create solutions for conserving existing water storage facilities in order to enable their functions to be delivered for as long as possible, possibly in perpetuity.

2 RESERVOIR SEDIMENTATION PROBLEM IN NHPC'S RESERVOIRS

NHPC Limited (formerly known as National Hydroelectric Power Corporation) was incorporated on 7th November 1975 as a Schedule 'A' Enterprise of Government of India for development of Hydro Power in Central Sector. The company is mandated to plan, promote and organize an integrated and efficient development of power in all aspects through conventional and non- conventional sources in India and abroad. With an authorized share capital of 2.1 Billion USD, NHPC is a premier organization in India for development of hydro power. Along the journey of over 45 years, NHPC's total installed capacity has reached to 7071 MW from 24 projects including joint ventures (JV), Solar and Wind. Major power stations of NHPC are shown in **Figure-1**.

Figure-1 Location of Power Stations and Construction Projects of NHPC

As can be seen from **Figure-1**, most of the power stations of NHPC having small and medium size of reservoirs are located in Himalayas. The problem of sedimentation is serious for these hydropower plants as Himalayan Rivers carry huge sediment both as bed load and suspended load during monsoon. More than 80% of average annual sediment comes during the monsoon season. Efficient sediment management system is needed in monsoon season to protect the economic and useful life of the reservoirs. These techniques are required to be customized for different projects depending on their reservoir size, valley shapes as well as their unique design features. The present papers aims at showing the reservoir sediment management practices being adopted by NHPC in its existing power stations.

3 ASSESSMENT OF SEDIMENT LOAD INTO THE RESERVOIR BY NHPC

Estimates of the amount of sediment transported by rivers are important for evaluating the impacts of reservoir sedimentation and its management. The amount of sediment entering into the reservoir upto project site is broadly estimated on basis of:

- Sediment Observation at Project Location:
  It involves concurrent measurement of discharge and suspended sediment concentration. In NHPC's power stations, it is a regular practice to observe suspended sediment near dam/intake, upstream of reservoirs, TRT outlets, SFT outlet and other important locations on daily basis. Fractional distribution of sediment (coarse, medium & fine) is measured at important locations. Frequency of sampling is more during monsoon.

- Bathymetric Survey of Reservoir:
  Bathymetric surveys of the reservoir are carried out at regular intervals. Comparison of the bathymetry thus developed with respect to the original survey of the reservoir allows the volume of sediment that has been deposited over a certain period to be quantified. Bathymetric survey is carried-out annually (post monsoon) in all NHPC's reservoirs.

- Empirical methods:
  Empirical methods are used to estimate average annual sediment yield in circumstances when long term sediment data and bathymetric surveys are not available. These include using sediment yield maps of the area, empirical relations etc. This method is seldom used in NHPC except during planning stage of the projects in un-gauged catchments.

4. SEDIMENT MANAGEMENT TECHNIQUES BEING FOLLOWED IN NHPC

Sediment management techniques being adopted in NHPC are explained in detail as below.

4.1 *Sediment Yield Reduction:*

Catchment area treatment, afforestation etc are generally adopted in NHPC's Project as a part of EIA/EMP study. Integrated approach is adopted under CAT plan which includes various biological, engineering, and bio-engineering measures. Afforestation (to compensate for the forest land submerged due to impoundment of reservoir and other structures) is an effective tool for arresting soil erosion and up-gradation of environment and it includes soil conservation and moisture retention measures. Also lots of protection works are done to stabilize hill slope in the vicinity of reservoir and adjoining hill road sides, which reduces sediment inflow into reservoir.

4.2 *Sluicing :*

It is an international practice to maintain the reservoir at low level during monsoon so that majority of incoming sediment is passed in the downstream through the spillway. During sluicing, reservoir is maintained at lower levels (normally near MDDL), which decreases the effective capacity of the reservoir. The decrease in capacity causes reduction in the capacity-inflow ratio, which in turn reduces the trap efficiency of the reservoir. The fine/cohesive sediment can be removed by drawdown sluicing thereby prohibiting consolidation of cohesive sediment particle which are difficult to scour once deposited.

Reservoir operation manuals have been prepared for all the power stations of NHPC in which it is advised to maintain the reservoir level at/near MDDL during monsoon period in all run-of-the-river projects/power stations. In case of high dams such as Chamera-I PS, low level under-sluices have been provided in dam body for sluicing of sediment from the reservoir.

4.3 *Flushing* **:**

Sediment flushing is a technique in which the flow velocities in a reservoir are increased to such an extent that the deposited sediments are remobilized and transported through bottom outlets. During draw down flushing the reservoir area takes the form of pseudo-river. Flushing is most effective if the reservoir is drawn down to the extent that the flow condition over the deposits approaches that of the original river (*ICOLD Bulletin 115*). In small size reservoirs of NHPC, generally reservoir flushing be carried out once in a month during monsoon period when river inflow exceeds a specified discharge. The discharge at which flushing is to be carried out is worked for each monsoon month on basis of 50% probability of occurrence of that discharge using inflow discharge data. Flushing in free flow condition is generally carried out for more than 12 hrs. Flushing is stopped when sediment concentration of inflow/outflow becomes almost equal for 2-3 hrs.

4.4 *Desilting basins/Chambers :*

Desilting basins/Chambers are used for removing sediment of specific size and quantity. The main key is to provide a section wide and long enough so that the resulting reduced flow velocity will permit the sediment to settle out. Desilting basins have become an integral part of the water conductor system of ROR hydropower projects to minimize the impact of damage due to suspended sediment on water conductor systems, turbine and other underwater parts. Desilting basins are provided just after power intake and discharge is passed through them before entering into the head race tunnel. Generally, desilting basins are designed for 90 % removal of suspended sediment particles of size 0.2 mm and above. However, basins may be designed to eliminate particles finer /coarser than 0.2 mm which will increase / decrease length of the basin and in turn adds / reduces cost of the project. In NHPC, desilting basins/chambers have been provided in Teesta V, Chamera-II, Chamera-III, Sewa-II, Dhauliganga, Tanakpur, Rangit, Dulhasti, Uri-I, Parbati-III, & Uri-II power stations.

4.5 *Silt Excluder and Silt Ejector:*

Silt excluder is provided near river bed u/s of diversion work and silt ejector is installed in canal bed d/s of regulator work. Silt excluders have been provided in Uri-I and Tanakpur Power Station. Silt ejectors have been provided in Tanakpur Power Station.

4.6 *Sediment Bypassing:*

In Baira Siul Power Station , diversion tunnel used for construction of Baira dam (53 high Rockfill dam) having intake about 200 m upstream of dam axis is being used as Sediment Bypassing Tunnel (SBT). This tunnel is also being used for drawdown flushing of Baira reservoir.

4.7 *Dredging/Excavation*

Dredging technique is used to remove deposited sediment from the reservoirs using dredging equipments, pumps or hydraulic suction. In Tanakpur power station reservoir capacity was regained by removal of accumulated sediment in the centre of reservoir through this technique. In TLDP III power station localized dredging is done during flushing to remove deposited sediment in front of intake.

5 LESSONS LEARNED

NHPC is operating 20 power stations and has gained a lot of experience from their operation. It has learned many lessons and improved its techniques of sediment management based on feedback from specific power stations, mathematical model as well as physical model studies. Lessons learned in some of the projects/power stations are explained below;

5.1 Salal Power Station (690 MW) in J&K, Chenab Basin –No Pondage, No Desilting basin

In Salal power station (commissioned in 1987/1995) water is fed to machines through penstocks directly from reservoir and there is no desilting basin in between intake and machine. Salal has six generating units coupled with Francis type turbines and the rated head is 89.88 m. All the six low level under sluices in the dam have been plugged permanently and sediment management is being done by flushing through 12 nos. spillway bays and limiting the sediment entry into the power house. Average annual sediment load entering into Salal reservoir is around 30 MCM. The Salal reservoir had initial reservoir capacity of 284 MCM, which reduced drastically in initial few years of operation. Subsequently following guideline has been adopted.

- When the sediment concentration is more than 3500 ppm and / or discharge crosses 2500 cumec (1500 cumec in September). Power house is shut down and flushing is being carried out through spillway gates to pass the excessive silt laden water.
- From May to August, if discharge does not exceed 2500 cumec (1500 cumec in September), then flushing is carried out on the last day of each month irrespective of discharge.

Since past 15 years, the reservoir capacity of reservoir has been maintained at around 12-13 MCM.

5.2 Baira Siul Power Station (198 MW) in Himachal Pradesh, Ravi Basin - with Diversion cum De-silting Tunnel

In Baira Siul power station (commissioned in 1982), water is fed to machines through 7.63 km long Head Race Tunnel from Baira reservoir. It has three units of Francis turbines with a net head of 259.5 m. Reservoir flushing is being done through a diversion-cum-desilting tunnel of size 5 m (W) x 7 m (H) located upstream of the Intake. The crest level of de-silting tunnel is 23.15 m below the crest of intake. In reservoir flushing, spillway also plays important role as crest level of spillway is 1.15 m below the crest of intake. A desilting basin (twin hopper type) 30 m long x 7m (W) x 12m (H) has also been provided in HRT to eliminate 0.2 mm and above particle size and efficiency of desilting basing is estimated to be 90%. When inflow sediment concentration exceeds 3000 ppm and/or discharge exceeds 100 cumec, the power house is closed and flushing of reservoir is carried out. By way of flushing through spillway and diversion tunnel, live storage of 0.6 MCM is generally maintained against the original capacity of 1.3 MCM.

5.3 Dhauliganga Power Station (280 MW) in Uttarakhand State, Sharda Basin: Low Level Outlet, Desilting Basin

Dhauliganga power station, commissioned in 2005, is in Sharda Basin, of India. Dhauliganga dam is a CFRD dam with two spillways consisting of low level outlets. Water is fed to the machine through 5.4 km head race tunnel. Two desilting chamber of size 13.0 m X 16.2 m with length of 314.40 m are provided. It has four units of Francis turbines with a net head of 297 m. Originally power station had the gross storage capacity of 6.20 MCM at FRL (EL 1345 m). During monsoon, the reservoir is being operated at MDDL (EL 1330 m) for discharge more than the design discharge. If the inflow in the river is less than design discharge, reservoir level is kept between EL 1330 m to EL 1340 m.

At present, 7 nos. of flushings per year have been recommended for effective management of sediment. Change in reservoir capacities of Dhauliganga Power Station after different years of operation are mentioned as below:

- During year 2008 -2012, the gross capacity was maintained nearly about 5 MCM.

- The reservoir lost its capacity majorly during 2013 Uttarakhand floods because of deposition of large amount of sediment in the reservoir thereby decreasing the gross and live storage by 34% and 45 % respectively.
- Afterwards, the gross capacity and live storage capacity was maintained nearly at 3 MCM and 2.3 MCM respectively from year 2014 to year 2016, by combination of drawdown sluicing and flushing.
- In 2017, power station could manage to conduct only 3 flushings and the reservoir level could not be lowered upto MDDL due to some project specific reasons, which resulted in decreased gross capacity from 3.08 MCM to 2.03 MCM.
- In year 2018, power station conducted all proposed flushing during the monsoon, thereby increasing the gross capacity from 2.03 MCM to 3.24 MCM, which proved the effectiveness of aggressive sediment flushing (in combination with sluicing) in removing the deposited sediment from the reservoir.
- Also, based on observed sediment data near intake and TRT outlet, sediment removal efficiency of Desilting basin of Dhauliganga Power Station was found to be around 50% of total observed sediment and around 82% for coarse sediment as was also predicted in Physical Model Study.

5.4 Teesta-V Power Station (510 MW), Sikkim : With Low level outlet and desilting basin

Teesta V power station, commissioned in 2008, is in Teesta Basin, Sikkim State of India. It has a 17.2 km length head race tunnel with diameter of 9.5 m through which water is fed to the machines. It has 3 nos of desilting chambers of size 19.7 m X 24.5 m. The length of desilting chambers is 250 m. It has three units of Francis turbines with a net head of 197 m.It has small reservoir storage capacity (Gross - 13.5 MCM, Live-6.3 MCM, initially) and sediment management is though low level spillway, combination of reservoir flushing and sluicing and desilting chamber.

Sediment got deposited within first year and reduction in gross and live capacity was 21% and 10.3% respectively. This loss in capacity was majorly due to full deposition upto spillway crest as expected as there was no opening below this level.

Due to present practice, after 11 years of commissioning, the live capacity is maintained at 5-6 MCM as compared to initial live capacity of 6.3 MCM. Desilting basin/SFT provided in the project also played effective role in reducing impact of sediment to turbines and other underwater parts. Sediment balance study showed that about 39 % of the incoming sediment has been flushed out during flushings, 10 % has been passed out through SFT, and around 23 % has been spilled out through spillway. Balance 28% of sediment passes through machines.

On river Teesta four projects namely Teesta III (1200 MW) and Teesta V (510 MW), TLDP- III (132 MW) and TLDP –IV (160 MW) have been commissioned and are in operation. Teesta III and Teesta V are in vicinity of each other whereas TLD- III is quite far from Teesta V. Flushing operations of Teesta V vis a vis TLD III and TLDP IV have been delinked.

5.5 Chamera Stage-I Power Station (540 MW), Himachal Pradesh, Ravi Basin : Under Sluices, no desilting basin

Chamera I power station, commissioned in 1994, is in Ravi Basin, Himachal Pradesh State of India. It has large reservoir capacity (around 391 MCM initially). It has 6.4 km head race tunnel with 9.5 m diameter. Power is being generated through 3 units of francis turbine with gross head of 207 m.

Sediment management is done by sluicing through low level sluice outlets (4 nos) and following reservoir operation rules. The low level sluice outlet helps in achieving better sediment environment in the vicinity of dam to the downstream channel. The level of reservoir is kept at near to lower operating levels during monsoon season so that sediment may be routed to the downstream. No sediment related problem has been reported in underwater parts from

Chamera-I power station which was commissioned about 25 years ago, even though it does not have desilting chambers. The sediment management practice adopted in this project results only a loss of around 0.5% in live capacity per year. (Joshi et al, ICOLD-2018)

5.6 Chamera-II Power Station (300 MW), Himachal Pradesh, Ravi Basin : Low Level Outlet, Desilting Basin

Chamera-II power station, commissioned in 2003, has three generating units coupled with Francis type turbines and design head is 243.0 m. Four low-level spillways have been provided for reservoir flushing. Two de-silting chambers of 16 m width and 375 m length have been provided in HRT to eliminate 0.2 mm and above particle size. During peak water inflow, reservoir level is maintained at a level lower than FRL, to pass most of the silt laden water downstream of the dam. When sediment concentration increases above 5000 ppm and/or discharge exceeds 300 cumec, the power house is closed and flushing operation is carried out by opening all the spillway gates gradually. Four flushings, one in each monsoon month are carried out from June to September. After 15 years of commissioning of project the live capacity has been maintained at 1.4 MCM (post monsoon 2018 survey) as compared to original capacity of 1.8 MCM.

Chamera II power station is in cascade with Chamera III power station. Chamera III is located at 24 km upstream of Chamera II dam along the river Ravi. Reservoir flushing at Chamera II power station is carried out in tandem with flushing at Chamera III power station. Chamera III starts the flushing first and give prior intimation to Chamera II to plan its flushing accordingly.

5.7 Mangdechhu Project (720 MW) in Bhutan: Low Level Outlet, desilting basin

Mangdechhu dam has been provided with an orifice spillway with 4 gates (10 m wide x 16 m high). The crest of the spillway is at EL 1702.2 m. Two Dufour type desilting chambers of size 14.0 m (W) x 17.7 m (H) are provided to remove 90% of 0.2 mm and above size sediment particles. The power intake is located just upstream of spillway on the left bank with invert level at EL 1720 m and comprises twin intake tunnels leading to a single power tunnel. The sediment laden water is removed through silt flushing tunnels.

Though free flow flushing in combination with sluicing with reservoir at low level, has been proved to be effective in reservoirs with small capacity. However for Mangdechhu Project reservoir operation and flushing guidelines has to be framed keeping structural safety in mind due to typical upstream geometry and river slope. As per physical model study, due to the distinctive site specific flow conditions, after carrying out many alternative physical model studies for a range of discharges, it has been decided to adopt controlled gate operation (orifice flow) for discharge rates more than 1200 m^3/sec (i.e around 18% of PMF) to ensure safety of the structure. Moreover, during high flood events (above 1200 m^3/sec), reservoir levels higher than MDDL, are recommended to arrest turbulent flow and adverse flow conditions. In addition, for better performance of Ski Jump Bucket during high flood events, it is proposed to avoid free flow condition. (Joshi et al, ICOLD-2019)

5.8 Projects/power stations in cascade:

The sediment management techniques being followed in power stations in cascade are different than being followed in standalone projects. For projects in close vicinity to each other, it becomes essential to carry out flushing in tandem so that the sediment flushed out from the upstream reservoir is not allowed to settle in the downstream reservoir. In case of cascade projects having large distances in between, the in tandem flushing has to be analyzed depending upon the river slopes, travel time, sediment carrying capacity of the river, river inflow, reservoir capacities and loss in power generation.

Some of power stations of NHPC in river basins such as Teesta and Ravi are in cascade with each other. The reservoir operation in cascade run of the river projects is divided into two parts: (i) Sediment Management in monsoon period (ii) Optimization of peaking in period other than monsoon. NHPC has reviewed the operation philosophy for the power stations lying in cascade after commissioning of more than one power station in the basin and revised the reservoir operation manuals accordingly by coordinated and synchronized sediment management approach. In case of cascade projects having large intermediate catchment areas and distances the high sediment concentration flushed out from the upstream project does not reach up to the downstream project. In such projects, the reservoir flushings can be delinked with each other.

The summary of sediment management practices adopted for above power stations along with the gross and live capacities is given in Table 1.

Table1 : Sediment Management techniques being followed in NHPC Power Stations

Project →	Salal	Bairasiul	Dhauliganga	Teesta V	Chamera I	Chamera II
Installed Capacity	690 MW	180 MW	280 MW	510 MW	540 MW	300 MW
Year of Commissioning	1987/1995	1982	2005	2008	1994	2003
Sediment Management Technique	Flushing	Desilting (bypass) tunnel , desilting basin , flushing	Low level outlet, desilting basin, sluicing, flushing	Low level Outlet, desilting chamber , flushing	Under sluices	Desilting chamber Low level outlet , Sluicing, flushing
Original Gross Capacity(MCM)	284.1	3.8	6.2	13.5	391.3	2.3
Present Gross Capacity(MCM)	12.4	0.7	3.2	9.3	195.1	1.7
Original Live Capacity(MCM)	Not Provided	1.3	3.2	6.3	109.6	1.6
Present Live Capacity(MCM)	Not Provided	0.6	2.3	5.6	87.9	1.4

6 SUSTAINABILE SEDIMENT MANAGEMENT: BEST PRACTICES

Sustainable sediment management seeks to maintain long-term reservoir capacity, retarding the rate of storage loss and eventually bringing sediment inflow and discharge into balance while maximizing usable storage capacity, hydropower production, or other benefits. Based on experience gained by NHPC, best practices for sustainable sediment management are as follows:

(i) Prepare project specific guidelines and detailed standard operating procedures for management of sediments for each project/power station.
(ii) Observe sediment data regularly and accurately, maintain long term record.
(iii) Conduct bathymetric surveys at fixed locations soon after initial filling and thereafter at regular intervals.
(iv) Adopt low level outlets, operation of reservoirs at/near MDDL during high flow periods and free flow flushing, in run of the river schemes with small storage capacities in order to reduce filling of live storage capacity.
(v) Keep intake level sufficiently above spillway crest to reduce the entry of sediment into water conductor system.
(vi) Make arrangements for exclusion of sediments larger than a particular size (usually 0.2 mm) from the water entering into water conductor system and turbines.
(vii) Simulate long-term reservoir sedimentation by mathematical modeling, extending the modeling period until a stable longitudinal profile and sediment balance across the dam have been achieved. It assists in the evaluation and quantification of the effectiveness of

operational rules for sediment management and provide an idea of the extent and geometry of sediment deposits, which helps designers to select the location and configuration of outlet works to best handle anticipated future sedimentation conditions.

(viii) Carryout physical model study for each project to understand the behavior of flow through spillway, flushing/sluicing operation, feasibility of proposed sediment management techniques, effect of reservoir operation on safety of structure etc.

(ix) Coordinated and synchronized reservoir operation and sediment management approach for projects in cascade in a basin

An effective combination of drawdown sluicing and flushing helps to maintain the useful and long life of the reservoir. Elaborate reservoir operation manuals have been developed for these power stations by NHPC. Due to this, NHPC has been successful in maintaining the live capacities of most of its reservoirs to a satisfactory extent thereby achieving the generation targets and other intended purposes of the plant even after almost more than 20 years of commissioning in many projects. The comparison of original and present reservoir capacities of some of the reservoirs of NHPC is shown in Figure-2.

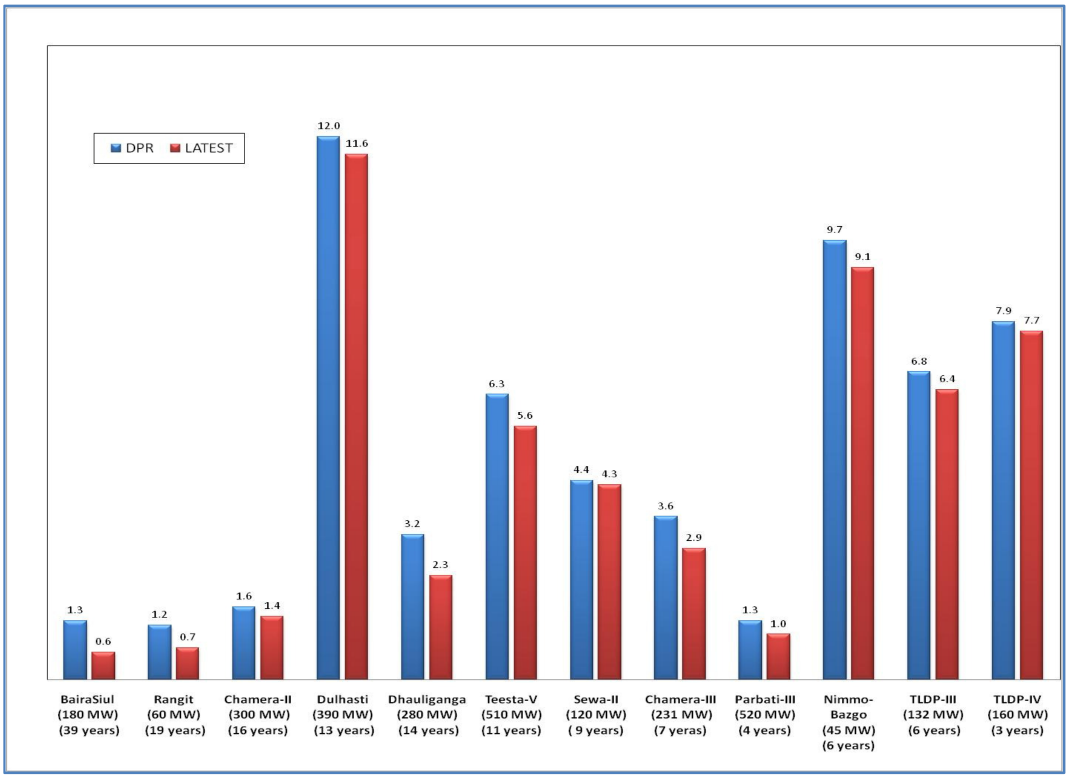

Figure-2 Change in Live Reservoir Capacities of Some of the Power Stations of NHPC

7 CONCLUSION

Sedimentation is threatening the existence of all kind of reservoirs. Himalayan rivers carry much more sediment load than the capacities available in the reservoirs of power stations located in this region. The annual loss in generation due to sedimentation has been estimated about 1% of the overall generation as per NHPC's experience. NHPC Limited is maintaining 20 power stations in Himalayan region and has been successful in maintaining gross/live capacity of reservoirs of these power stations satisfactorily by combination of providing low level spillways, drawdown flushing and sluicing. Desilting basins/silt excluders/silt ejectors have played their role in reducing the impact of sediments in water conductor system, turbines and other underwater parts. These techniques, are, however required to be customized for different projects depending on their reservoir size, valley shapes as well as their unique design features.

It has been observed that if proper reservoir operation and flushing guidelines are not adhered to, along with significant loss in reservoir capacity, the runner and guide vanes are required to be repaired every year. However, after following guidelines as proposed in the manuals, the repair cycle of runner and guide vanes has increased to 2-3 years and 3-4 years respectively. These project specific guidelines have been extremely helpful in preserving the reservoir capacity and ensuring smooth running of power plant.

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