SEDIMENTATION MANAGEMENT – A CASE STUDY OF CHAMERA STAGE-II & CHAMERA STAGE-III HYDROPOWER STATIONS, H.P., INDIA

MANJUSHA MISHRA
General Manager (Hydrology, D&E) at NHPC Ltd.

PRAVEEN KUMAR JAIN
Deputy General Manager (Hydrology, D&E) at NHPC Ltd.

1. INTRODUCTION

Sediment has been defined generally as solid particles which are moved or might have been moved by flow in a channel. It creates numerous problems for the engineers. Sediment in river water causes mainly loss of storage capacity of reservoirs and damage to turbines and other underwater parts in hydropower plants in addition to changing river regime increased flooding, sedimentation of intakes and loss in power generation due to sediment deposition in the reservoir, etc. All the reservoirs, big or small, created by constructing a dam across rivers is subjected to sedimentation which results in reduction of storage capacity. In storage schemes, with typically large reservoirs, the reservoir acts as a large settling tank and most of the sediment settles in the reservoir (reduction in storage capacity) and clearer water enters the intake and goes off to the power house. In run-off-the-river schemes, the river flow is diverted without creating a large storage to power house through water conductor system. During monsoon, a lot of sediment enters the power plant with water, causing erosion and damages of varying degrees of underwater components. The problem is more serious in case of hydro plants located on Himalayan Rivers as they carry a huge sediment both as bed load and suspended load during monsoon. The catchment area treatment which aims at preventing the entry of sediment in the reservoir gets mired in multiplicity of agencies having different target strategies and modes of execution. A sizeable work has been done by various individuals and organizations on the prevention, exclusion and management of sediment entering the reservoirs. The work of exclusion and management of sediment being largely of recent origin requires supplementation by drawing on experience from present practices so that better strategies for tackling the sedimentation problem could be evolved. This paper aims at sharing the experience of sediment management being practiced in two reservoirs in Himachal Pradesh, India.

2. GENERAL FEATURES OF CHAMERA-II & CHAMERA-III RESERVOIRS:

The Chamera Stage-II (300 MW) & Chamera Stage-III (231 MW) hydropower stations are located across Ravi river which is a mountainous river of western Himalaya. The river Ravi originates at an elevation of about 6000m from Bara Bhangal glaciated area and is formed by the confluence of two streams.

The major tributaries joining the River are Kalihan Nala, Budhil Nala and Tundah Nala, before the Chamera Stage-II Dam at Bagga. The Catchment area of Chamera-II power station is bounded between latitude 32°10’ N to 32°40’ N and longitude 76°11’ E to 77°04’ E. Chamera Stage-II power station is located on main Ravi River near Chamba town and the catchment area is 2596 sq km. Chamera Stage-III Dam is located on river Ravi at 24 KM upstream of Chamera Stage-II Dam & downstream of confluence with Tundah Nallah in Chamba district of Himachal Pradesh, the catchment area at this location is 2203 sq. km. The entire catchment is thinly populated and is covered with forests. It is made up of mountainous terrain with steep hill slopes. The location map and line diagram of Chamera Stage-II & Stage-III Projects are shown in Figure 1 &2.

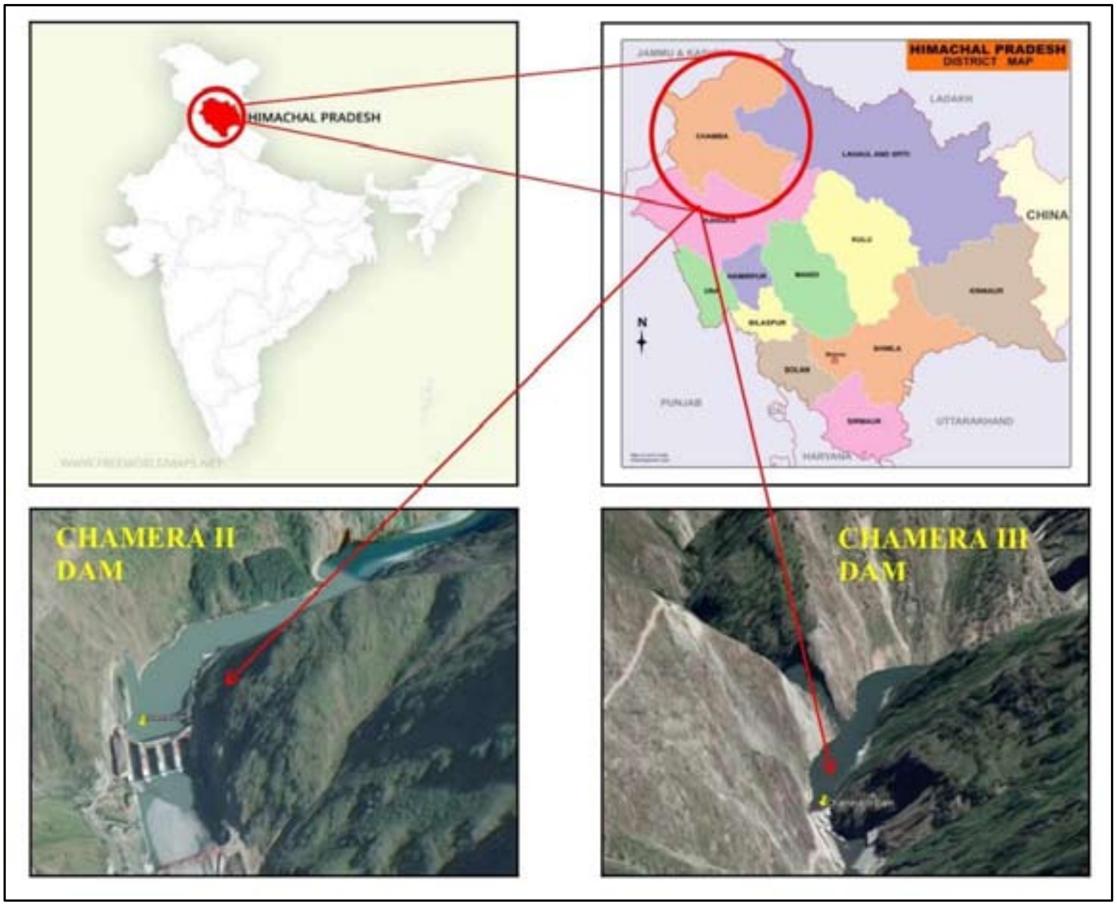

Fig. 1 : Location Map of Chamera Stage-II & Chamera Stage-III Power Station

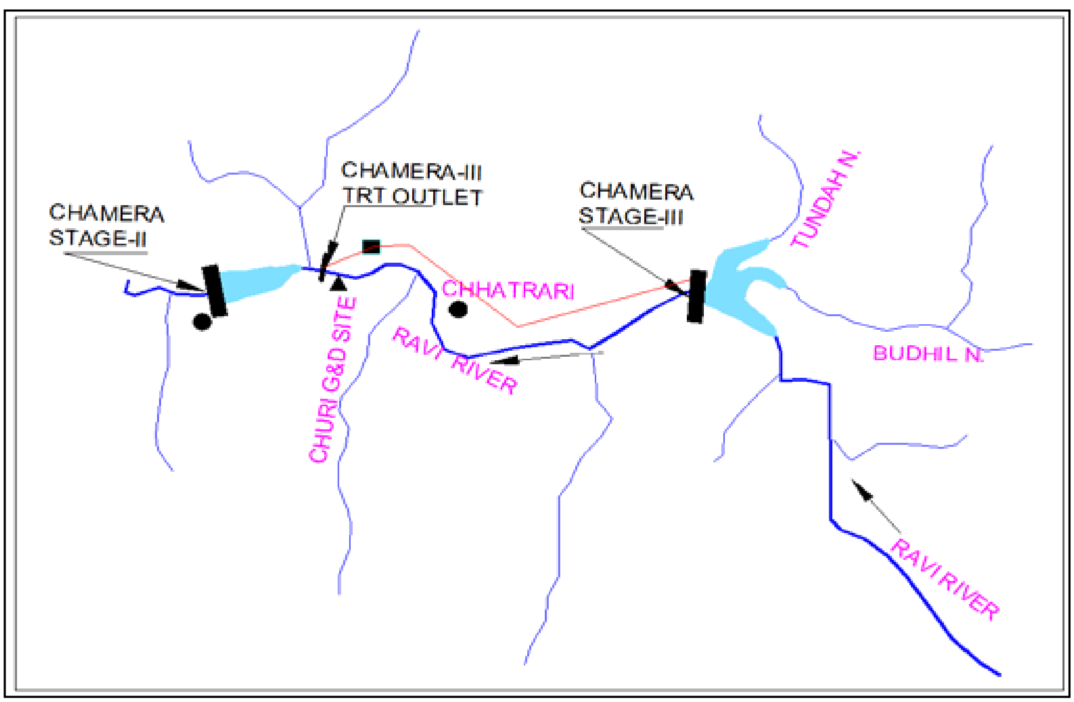

Fig. 2 : Line Diagram of Chamera Stage-II & Chamera Stage-III Power Station

The Chamera Stage-II reservoir on main Ravi is about 3 km in length. The power station consists of a 43 m high concrete gravity dam across river Ravi from the deepest foundation level. The top level of dam is at EL 1166 m with provision of 4 bays (15 m wide and 21 m high radial gates each) of gated spillway. The crest of spillway is at EL 1141 m. The MWL, FRL and MDDL of the reservoir are at EL 1164.85 m, EL 1162 m and EL 1152 m respectively. The Chamera Stage-II reservoir had a gross capacity of 2.25 MCM at FRL i.e. EL 1162 m whereas the live and dead storage were 1.66 MCM and 0.59 MCM respectively as per Feb-2004 survey (before commissioning).

The Chamera Stage-III reservoir on main Ravi is about 3 km in length and also extends in Tundah and Budhil Nallah for about 1 Km. The project consists of a 64 m high concrete gravity dam across river Ravi. The top level of dam is at EL 1399 m with provision of 3 bays (12.5 m wide and 16.5 m high radial gates each) of gated spillway at EL 1360 m and one Chute spillway at EL 1382m for a size of 10m wide & 15m height. The FRL and MDDL of the reservoir are at EL 1397.0m and EL 1380.0m respectively. The gross storage capacity of Chamera Stage-III reservoir was 5.48Mcum at FRL i.e. EL 1397m whereas the live and dead storage were 3.64Mcum and 1.84Mcum as per DPR stage studies.

3. ANALYSIS OF SEDIMENTATION ON CHAMERA STAGE-II RESERVOIR

Chamera Stage-II power station was commissioned in the year 2004. The gross original capacity at FRL i.e. 1162 m was 2.25 MCM. The reservoir capacity survey is being carried out every year in post-monsoon period. The latest reservoir capacity as per Dec-2018 survey is 1.68 MCM. The total amount of sediment deposited since commissioning till Dec-2018 is 0.57 MCM. Most of the sedimentation of the reservoir takes place during monsoon season when river discharge and sediment concentration remains high. The longitudinal profile of Feb-2004 plot (before filling of reservoir) and sedimented bed profiles as per hydrographic survey data for years 2006, 2010, Dec-2014 and Dec-2018 have been plotted in Figure 3.

Figure 3 describes lowest river bed along the reservoir as well as sediment deposition profiles from 2004 to 2018. It is observed that during all the operation years the deposition is almost uniform throughout the reservoir from dam upto tail of the reservoir. The Chamera Stage-II reservoir being small with frequent water level fluctuations during monsoon has produced nearly uniform deposition depths along the reservoir.

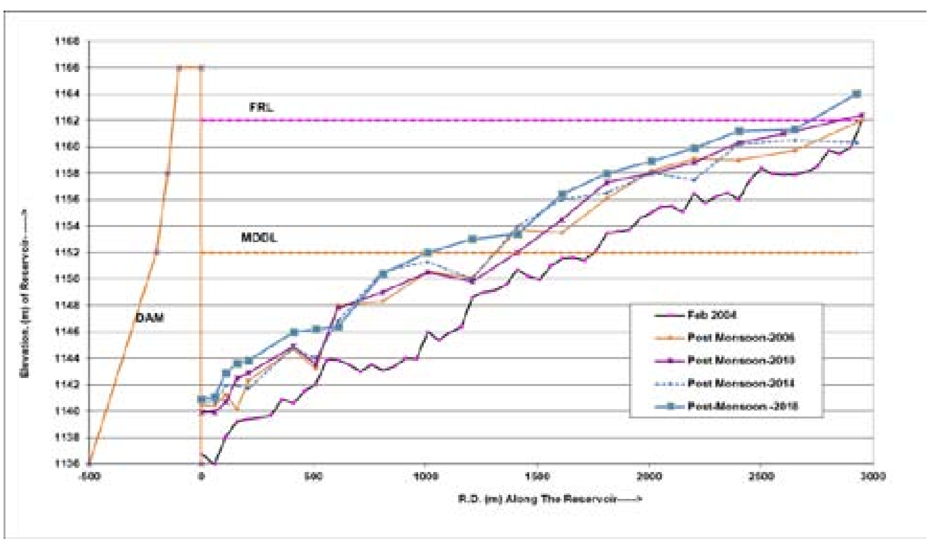

Fig. 3 : Chamera Stage-II Reservoir Longitudinal Section Profile

4. ANALYSIS OF SEDIMENTATION ON CHAMERA STAGE-III RESERVOIR

Chamera Stage-III Power Station was commissioned in the year 2012. The gross original capacity at FRL i.e. 1397 m was 5.48MCM. The reservoir capacity survey has regularly been carried out in post-monsoon period. The latest reservoir capacity as per Dec-2020 survey is 3.23 MCM. The total amount of sediment deposited since commissioning in 2012 till Dec-2020 is 2.25 MCM. The major sediment deposition in reservoir can be seen after the first monsoon since the operation of the Project, after which the capacity of the reservoir is maintained by efficient sediment management techniques. The longitudinal profile of reservoir at DPR Stage (i.e. before filling of reservoir) and sedimented bed profiles as per hydrographic survey data for subsequent years 2014, 2015 2016, 2017, 2018, 2019 and 2020 have been plotted in Figure 4.

As can be seen in Figure 4, the sediment profile in 2014, 2015 2016, 2017, 2018, 2019 and 2020 survey is wedge shaped near the dam and the reservoir bed level is having same slope and level as of the orifice spillway opening. In initial years, the sedimented profile near the dam is wedge shaped due to transport of finer sediment particles to dam by turbidity currents. Keeping the reservoir level at lower levels during monsoon draws the incoming sediment to the vicinity of dam and most of the sediment is flushed out of the reservoir through the low level orifice spillway leaving only coarse sediment deposited below the spillway.

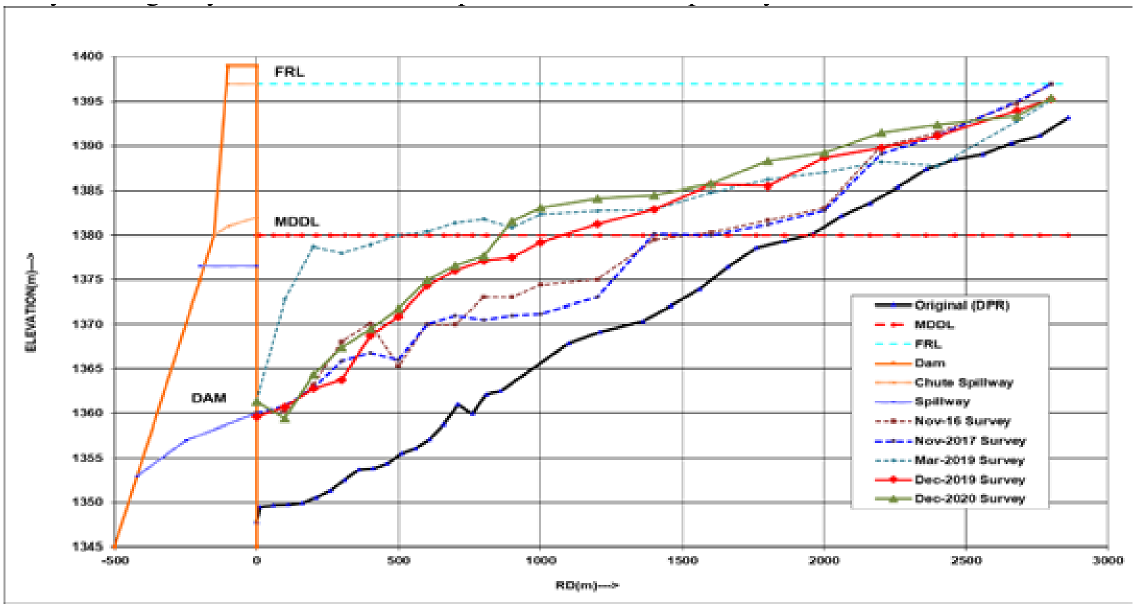

Fig. 4 : Chamera Stage-III Reservoir Longitudinal Section Profile

5. RESERVOIR OPERATION IN CHAMERA STAGE-II AND CHAMERA STAGE–III RESERVOIR.

The Chamera Stage-II and Chamera Stage-III reservoir are small reservoirs and are in cascade, Chamera-III dam being located about 24 km upstream of Chamera-II dam along the river Ravi. The TRT outlet of Chamera Stage-III power station is just upstream of Chamera Stage-II reservoir. So literally Chamera Stage-II power station is using the discharge being released from Chamera Stage-III machines, during the period when the discharge is around 135 cumec or less. Chamera Stage-II would receive regulated flows from Chamera Stage-III so the reservoir operation of Chamera Stage-II should be done in consideration with reservoir operation of Chamera Stage-III. Reservoir operation of these two run-of- river power stations must be planned so as to maintain the capacity of reservoirs as well as allow uninterrupted generation as explained below.

(A) Peaking

After commissioning of Chamera Stage-III Power Station, there is a possibility that all the Chamera Stage-III machines trip suddenly, thus reducing/stopping all the flows going to Chamera Stage-II Power Station, resulting the Chamera-II reservoir level going down below MDDL (EL 1152m), if not attended in time. Thus keeping in mind the above fact, the release and retention of discharge at both the Reservoirs for optimized operation of both the Power Station is done judiciously and in a coordinated manner. To address this issue, the entire year is divided in two parts:-

(i) Low Flow Season (Oct to May): when the river inflow at Chamera Stage-III is less than 130.6 cumec

(ii) High Flow Season (Jun to Sep): when the river inflow at Chamera Stage-III is more than 130.6 cumec

(i) Low Flow Season (Oct to May): when the river inflow at Chamera Stage-III is less than 130.6 cumec

The peaking of both the power stations shall be done in tandem with a time gap of 15-30 minute approx. While carrying out peaking, the reservoir level of Chamera Stage-III power station shall vary between FRL EL1397 m and MDDL EL1380 m and the reservoir level at Chamera Stage-II power station shall be kept at FRL i.e. EL1162 m. Chamera Stage-III power station should start generation earlier than Chamera Stage-II by around 15-30 minutes. Any tripping or starting of the machine at Chamera Stage-III power station should be intimated to Chamera Stage-II power station immediately by Chamera Stage-III power station. Chamera Stage-III power station shall intimate at the interval of 1 hours, the reservoir level, total inflow at dam, machine running at particular load, downstream release at that time and sediment concentration in front of intake etc. to the Chamera Stage-II power station for better understanding of the scenario in the upstream reach of the river.

(ii) High Flow Season (June to Sep): when the river inflow at Chamera Stage-III is more than 130.6 cumec

During high flow season, the discharge between 130 cumec and 250 cumec has been considered, as at 250 cumec it is proposed to carry out reservoir flushing at Chamera Stage-III power station.

The reservoir level at Chamera Stage-III during high flow season (Jun to Sep) for different period/months shall be maintained as per Table-1:

Table 1 : Reservoir level during High Flow Season at Chamera Stage-III power station

S. No.	Months	Reservoir level at Chamera Stage-III
1	Jun (16th to 30th)	EL ± 1390.0 m
2	July	EL ± 1380.5 m
3	Aug	EL ± 1380.5 m
4	Sept	EL ± 1390.0 m

A reservoir rule curve had been evolved at the time of commissioning of Chamera-II Power Station which had to be modified following the commissioning of Chamera-III hydropower project as the effects of sudden tripping of machines at Chamera-III Power Station was also accounted for in deciding the reservoir levels to be maintained at both the Power Stations. The reservoir levels at Chamera Stage-II Power Station has been worked out based on inflow range observed at Chamera Stage-III Dam & intermediate catchment contribution. The intermediate catchment area is 393 Sq.Km, which contributes about 20% of the inflow being observed at Chamera Stage-III. Thus taking 30 min as the safe reaction time for Chamera-II Power Station in case of sudden tripping of machines at Chamera-III, Chamera-II is advised to keep reservoir levels as per Table-2 during high flow season (Jun to Sep) :

Table 2 : Water Level during Flood Season at Chamera-II Reservoir

S. No.	Inflow at Chamera-III dam (cumec)	Reservoir Level at Chamera-II dam (m)
1	130 to 170	EL 1156.0
2	171 to 210	EL 1155.5
3	211 to 250	EL 1154.5

Chamera Stage-III reservoir level is maintained as per the Table 1 and it is ensured that no additional storage is allowed at Chamera Stage-III power station in case of tripping of the machines to ensure a continuous release in downstream. Chamera Stage-II power station may take necessary action based on the actual inflow at Chamera Stage-II Power station.

(B) Sediment Management

Erosion of top soil cover of catchment due to rainfall-runoff, snowmelt, landslides and erosion of river channel due to flow in river, generate a continuous supply of sediment inflow. It is presumed that due to construction activities of Chamera-III H.E. Project from 2006 to 2012 sediment transportation has increased into Chamera-II reservoir. Sediment is hydraulically transported from catchment through the drainage system, deposits into reservoirs and reduces its economic & useful life. Most of the sediment deposition in the reservoir takes place during the high flow season. Therefore, there is essential need of efficient sediment management system in monsoon season along with power optimization to protect the economic and useful life of both the reservoirs.

Sediment management at both the reservoirs is done by reservoir flushing operation for removal of deposited sediment in the reservoir by depleting as well as keeping reservoir level below FRL in the monsoon months. The sediment control strategies like routing sediment hydraulically beyond storage pool (drawdown sluicing) and sediment removal by hydraulic flushing (reservoir drawdown flushing) are being used to maintain the useful life of Chamera-II and Chamera-III reservoir.

(i) Reservoir Level Regulation and Drawdown Sluicing:

Drawdown sluicing is an operational technique in which sediment laden inflows are released through a dam before the sediment particles can settle, thereby reducing trap efficiency of the reservoir. This is accomplished in most power plants worldwide by operating the reservoir at a lower water level during the flood season so that velocities are increased to improve sediment transport capacity through the reservoir. The Himalayan Rivers carry large sediment load during monsoon. The sediment load carried by the rivers can be classified broadly into two types:

(i) Coarse sediment which is non-cohesive

(ii) Fine sediment which is cohesive.

The fine/cohesive sediment can be removed by drawdown sluicing while the coarse/non-cohesive particles can be removed by retrogressive flushing. Once consolidation of cohesive sediment has taken place, it becomes practically impossible to scour significant quantities of such sediment from reservoirs. Thus, sluicing does not allow consolidation of cohesive sediment, as the incoming sediment is released downstream before settling down in the reservoir. The operation of reservoir is done in two ways i.e. sluicing with drawdown and flushing, to remove both cohesive and non-cohesive particles.

At the Chamera Stage-III reservoir it has been suggested that during monsoon season (Jun to Sep) for different period the reservoir level shall be maintained as per the Table-1. Chamera Stage-III power station shall be releasing all excess water such that incoming sediment is sluiced downstream through the sluice spillway gates before it deposits in the reservoir. Considering safe operation of both the Power Stations and mitigating the effect of sudden tripping of machines at Chamera-III on Chamera-II Power Station, Chamera-II reservoir levels have been decided as per Table 2 vis-à-vis inflow at Chamera-III reservoir during flood season (Jun to Sep).

(ii) Free Flow Flushing of Reservoir:

Reservoir drawdown flushing is a technique in which the flow velocities in a reservoir are increased to such an extent that deposited sediments are remobilized and transported through low level sluice spillways. During drawdown flushing, the reservoir area takes the form of a pseudo- river.

The inflow discharge data for the months Jun, Jul, Aug & Sep have been analyzed and based on the results of inflow discharge frequency, it has been proposed that Chamera Stage-II and Chamera Stage-III reservoir sediment flushing be carried out as per guidelines mentioned in Table 3:

Table 3 : Guide Lines for Sediment Flushing of Chamera-II and Chamera-III Reservoir

Sl. No.	Period	Monthly flushing to be done when discharge exceeds		Remarks
		At CPS-III	At CPS-II	
1	1st Jun to 31st Aug.	250 cumec	300 cumec	If discharge does not exceed during each month then flushing is to be carried out around the last day of each month irrespective of the inflow discharge.
2	1st Sep. to 30th Sep.	200 cumec	250 cumec	If discharge does not exceed during 1st to 25th Sep. then flushing is to be carried out between 26th to 30th Sep irrespective of the inflow discharge.

However, if Chamera-III reservoir receives higher discharge (greater than 450 cumec) immediately after flushing, then this flood should also be utilized for flushing operation because, floods carry majority of the annual sediment inflow and by maintaining the continuity of flow (least obstruction to flow, as in flushing operation) it is possible to pass the bulk of the inflow sediment during sediment flushing. The reservoir sediment flushing operation shall be carried out on the same day for both the power station and Chamera Stage-III power station shall give prior intimation of the flushing operation schedule to Chamera Stage-II power station

The flushing operation is started in the rising limb of hydrograph to ensure the best utilization of peak discharge of inflow hydrograph for effective flushing. During silt flushing, observations are made on hourly basis for discharge, sediment concentration (both u/s and d/s of dam) and water level. When for continuous 2 hrs to 3 hrs, the u/s silt concentration and d/s silt concentration attains the same value, the silt flushing operation is stopped, provided the total duration of silt flushing is not less than 12 hrs.

Chamera-II Reservoir Flushing Reports:

Right from the commissioning year i.e. 2004, reservoir drawdown flushing operation has been practiced regularly. Normally 4 flushing operations are carried out in a flood season; this not only increases reservoir capacity but also prevents sustained deposition of silt in reservoir. The below mentioned Table-4 describes the reservoir flushing details carried during years 2008 to 2020.

Table 4 : Data of Chamera-II Reservoir Flushing Operations during Different Years

Year	No of Reservoir Flushing operation	Cumulative Hours of Flushing	Max Sediment concentration Observed During Flushing (ppm)	Total Sediment removed By Flushing (M ton)
2008	4	44	102250	2.5
2009	4	53	143560	2.7
2010	8	156	76450	5.7
2011	4	67	134330	4.3
2012	4	21	256940	2.7
2013	1	18	143110	0.9
2014	1	14	22600	0.28
2015	4	56	120470	1.68
2016	1	8	47650	0.413
2017	2	25	100650	1.21
2018	3	38	95600	1.77
2019	4	105	58410	5.62 (Flood in Aug 2019)
2020	2	36	88640	2.28

The year wise reservoir capacities of Chamera-II reservoir maintained as a result of drawdown sluicing and reservoir flushing are shown in Figure 5. There has been initial loss of live capacity upto year 2009 after that the live capacity has been maintained by adopting efficient sediment management techniques. There are also years in which the capacity in the preceding year is less than the succeeding year. This could be attributed to the fact that in initial years sediment load increased due to construction of upstream hydro projects leading to loss in capacity initially. Thereafter due to efficient sediment management techniques being practiced at Chamera-II power station, some of the lost capacity could be recouped. Drawdown flushing were carried out aggressively (Monsoon- 2010) as can be seen from Figure 5.

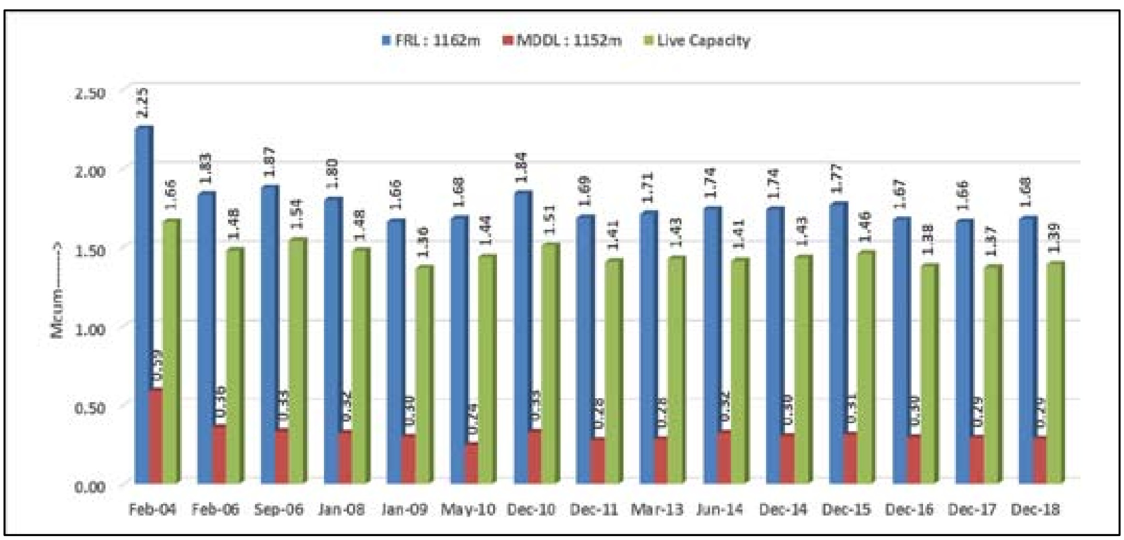

Fig. 5 : Chamera Stage-II Reservoir Capacities

Chamera-III Reservoir Flushing Reports

Right from the commissioning year i.e. 2012, reservoir drawdown flushing operation has been practiced regularly. The below mentioned Table 5 describes the reservoir flushing details carried during years 2013 to 2020.

Table 5 : Chamera-III Reservoir Flushing Operations during Different Years

Year	No of Reservoir Flushing operation	Cumulative Hours of Flushing	Max Sediment concentration Observed During Flushing (ppm)	Total Sediment removed By Flushing (M ton)
2013	1	19	84780	1.26
2014	1	19	41630	0.45
2015	4	64	150770	2.61
2016	1	15	107800	0.47
2017	2	37	103520	1.2
2018	3	43	103160	2.12
2019	3	61	198820	6.32 (Flood in Aug 2019)
2020	2	26	91560	0.75

The year wise reservoir capacities of Chamera Stage-III reservoir at FRL & MDDL and live Capacity maintained as a result of drawdown sluicing and reservoir flushing are shown in Figure 6.

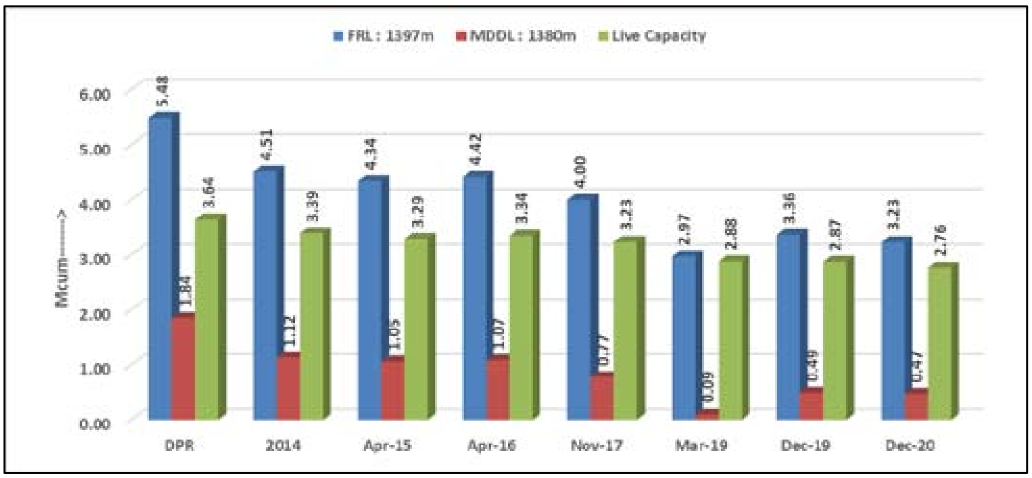

Fig. 6 : Chamera Stage-III Reservoir Capacities

6. CONCLUSION:

The sedimentation is a menace which threatens the existence of medium and small reservoirs alike. Sediment deposition is the principal problem affecting the useful life of Reservoir. The methodology of prevention of sediment entering the reservoir by way of catchment area treatment is yet to establish itself due to multiplicity of departments and their own target strategies. The management of sediment by evolving techniques like sediment exclusion and flushing has a large role to play in the reservoir conservation.

The reservoir of Chamera Stage-II power station having gross capacity of 2.25 MCM has been maintained in a satisfactory state despite the fact that in the upstream of Chamera Stage-III Dam, construction activities were going on for Chamera-III H.E Project during period 2006 to 2012. The average annual sediment load at Chamera-II reservoir is 2.65 MCM which is more than the capacity of the reservoir. Despite such high sediment load, even after Eighteen years of commissioning of project, the gross capacity has been maintained at 1.68 MCM. The live storage capacity of reservoir which was reduced to 1.39 MCM has been maintained by aggressive drawdown sluicing and reservoir flushing.

Chamera-III Power Station having gross capacity of 5.48 MCM has been reduced to only 3.23 MCM in its nine years of operation whereas original live capacity 3.64 MCM has been maintained at 2.76 MCM as per Dec-2020 survey. The method of sediment management in Chamera-II and Chamera-III Power Station appears quite effective, resulting in initial loss in the live capacity in Chamera-II reservoir whereas since last eleven years the live capacity is almost constant. Hence combinations of the drawdown sluicing i.e. maintaining the reservoir at lower levels during monsoon and reservoir flushing are the optimum and practical techniques to manage the reservoir sedimentation in the small reservoirs in Himalayan Region.

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