RESERVOIR SEDIMENTATION AND ITS REMEDIES

-A CASE STUDY ON PANCHET RESERVOIR

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ABSTRACT
To discuss about reservoir sedimentation, its prediction of distribution is an important issue for dam designers to determine the reservoir active storage capacity, outlet sill elevation, dam stability, and back-water conditions. There are various methods available to predict the distribution of sediment along the depth of a reservoir. Out of that, Area Increment and Empirical Area Reduction methods are widely used. These methods were applied to the Panchet reservoir to get an idea about the predicted sediment distribution in the projected years. Verification of the suitability of the stated models for this reservoir was carried out by comparing the results with the actual observed survey capacity data. In this study, reduced capacities in different storage zones of the reservoir at different time intervals have been predicted up to the year 2060. Here an attempt has been made to conceive or to visualize the actual sediment deposition pattern that may follow in this reservoir in the future scenarios. Considering the rates of reduction of capacity in different storage zones of this reservoir due to siltation, it is felt that some strategy must be adopted for this reservoir either to control deposition rate or to remove silt from the reservoir bed. An attempt has been made here to discuss various techniques usually adopted to reduce the silt entry or to remove the sediment from a reservoir. Emphasis has also been given on a few techniques which may be applied to the reservoir at Panchet for removal its deposited sediment.

INTRODUCTION
Significant advances have been made in understanding the importance of the factors involved in reservoir sedimentation. Lot of studies have been carried out over these issues and different numerical models as well as empirical and semi empirical methods have been developed to predict sediment distribution within the reservoirs. However, accurate prediction of accumulation of sediment in a reservoir is still a complex problem. From capacity survey data of different reservoirs at different intervals, it is observed that the pattern of sediment deposition not only varies with space but with time or age of the reservoirs. As per latest survey report of 2010-11, it is observed that already 55% and 33% of the respective dead and live storage capacity of this reservoir at Panchet has been lost due to deposition of silt. So, it has been felt to study its life on ground of filling its dead storage zone by silt. Simultaneously, distribution of the total probable sediment (i.e. likely to be deposited) in this reservoir was arrived at different projected scenarios by the methods of Empirical Area Reduction and Area Increment. Consequently, an idea of reduction of capacity with time in different existing storage zones was obtained which is very useful for future planning or adopting future operation policies of this reservoir.

PROJECT CONCEPTION
The original plan of the Damodar Valley was developed by Mr. W. L. Voorduin, a senior engineer of TVA, USA where it was proposed for eight multipurpose reservoirs on the river Damodar and its tributaries flowing through two states West Bengal and Bihar (presently

portion of Damodar valley in the then Bihar lies under Jharkhand state) as shown in fig.1. It was to build reservoirs at Tilaiya, Balpahari , Maithon on Barakar River, at Bokaro on Bokaro River – a tributary of Damodar River , at Konar on Konar River – a tributary of Damodar River, at Aiyer, Bermo, and Panchet on Damodar River itself. However, on account of financial and other reasons, the participating Governments decided to implement the unified scheme in two phases. In the first phase, only four dams at Tilaiya, Konar, Maithon and Panchet were constructed in 1953, 1955, 1957 and 1959 respectively by DVC. Afterwards Government of Bihar constructed other dam at Aiyer presently known as Tenughat Dam on Damodar River which was impounded in 1970.

In case of the reservoir at Panchet, Dead storage zone has been defined to an elevation of 119.5 Mt. Conservation zone lies between an elevation of 119.5 Mt. and 125.0 Mt. and Flood zone is designed between elevation of 125.0 Mt. and 135.7 Mt. However, land could be completely acquired up to an elevation of 129.5 Mt. Above this level, Houses is acquired up to an elevation of 132.6 Mt. But, land could not be acquired till date beyond the elevation of 132.6 Mt. So it is understood that Flood cushion is not fully utilized due to want of land. Practically flood is operated mostly within the elevation of 129.5 Mt. However in case of extreme urgency, sometimes reservoir level is raised beyond this limit during flood operation. So, in case of the reservoir sedimentation study at Panchet, operational flood zone may be considered between the elevation of 125.0 Mt. and 131.1 Mt. as it has been detected from the past observed capacity survey data that above the elevation of 131.1 Mt. there is no effect of sedimentation in the reservoir spread area.

STUDIES OF SEDIMENT DEPOSITION

While studying past reservoir capacity survey data of Panchet reservoir, it was observed that after impounding of Tenughar reservoir, the rate of silt deposition in Panchet reservoir was reduced drastically in the range of 3.65–3.41 MCM/Year from the earlier range of deposition 13.19-8.69 MCM/Year before construction of Tenughat dam. However, it is observed from the Table 1 that silt deposition rate was reduced significantly during the years 1964-66. Record reveals that during this period, reservoir inflow was very low and deposited sediment surface was exposed to sky which caused a great shrinkage. It was further observed that sand stowing activities were also increased a lot during this period. Probably, remarkable reduction in the rate of deposition might occur due to all these stated factors. Average yearly inflow to this reservoir is observed around 4245 MCM (1993-2012). In this study, projected rate of silt deposition in Panchet reservoir has been considered as 3.5 MCM/Year after the survey year of 1985 considering trap efficiency around 90% and same has been used for analyzing projected sediment distribution by the methods of Empirical Area Reduction and Area Increment methods.

STUDIES OF PERCENT RELATIVE SEDIMENT DEPOSITION

It is observed from the plotting of the relative sediment depositions against various reservoir elevations that all individual curves are nicely converged as shown in fig. 2. Slope of the each curve (drawn at individual survey period) varies at different elevations indicating variations in the rate of sediment deposition. Even for a particular elevation, slope of the curves varies at different tenure of the survey periods as pattern of sediment deposition varies time to time. In some places curve shows a vertical rise, which indicates no deposition for that range of elevation in that period. Lesser deposition rate is observed in the dead storage and flood storage zone of the Panchet reservoir. It is also surprised to note that about no deposition is observed between its elevations 106.71 - 109.76 Mt. So, this sort of study provides detail behavior of the pattern of sediment-deposition in the reservoir.

APPLICATION OF THE MODELS

Following the method of reservoir classification as suggested by Borland and Miller, the Panchet Reservoir was found to be Type II. It indicates the shape of the reservoir belongs to a type of Flood-plain or foothill or in-between. He introduced different curves giving the matching sediment distribution pattern against each type of reservoir as per shape. So, sediment was distributed in the projected scenarios using Type II distribution curve in Empirical Area Reduction method.

VERIFICATION OF THE APPLIED MODELS

The projected sediment distribution, in the year of 1996 as obtained by the methods of Empirical Area Reduction (EAR) and Area Increment (AI), has been compared with the sediment distribution found from actual capacity survey data. In case of the Panchet reservoir, correlation was found as 0.992 between the distributions derived from EAR (Borland & Miller) method and observed capacity survey data. When sediment distribution derived from AI method was compared with actual surveyed sediment distribution, correlation was observed 0.993. It is also noted from the fig. 3 that the sediment distributions obtained from EAR and AI methods vary a little from the actual distribution.

ZONE-WISE REDUCTION OF STORAGE AS OBTAINED FROM THE VARIOUS MODELS

Said methods were used (Chaudhuri, 2012) after verification of the models as stated above, for the Panchet reservoir to find reducing capacity of dead storage, live storage and flood storage zones at different projected time intervals limiting to the year of 2060. Future projected trends of reducing capacity for each zone derived from the above said methods, have been compared with the past trend of actual reducing capacity obtained from historical reservoir capacity survey data. Also, zone-wise projected reducing capacities obtained by the different methods have been compared with the ones obtained from the capacity survey carried out in the years 1996 and 2011 at Panchet reservoir.

REDUCTION OF DEAD STORAGE

Predicted reservoir sediment distribution carried out by using different methods as stated at different time intervals indicate that the dead storage zone of the Panchet reservoir may be fully depleted by the sediment around the year of 2060-2070 as observed in the fig. 6. A study (Kumar et. al.; Research Scholar of IIT Kharagpur) by application of SWAT model also reveals that the dead storage of the Panchet reservoir is expected to fill fully by the year 2076. But, it is observed that the projections (fig. 4) of the storages in the years 1996 and 2011 by the said methods differ significantly from the surveyed ones.

REDUCTION OF LIFE AND FLOOD STORAGE

During study of reducing live storage (fig. 5) in the reservoir at Panchet, it was observed that live storages obtained from the surveyed capacity during the years of 1996 and 2011 almost match the projected reducing live storage line derived from the methods of EAR and AI. It is observed from the fig. 5 that around the year 2060-70, available life storage will be around 100 MCM only. But during the studies of reduction of the flood storage zone, it is observed that the projected flood storages obtained from the EAR and AI methods differs a lot from the reality as shown in fig. 6. Actually, factors of uncertainties like reservoir operation policies, inflows, catchment area attributes, grain size distribution etc. play a major role to decide the filling pattern and filling time particularly within live and flood zones of any reservoir.

SEDIMENT CONTROL STRATEGIES

From the above discussions regarding reduction of storage zones, it is felt that some strategies must be adopted either to reduce the silt delivery in the reservoir or to remove the sediment from the reservoir bed itself by implementing different techniques. Prior to discuss the specific policies that may be adopted for the Panchet reservoir, some principle strategies related to sediment control as worked out by Dr. G. L. Morris (Morris, 1991) are described briefly at below which has been adopted in many reservoirs throughout the world.

1) **Reduce sediment delivery:** The volume of sediment delivered to the reservoir can be reduced by controlling erosion within the tributary watershed or constructing sediment traps or debris basins to capture eroded sediments before they enter the reservoir.
2) **Route sediments through or around the reservoir:** Techniques to pass sediment through or around the reservoirs include the venting of density currents, reservoir drawdown during periods of high sediment discharge to reduce detention time and sediment accumulation, and construction of off-channel structures including sediment diversions and off-stream reservoirs.
3) **Removal of deposited sediments:** Previously deposited sediments may be removed by hydraulic scouring, dredging, explosive mobilization or excavation using earth moving equipment in the empty reservoir.

The use of one strategy does not preclude the use of another as they are all complementary. Table 2 contains a representative list of reservoirs worldwide where these methods have been used to reduce or completely control sediment accumulation. In the following sections, different techniques adopted for routing and removal of sediment are described in short.

ROUTING OF SEDIMENT

Sediment routing refers to the methods of maintaining the flow of fluvial borne sediments beyond the impounded reach. Sediment routing differs from sediment flushing in that the objective of the former is to prevent sediment deposition within the reservoir pool and the objective of the latter is to erode previously deposited sediments. When reservoir drawdown is used to control sedimentation, both sediment routing and sediment flushing can occur simultaneously.

Sediments are mostly discharged over relatively short periods of time when both discharge and sediment concentrations are high. Sediment routing techniques focus on separating the run off hydrograph into two parts, a “clean water” part and muddy water” part, and then transporting the “muddy water” with high sediment concentration to a point downstream of the dam without allowing these sediments to settle in the reservoir. Different sediment routing techniques are briefly discussed below.

Reservoir Drawdown

Most sediment load enters the reservoirs during floods. In conventional operation, Floodwater is impounded behind the dam and the sediment load which is being transported by the floodwaters becomes trapped in the reservoir as flow velocity and transport capacity

decreases within the impounded area. Reservoir drawdown may be used to decrease reservoir storage capacity during the period of high flood flows, thereby decreasing (temporarily) the capacity-inflow ratio and trap efficiency during periods of greatest sediment discharge. When the reservoir capacity is decreased, sediment-laden water has a shorter residence time within the reservoir, velocities and bed shear stress are higher, and lesser sediments are deposited. A drawdown strategy can be particularly important for passing the rising limb of a storm hydrograph through the reservoir, since sediment concentrations tend to be higher during the first part of the storm runoff than in the latter part.
The Chinese have coined the slogan for this type of strategy, "Impounding the clear water and releasing the muddy flow" (Wu, 1984). Operation of reservoirs by lowering the pool level during the flood season to sluice out waters with high sediment concentration is normal in many reservoirs in China. The mode of operation is based on the fact that 80 to 90 percent of the annual sediment load carried by the river is discharged in July and August, whereas only 25 to 50 percent of the annual runoff occurs in the same period.

Reservoir emptying

Reservoir emptying operations may be used periodically for a small reservoir where the storage capacity could not be maintained for beneficial use after a period of several years of operation. For instance, in a moist area where the base flow is adequate for the projected uses during the wet season, but not during the dry season, water may be allowed to flow freely through the reservoir during the wet season, in essence operating under a condition of full drawdown. This will not only minimize the sediment accumulation by producing a capacity-inflow ratio near zero during the wet season when most sediments are discharged, but sediments deposited during the previous impounding period may also be scoured from the bottom during this period. The reservoir would be filled toward the end of the wet season, to provide releases during the drier season.

Sediment By-Pass

Sediment-laden floodwater can be routed around a reservoir by using a diversion tunnel. In effect, the tunnel acts as a bottom sluice. This strategy has been used in Switzerland (Reed, 1931), at the Sautet and Chambon reservoirs in France (Remenieras and Braudeau, 1951) at the Nagle reservoir in S. Africa (Annadale, 1987), and at the Ho-Ku and Nan-Hua reservoirs in Taiwan (Hawang, 1985). The Nan-Hua example is interesting because the upstream portion of the reservoir is managed for sediment flushing, and only relatively clear water is permitted into the downstream after bay which contains the main storage volume of the reservoir (fig. 7). This "compartmented reservoir" strategy is limited to those sites where topography permits relatively short tunnels.

Off-Stream Reservoirs

An off-stream reservoir can draw water from a stream using a schedule which excludes the peak sediment loads. This strategy was analyzed for a small proposed municipal supply reservoir on the Fajardo River in Puerto Rico. Based on a hydrologic analysis of the average daily flows and a sediment rating curve based on these daily flows, the reservoir was conceptually designed to be supplied by a pipeline or canal from a stream diversion. As long as the reservoir is not full, this diversion will discharge into the reservoir a flow equal to the capacity of the stream diversion canal or the base flow of the river, whichever is smaller. Sediment inflow into the reservoir is automatically minimized under this operation because during wet periods when peak flows and peak sediment discharges occur, the reservoir will be full or nearly full as a result of preceding rains.

Parallel Reservoirs

The Dalingkou reservoir in Hebi Province of China took advantage of local topography by building two parallel reservoirs connected by a water supply tunnel. The reservoir in the smaller watershed with better vegetation was used as clear water storage for water supply, while the other mainly worked as a flood retention reservoir. This layout provided an operation scheme permitting water storage as well as sediment flushing. This scheme could be feasible where the appropriate topographic conditions prevail, to minimize construction costs.

Reservoirs in Series

The presence of series of reservoirs on a river presents special problems as well as opportunities for sediment control. At Jiaojiazhuang in the Herbi Province of China, two reservoirs were constructed in series, 2.5 km apart, on the same river. At the upper reservoir, the initial stage of the flood containing high sediment concentrations is allowed to pass and the gates are closed to retain the clearer water in the falling limb of the hydrograph. The muddy flow passing through the upstream reservoir is captured at the downstream site. After the water in the downstream reservoir has been diverted to beneficial use, the clear water from the upstream reservoir is released to scour the deposited sediment from the downstream site (Zhang Hao et al, 1976).

Based on flushing experience at the three Rioni hydropower reservoirs in Soviet Georgia, it was found that best results were obtained if flushing was initiated at the downstream reservoir to create a channel which will transport, without settling of the sediments, subsequently flushed from the more upstream sites. If the upstream reservoir is flushed first and a channel has not been scoured through the bed of the downstream reservoir, the sediments flushed from the upstream site tend to spread out and settle onto the sediments of the downstream site (Kereselidze et. al., 1985).

Venting of Density Currents

Floodwaters with a heavy sediment load are denser than clear water and when they enter a reservoir they tend to sink beneath the surface and travel downstream beneath the clear water (Fig. 8). Under favorable conditions these submerged density currents can travel more than 50 km downstream, eventually reaching the face of the dam (Bell 1942). For venting to be successful, without any excessive wastage of water, the vents must be opened at the appropriate time based on the travel time of the density current through the reservoir. Also, the use of numerous small valves is reportedly more practical than the use of one or two larger ones, since the larger flow will pull in water from above the density current zone, increasing the water / sediment ratio.

Venting of sediment-laden density currents has reportedly be successful in discharging over half the annual sediment load to the Iril Emda Reservoir in Algeria and the Nebeur Dam in Tunisia (Duquennois, 1956), and there has been considerable success using this technique at a number of sites in China (Fan, 1985,1986). Speaking of reservoirs in India, Murthy (1977) observed that “Many of our reservoirs are having a very high trap efficiency and the assumption that most of the fine silt and a part of the medium silt would pass out of the reservoir through the spillway and other outlets as density currents etc., does not hold in practice” (p17).

SEDIMENT REMOVAL

The methods of sediment control stated previously cannot completely arrest sediment accumulation; the reservoir will continue to accumulate sediments, even if at a greatly reduced rate. Sediment must be removed from the reservoir eventually if it is to remain in service indefinitely. Sediment removal methods tend to be costly and have large environmental impacts, as compared to the other methods previously discussed. There are two principal means for the removal of previously deposited sediments from a reservoir: one, hydraulic flushing with scour and other, dredging. A third method explosive mobilization is also found in different literatures.

Hydraulic Flushing

Hydraulic Flushing involves the release of water from a reservoir through a low level outlet, and then allowing the water to flow across and it hydraulically scours the deposited sediments. When this process is initiated in a reservoir which has already accumulated a considerable sediment deposit, it will erode (fig. 9) a "main channel" through the sediments while leaving "floodplain" deposits relatively unaffected by scour. The flushing can be conceptualized in three stages: drawdown, erosion and refill. The flushing sequence is described as follow. The drawdown stage corresponds to the release of water from the reservoir to reduce pool level to the minimum level. The erosion stage corresponds to the full drawdown of the reservoir. Pool level is reached its minimum level and flushing outlets are fully opened. Following the flushing, the bottom outlet is closed and the reservoir is allowed to refill, returning it to normal service. In China, where flushing periods are usually prolonged, a specific date is usually established to begin the refill. This date may represent a compromise between many conflicting purposes.

Explosive Mobilization

It is possible to mechanically mobilize reservoir sediments using explosives so that they could be washed and expelled at downstream. This procedure might be particularly attractive for cohesive sediments, which are difficult to erode by hydraulic action. This method has been used at some small and medium sized reservoirs in China, such as the Zhiyu reservoir in Guangling County, Red Flag reservoir in Pinglu County, Shan Xi Province, as well as Gufengshan reservoir. One article in Chinese experience, described the investigation of the effectiveness of blasts in saturated silt. Based on experiments carried out on a floodplain of the Yellow River, it was found that in saturated silts, the vibration inducted by the blast is comparatively intense and degenerates slowly, especially for low frequency vibration. It was reported that 0.67 kg of dynamite is required to excavate 1 m^3 of earth for a flushing channel on the flood plain and 0.23-0.5 kg dynamite is needed to excavate 1 m^3 of earth on the side slope of the channel (Hu, 1989). The use of explosives was examined at the Lofza reservoir in Puerto Rico, where it was determined that nitro-methane could be implanted into the sediments and detonated during the passage of a flood which would carry the mobilized sediments at downstream. One of the principal impediments to this method is that it would create sediment concentrations in excess of 50,000 mg/lt. at downstream of the dam, which is unfavorable to environmental implications.

Dredging

Dredging is frequently used to recover storage capacity of the reservoirs. It is observed from Table 2 that deposited reservoir-sediment has been removed by dredging in various small reservoirs in different countries. Dredging was carried out in the delta region of the Lake Springfield, Illinois in United States to remove sediment amounting about 2.7 MCM. Dredged materials were heaved within 1 Km. of the reservoir. Though, typically, dredging is done frequently in US in the lakes having capacity less than 1 MCM. Recently dredging projects have been taken up in US for removal of sediment amounting 0.76 MCM from the Mission lake located in Kansas. The Guanting reservoir in Beijing receives three tributaries Sanggan, Yongding and Guishui River. To control the reservoir sedimentation, a dredged channel about 3.2 km long on the mouth bar near confluence of Yongding and Guishui River was suggested. To make use of the water below elevation 474 m in the Guishui Zone, a channel about 4.5 km long, 15 m wide at the bottom and 2 m deep was dredged in the mouth bar area in 2002. So, it is observed that dredging has been carried out in many reservoirs to remove deposited sediment with aims of different operational purposes.

REMOVAL OF SEDIMENT IN PANCHET RESERVOIR

In case of the Panchet reservoir, it is observed from the study of the past trend in fig. 4 that the rate of deposition within the dead storage zone of the reservoir has been reduced since 1985 and onwards. It is also observed from extrapolation of the past trend of actual deposition in another study (Chaudhuri, 2012) that the dead storage zone will be silted very slowly and it will take a considerable period of time to be filled fully with sediment. Further, it is observed in fig. 6 that already rate of deposition has been increased in the flood zone, so, it is expected to increase the rate of siltation in the coming years in the live zone also. However, it is observed from the capacity survey data in the year 2010-11 that the capacities amounting 130, 83, and 66 MCM have been lost from the original dead, conservation and flood storage capacities of 236, 252 and 500 MCM respectively due to sedimentation since inception. So, considering the volume of deposition and the pattern of the rate of deposition in the various zones of the reservoir, it is appropriate time to think about the strategies that may be taken up for this reservoir to increase the storage volume.

SEDIMENT REMOVAL STRATEGIES

Usually, the Panchet reservoir is filled to its top of conservation level during the month of October. Subsequently, reservoir level reaches slowly nearer to its dead storage level in the month of May just at the end of the water year. So, after the end of the monsoon period, dredging may be started in the reservoir bed of the flood zone and gradually it may be encroached to the bed of the conservation zone as shown in the schematic diagram in fig. 10. The dredged materials of the reservoir may be heaved into the borrow areas or into the abandoned open mines by rolling buckets placed on a conveyer belt. As the excavated soil is very much fertile, it will convert the barren areas into a productive green belt. So, developed greeneries will also enhance the environment of the neighboring areas. In case of the removal of deposited sediments from the dead storage zone, hydraulic flushing may be carried out on regular basis during monsoon period; same may scour the long-standing silts from the reservoir bed located nearer to the dam or spill-way. In this context, it is felt to discuss a strategy regarding re-use of the excavated earth that may be obtained from the de-siltation of Maithon reservoir. If formation of the ring embankment around the periphery of the Maithon reservoir is found feasible to increase the height of the reservoir, the excavated earth of the reservoir may be re-used to construct the ring dykes around the reservoir.

COST EFFECTIVE MEASURES FOR REMOVAL OF SEDIMENT

There are two big issues usually faced in case of the mechanical dredging, one, cost and other, heaving-place of the dredged materials, while deciding the strategy of dredging in a large reservoir. Already, regarding place of heaving to dump dredged materials of the Panchet reservoir and way of transport have been discussed above. Obviously, use of rolling bucket on conveyer belt will reduce the transportation cost and time. To reduce the involvement of at a time cost, mechanical dredging may be taken up in this reservoir in a phase wise manner. In this section, some strategies regarding effective removal of deposited sediment from the reservoir are discussed briefly. For effective removal of deposited sediment, earth may be excavated in the shape of channel at frequent intervals up to the depth as much as possible, so that maximum disturbances of the excavated surface occur within the reservoir bed. The preferable locations of these dredged channels are at away from the main channel. If the dredged channel is close to the main channel, a large amount of sediment would directly enter and deposit in the dredged channel. It is anticipated that during monsoon flood period, density current of the incoming flood may scour the earthen heaves in between the successive channels in filling process. Portion of the scoured earth will be deposited at the bottom of the channels and the remaining scoured earth may be expelled out through the under sluices of the dam by flushing. Maximum removal of the loosen earth and scoured soil may be achieved by venting out the density current through the under sluices of the reservoir. Naturally, during this process, hydraulic flushing will also be occurred which may scour the reservoir bed of dead storage zone nearer to the dam to form channel. Thus, venting of the density current may expel considerable earth from the reservoir after dredging and in overall the said process will reduce the cost of disposal of over-all sediment.

AN ALTERNATE OF HYDRAULIC FLUSHING

If hydraulic flushing as discussed earlier does not work well for removal of deposited sediment in the dead storage zone, hydraulic dredging may be performed for the same. It may be done by a movable pipe equipped with a self-suction head, which is powered by natural water head difference and is used to discharge the deposits from a reservoir to the place at the outside. This process has been applied in the several medium and small-sized reservoirs in US and China, it shows that the approach, when applied in a proper manner with availability of rich water, is able to discharge not only the deposits formed in the year, but also those formed in the previous years, with the cost being a quarter of that with a dredging ship. The dredging approach using self-suction piping is found efficient in sediment discharging, and economic in energy consumption. This process (Enhui, J. et. al.) is also applicable in large-sized reservoirs where there are large enough water head differences available and where the deposits consist of mainly fine sediment particles and comparatively less consolidated.

CONCLUSION

It is observed from the above studies that the different storage zones of the Panchet reservoir are silting up rapidly where reduced life storage is expected to be available around 100 MCM by the year of 2060-70, if further action is not taken to reduce the rate of silt deposition or to remove the deposited sediment. So, it is definitely required to evacuate the silt from the reservoir to increase its operation life. Now, it is a great question that how it may be achieved. Definitely, the only answer is “Good will”. This study recommends that on an experimental basis, silt evacuation process may be started by dredging followed by venting of density current. It is also required to observe or to monitor the amount of silt vented out from the reservoir by sluicing or hydraulic flushing. If experiment-operation is found successful, de-silting work may be taken up in phase wise manner to restore the original live capacity. Obviously cost effective means are to be explored while finalizing the dredging strategies. But, it is sure that only planned actions and determinations may bring the success of silt evacuation for this reservoir.

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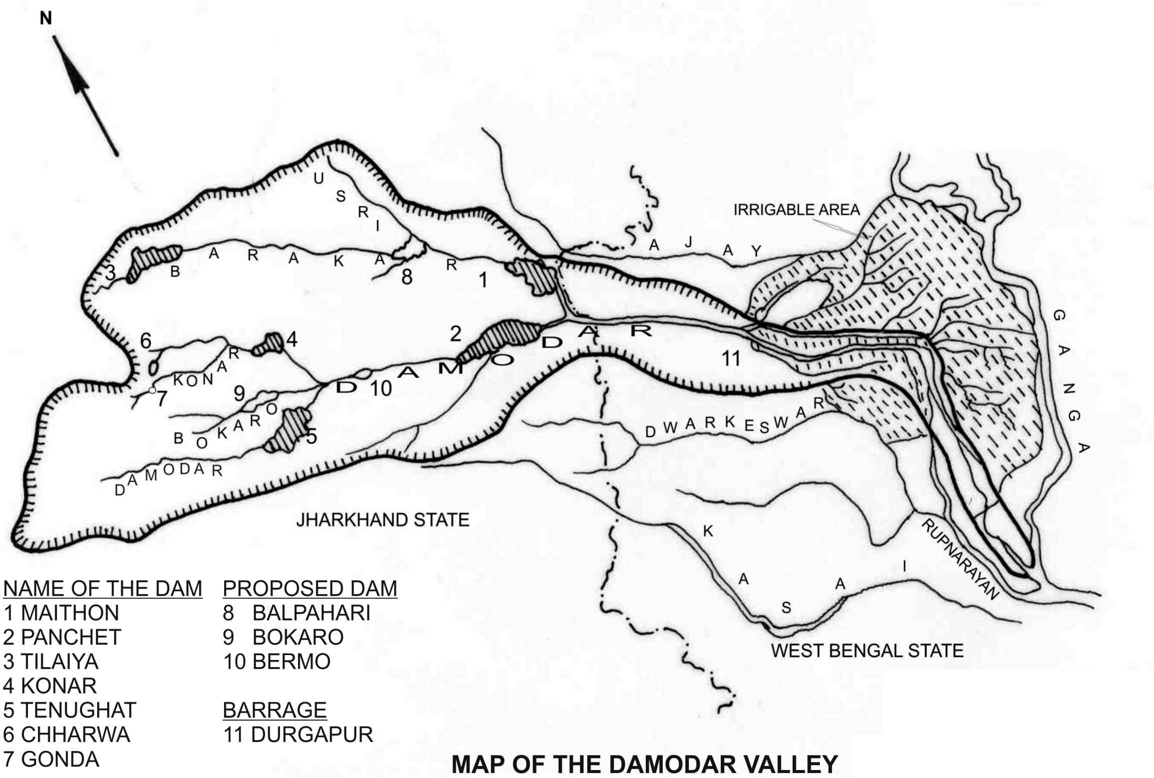
TABLE 1 STUDY OF SILT DEPOSITION RATE IN PANCHET RESERVOIR

YEAR	SEDIMENT DEPOSITION		YEAR	SEDIMENT DEPOSITION	
	MCM	MCM/YR		MCM	MCM/YR
1956-62	79.16	13.19	1956-62	79.16	13.19
1956-64	96.54	12.07	1962-64	17.39	8.69
1956-66	105.79	10.58	1964-66	9.25	4.62
1956-74	145.12	8.06	1966-74	39.33	4.92
1956-85	185.32	6.39	1974-85	40.20	3.65
1956-96	222.80	5.57	1985-96	37.48	3.41

Table 2 SEDIMENT CONTROL STRATEGIES ADOPTED IN THE RESERVOIRS WORLDWIDE

Reservoir	Country	Method	Original capacity MCM	Water shed area Sq. Km.
Flushing				
Sanmenxia	China	F,B	3500	684000
Helgshanz	China	F	13.3	163
Heisonglin	China	F,B	14.3	370
Honglinjil	China	F	16.6	1364
Zenziliang	China	F	36.6	1740
Shuicaozi	China	F	9.58	1233
Gensanpee	Taiwan	F	7.7	10.6
Guernsey	US	F	91	41,958
Grimsel	Switzerland	F,B	95	
Gebidem	Switzerland	P,B		150.3
Alps region	Austria	P,D	6.8	
6 med. Head res.	USSR	P,B		
Sto. Domingo	Venezuela	F,B	3	427
Sennar	Sudan	F	600	
Khahm el girba	Sudan	F	1300	112400
San giuliano	Italy	F	70	
Hamiz	Algeria	D,F	22	139
Meurad	Algeria	P	9.1	
Ksob	Algeria	F	6.4	
Iril ewda	Algeria	F,B		
Density current				
Nebeur	Tunis	V	300	10300
Serre-poncon	France	V	1272	
Fengjiasan	China	V	398	
Ighil emda	Algeria	V	160	
Dredging				
Rioumajou	France	D		
Rendina	Italy	D	7	
Cheur Fas	Algeria	D	82	4190
Sig	Algeria	D		
Fergoug	Algeria	D	18	
Springfield	IL, USA	D		
Paradise	IL, USA	D	3.87	
Barcroft	VA, USA	D	2.35	
Tiamjiawam	China	D	9.42	97
Flow Diversion				
Amsteg	Swiss	S	0.19	404
Rempen	Swiss	S		
Turgison	China	S,W		
Yuanhe	China	S		
Talagan	China	S	1.54	
Molimao	China	S		
Upstream debris Basin				
Wingzhaizi	China	U	2.1	
Jiaojiazhuang	China	U		
Guanting	China	U	2270	43000
Naodehai	China	U		

F: Full drawdown Flushing; P: Partial drawdown flushing; V: Venting density current; S: Sediment or flow diversion; W: Warping (Diversion of muddy flow to irrigation); B: Bottom Sluice used; D: Dredging; U: Upstream Debris Basin.



MAP OF THE DAMODAR VALLEY
FIG. 1

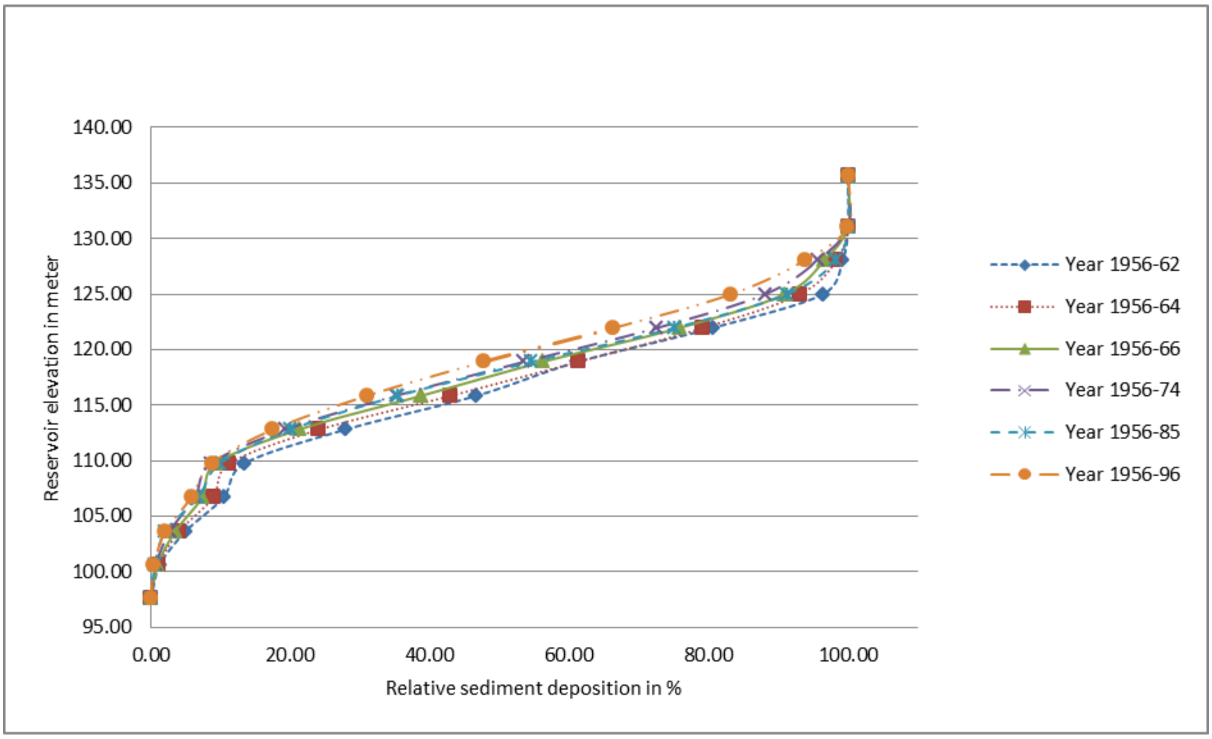


Fig. 2 Plotting of Relative Sediment Deposition VS. Elevation for Panchet Reservoir

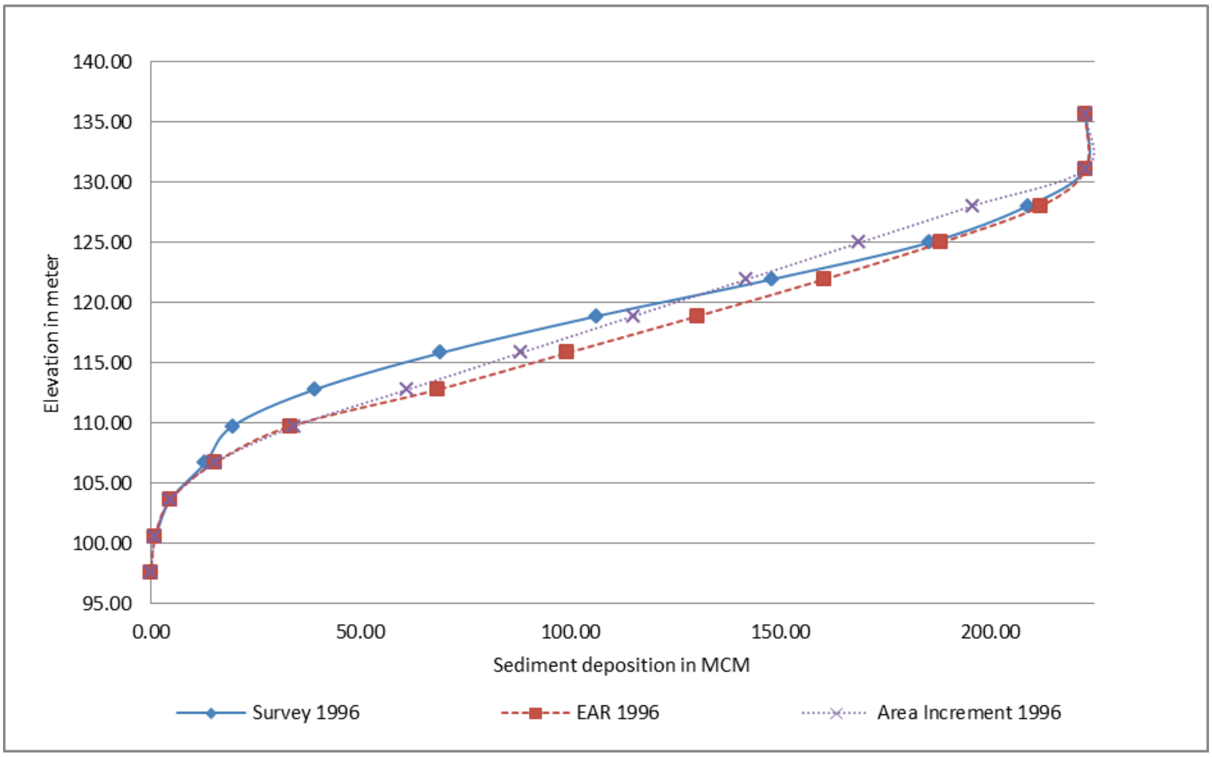


Fig. 3 Verification of Models applied to Panchet reservoir

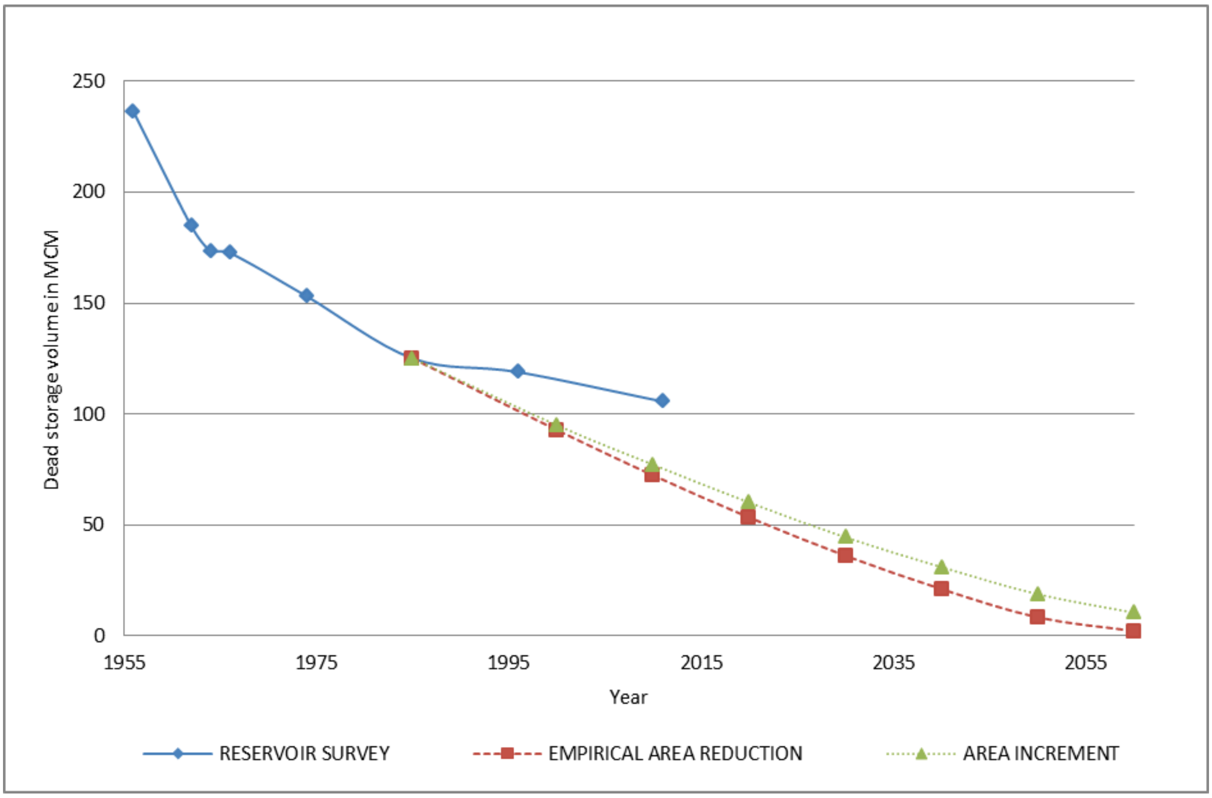


Fig. 4 Reducing dead storage of Panchet reservoir

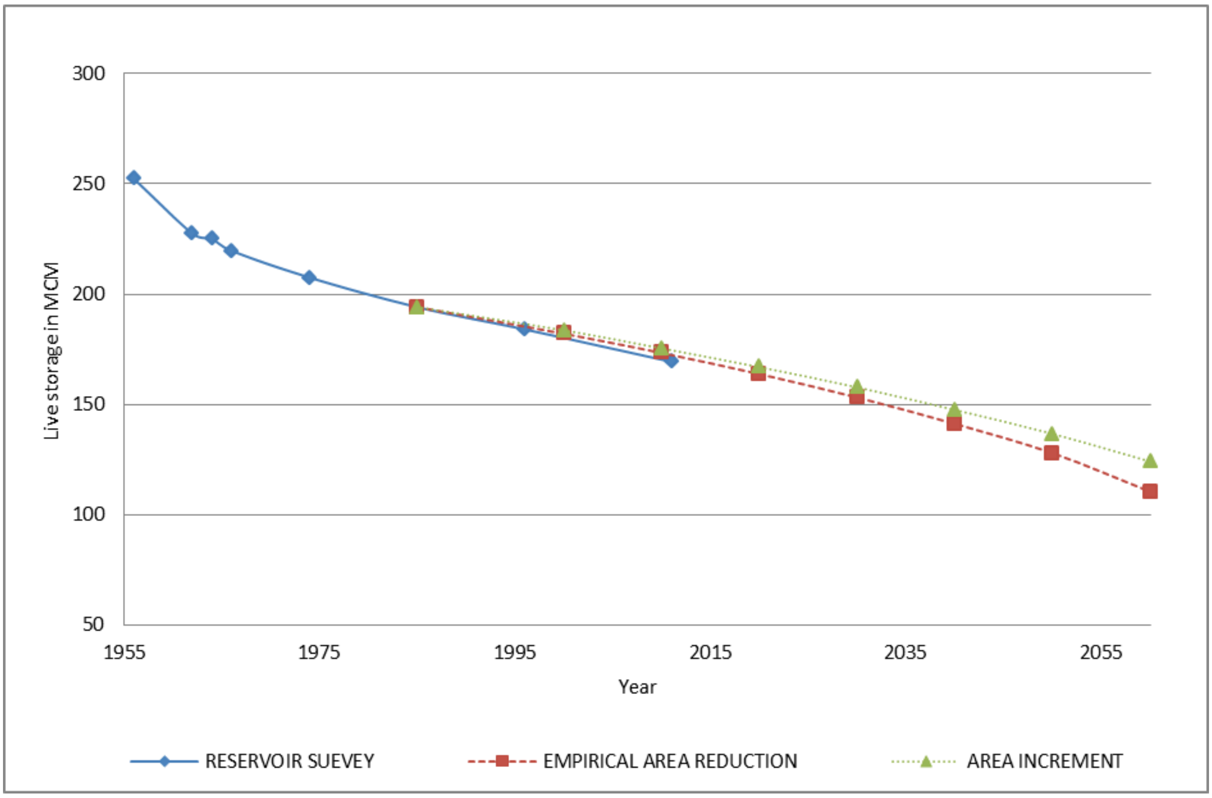


Fig. 5 Reducing live storage of Panchet reservoir.

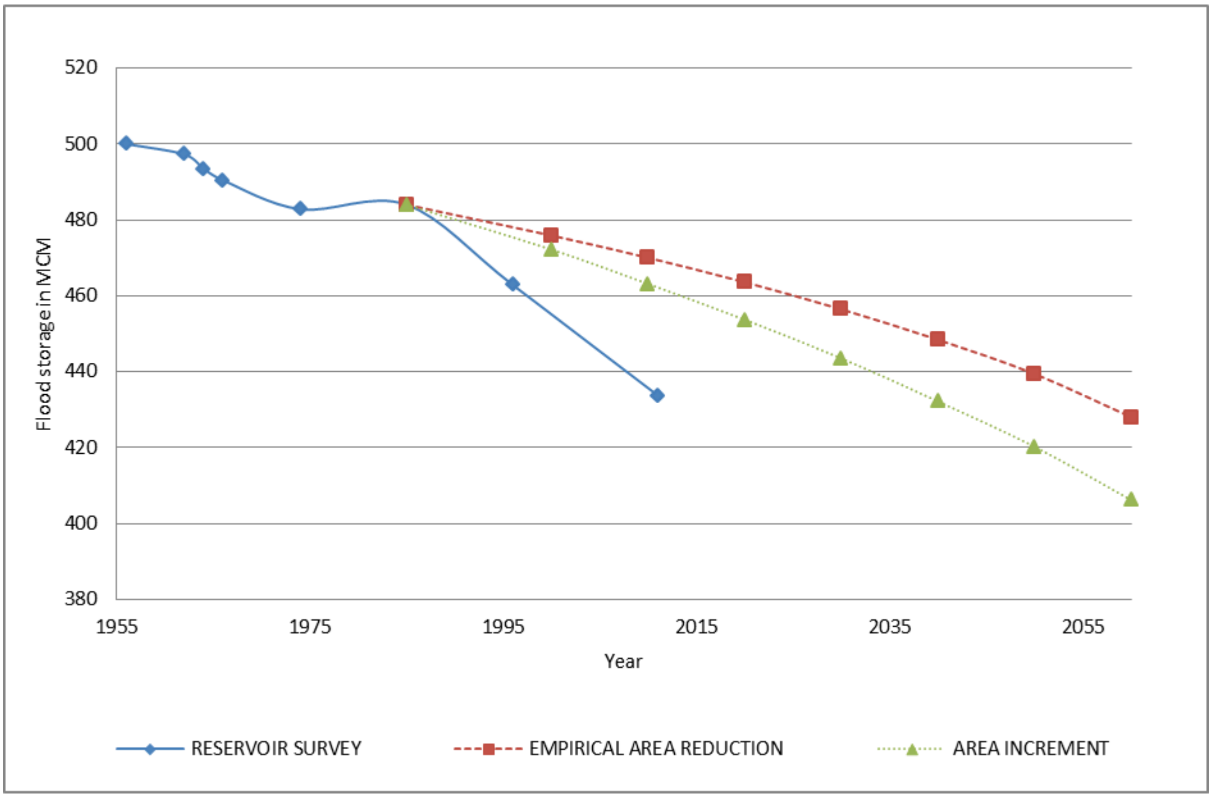


Fig. 6 Reducing flood storage of Panchet reservoir.

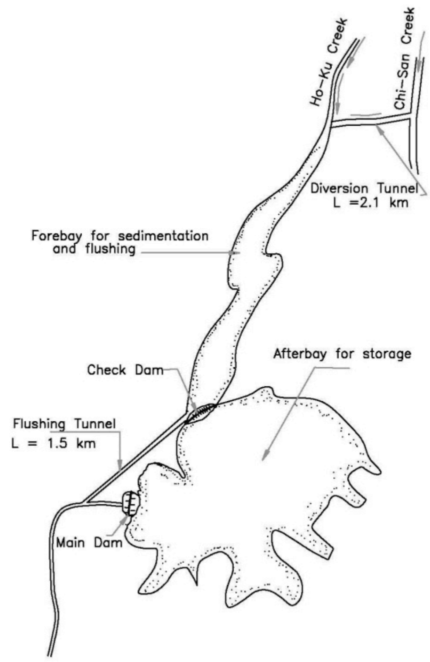


Fig. 7 Schematic diagram for By-passing of sediment at Nan-Hua reservoirs

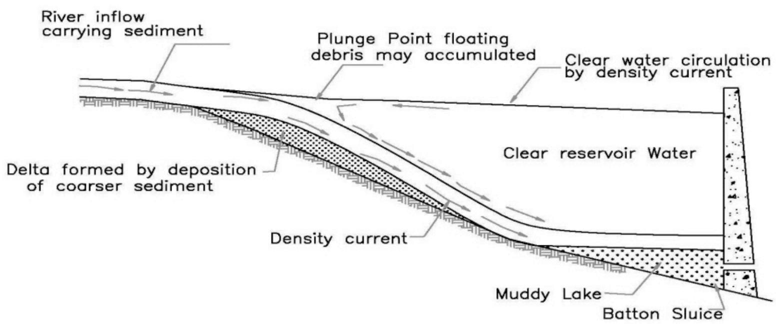


Fig. 8 Lay-out diagram for formation of density current in a reservoir

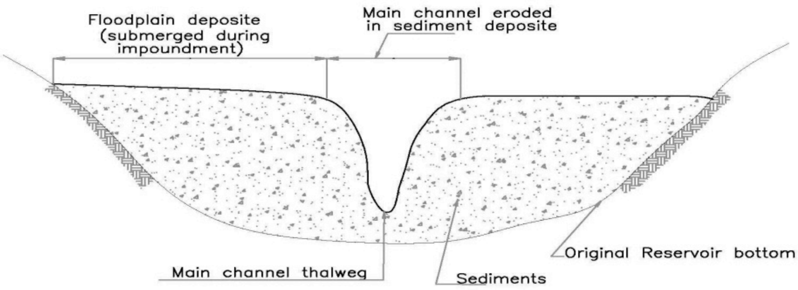


Fig. 9 Formation of channel in the reservoir near to dam during flushing

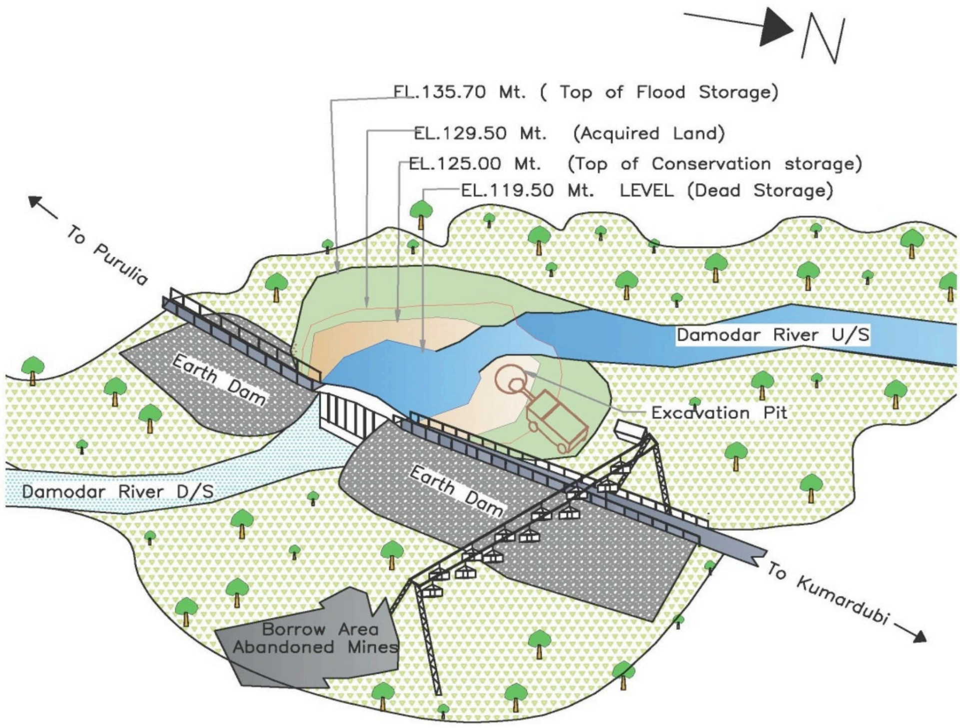


Fig. 10 Schematic diagram for dredging and transportation of excavated earth