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Tel: 011- 29583628

**Government of India**
**Central Water Commission**
**Hydel Civil Designs (N&W) Dte**
*******

8th Floor (S), Sewa Bhawan
R.K. Puram, New Delhi
Date : 03/10/2018

**Sub : Guidelines for Sediment Management in Hydropower Projects.**

Sir/Madam,

Reservoir sedimentation has been a pertinent issue for diversion structures for a very long time. Sedimentation of reservoirs pose problems like loss of live storage, erosion of turbine coating, frequent shutdown of power due to maintenance of hydraulic machinery etc. Considering the need of the hour to address these issues, Central Water Commission had constituted a committee for Formulating Guidelines on Planning of Structures of Hydropower projects on Sediment Management for sediment management in hydropower projects vide letter dated CWC. No 06/14/2014-CMDD(NW&S)/362 dated 20/11/2014. Four meetings of the committee took place wherein the guidelines were discussed in detail. After due consultation and studies, the final draft of the guidelines "Sediment Management in Hydropower and Water Resources Projects" (enclosed herewith) is prepared duly incorporating suggestions that evolved during the meetings and otherwise from committee members and special experts.

Now, it is desired that any valuable and relevant views/suggestions on the above mentioned guidelines, may be send to email address cedesnw@nic.in within 4 weeks of issue of this letter.

**Encl. As above**

Yours Sincerely,

**(M RAMESH KUMAR)**
**DIRECTOR**

**To :**

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3. Chief Engineer, Designs(E&NE), CWC, New Delhi
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**(M RAMESH KUMAR)**
**DIRECTOR**

सत्यमेव जयते

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION

# GUIDELINES FOR SEDIMENT MANAGEMENT IN HYDROPOWER & WR PROJECTS

DESIGN (N&W) ORGANISATION

**SEPTEMBER, 2018**

# Table of Contents

## Table of figures

# Part-I

# Management of Reservoir Sediment

## 1. Introduction

Handling of sediments is a major challenge in the design and operation of hydropower plants (HPPs). At medium and high-head HPPs on sediment-laden rivers, hydro-abrasive erosion on hydraulic turbines is an important economic issue because it increases maintenance costs, and reduces turbine efficiency, electricity generation and hence revenues. Reservoir sedimentation may have the following negative effects:

- Loss of active storage volume, and thus reduced ability to compensate in- and outflows for hydropower, irrigation, drinking water and flood retention;
- Increased turbine erosion because of higher suspended sediment concentration (SSC) and coarser particles in power waterways due to reduced trap efficiency of the reservoir.
- Changes in approach channel hydraulics leading to difficulties in diversion discharges through the intake. (Applies to barrages and small dams)

The wear of turbines by sediments may be high if the water head is over 20 m and very high for high heads, especially if the quartz content of sediments is high. In some past cases turbines have been abraded too badly for further use after just a few months of operation. This has resulted in high financial losses due to reduced power revenue and repair costs.

## 2. Sediment Data

Many past damages or losses from reservoir siltation were in fact linked with incorrect evaluation of the sediment volume and size and could have been much better mitigated by tailored design and operation. In many cases, the catchment area, land use undergoes considerable land use changes leading to departure from the design stage assumptions.

Sediment load is also governed by geomorphological changes encountered in the geologically young areas like Himalayas where most of the hydropower development is concentrated. Relatively small reservoirs for diurnal storage are strongly affected by major landslides induced due to various reasons like severe rainstorms or earthquakes. In such cases a few pulses of large sediment load virtually fill up the reservoir in a single flood as witnessed in some of the projects in the state of Uttarakhand.

The evaluation of sediment inflow is difficult because the sediment content varies considerably for a same river according to the flow and the season. It may be much higher during the first part of a flood and the total yield may vary over the years. It is thus essential to devote enough time and cost to this problem and choose the right method and place of measurement. However, the result cannot be very precise and the design should take into account the associated uncertainties. Better data will be obtained during the first years of operation and will favour optimised reservoir management. Data observed at the existing HPP's around the project also need to be pooled.

## 3. Concepts of Reservoir Life

Dams (or Reservoirs) were previously (even currently too) designed using "design life" approach. This approach assumes a finite project life and gives superficial attention (if any) to what will happen to the dam at the end of its life.This results in substantial environmental, social, economic and safety considerations being left to subsequent generations.

With the increasing pressures on availability of land and environmental concerns, it is no longer possible to consider a reservoir site as "consumable" and therefore it is imperative to consider conservation of the capacity of the reservoir for an indefinite period in future irrespective of its "economic" life considered for the investment purposes. Based on this consideration, an alternative approach is being now advocated for adoption called - "life cycle management". The ultimate goal of this approach is sustainable use, where the major functions of the dam are maintained, through good management and maintenance practices, in perpetuity.

The structural life of dams, with reasonable levels of maintenance, is unlimited. With the right design and sustainable management of reservoir siltation the envisaged benefits from any scheme can be secured on a long-term basis. The sustainable sediment management seeks to –

a) Retard the rate of storage loss
b) Maintain long-term reservoir capacity and
c) Bring balance into sediment inflow and outflow to maximize usable storage, hydropower production or other benefits

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 **[d]:**

- ***"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."***

# 4. Dealing with Reservoir Sedimentation

## 4.1 Watershed Management

There are broadly two strategies to reduce the sediment yield entering a reservoir: either prevent erosion (option-1) or trap eroded sediment before it reaches the reservoir (option-2). The option-1 can be realized through watershed management.

The rehabilitation of some watersheds can dramatically reduce the rate at which sediment, nutrients and other contaminants are delivered to a reservoir.

A number of reservoirs world over are undergoing sedimentation problems. An option to trap sediment upstream could be construction of upstream reservoirs that will act only as sediment retention structures. Aim should be to evolve a sustainable solution rather than postponing delivery of sediment to the main reservoir. This would require putting in place a bypass arrangement. This is especially relevant for large strategic storage projects of the country as their storage capacity is crucial for food and energy security of the country.

Identification of areas in the catchment on the basis of their erosion and silt yield criteria is needed at the planning stage. Such exercise can be carried out for the directly draining catchment for the reservoir and suitable sediment arresting measures can be incorporated in the planning and costing of the project. This exercise can be repeated at regular intervals like 10 years so that the changing situations are taken care of.

While locating the site for the dams, the potential localised sources of sediment can be avoided for longevity of the reservoir.

## 4.2 Sluicing

Sluicing is an operational technique in which sediment-laden inflows are released through a dam before the sediment particles can settle, thereby reducing the trap efficiency of the reservoir. This is accomplished in most cases by operating the reservoir at a lower water level during the flood season in order to facilitate sufficient sediment transport capacity (turbulent and colloidal) through the reservoir. After the flood season the pool level is raised to store relatively clear water.

This technique is quite useful for Himalayan rivers which are perennial in nature. In case of non-perennial river based reservoirs, a difficult choice exists between building up conservation storage versus managing the sediment laden floods. Many of the terminal reservoirs across Himalayan foot hills will have to address this problem.

For reservoirs which may be emptied every year at the end of the dry season, it is often advisable to use sluicing, i.e. to keep the reservoir empty during the first part of the flood season, operating the river as close as possible to natural conditions and thus avoiding most siltation. This solution is flexible, environmental friendly and can be applied to many dams, particularly irrigation dams. The optimum size of the sluicing gates deserves a specific study for each dam according to hydrology, purpose of the dam and sediment data. For many dams these gates may be used for both sluicing and flushing.

## 4.3 Diverting Floods

Sluicing cannot apply to reservoirs kept virtually full all the time. Diverting part of the flood discharge (when significantly siltated) by a tunnel by-passing all or most of the reservoir length may then be cost efficient especially if the rock quality favours unlined or partly lined tunnels and if the slope or curves of the rivers allow rather short tunnels. Another advantage of this solution is that most of the relevant investment may be made during operation when the need can be more precisely evaluated. Alternatively, such tunnels may sometimes be used also for diverting floods during construction. Canals may be used instead of tunnels for low reaches of very large rivers.

## 4.4 Flushing

Sediment flushing is a technique in which the flow velocities in a reservoir are increased to such an extent that deposited sediments are remobilised and transported through bottom outlets. Flushing increases water velocities through the reservoir temporarily in order to scour and remove sediment deposits. Worldwide efficiency of this has varied considerably and the cost efficiency seems mainly linked with the following conditions:

- A ratio of reservoir volume to the annual discharge of under 20 or 30%
- A ratio of the reservoir volume to the annual sediment discharge under 20 for early sluicing, under 50 for late sluicing
- A significant river slope.
- A rather narrow valley in the reservoir area

Successful flushing thus applies mainly to high or medium reaches of rivers. The choice of design and level of gates for flushing is a key problem. For gates operating with high head, the problem of wear or cavitation with erosive sediments may be high. For low dams, the gates should be close to the natural river bed. For high hydropower dams, the optimum level of sluicing gates may be 40 to 50 m under the reservoir maximum level, but is more generally dictated by the associated minimum operating level of the reservoir.

Usually flushing cannot avoid siltation in a part of the reservoir but may, after some years, reach an equilibrium between further sediment inflows and flushed sediment outflows.

Flushing in large hydropower reservoirs may be mainly for moving sediments from live storage to dead storage and thus keeping enough storage capacity in the upper part of the reservoir for daily power peaks. The width (in metres) of channels created by flushing in silt deposits is in the order of $\mathbf{10*q^{0.5}}$(where q is the discharge in $m^3/s$) and may thus be 100 m or higher. It is smaller if flushing is made only after some years of silt consolidation.

For each site, the efficiency and the optimum operation of flushing may be difficult to define precisely at the time of design, but the cost of flushing outlets is often a small part of the oveerall investment, and adding them later could be difficult and very expensive. Flushing (Drawdown) has proven to be quite successful in hydraulically evacuating reservoir sediments.

## 4.5 Density Venting

The density current, a gravity driven flow, occurs because of density differences between the sediment-laden flow and ambient stagnant water, which often governs the deposition process in reservoir sedimentation by transporting fine materials. The plunging current can move as an underflow over long distances toward the dam to form a submerged muddy lake. In the muddy lake, the suspended fine particles gradually deposit and consolidate, if they cannot be released from the reservoir during a flood. However, the density current may be vented through low-level outlets while it reaches the dam to reduce sediment accumulation within the impounding area [**e**].

For releasing a turbid density current from a reservoir, the planning and design of an outlet operation requires accurate prediction of sediment transport. The operation of an outlet structure, while the muddy lake is formed, is necessary to reduce sediment deposition.

Effectiveness of turbidity currents venting depends on:

- Topographic features of a reservoir
- Length of the reservoir
- Magnitude of the incoming flood peak
- Inflow sediment characteristics
- Water level in the reservoir during the period of venting
- Outlet elevation in relation to the reservoir bottom
- Discharge capacity of the outlets
- Mode of operation of reservoir

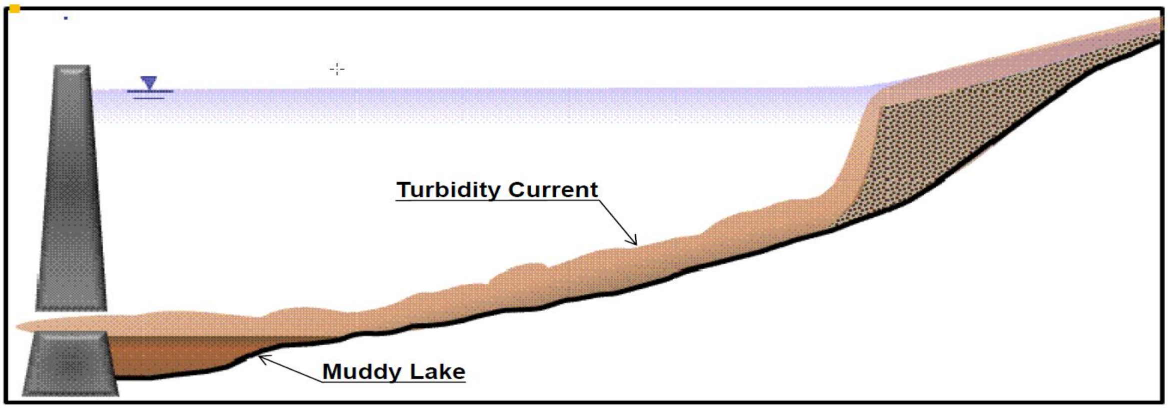


Fig.1 Release of turbid density current from reservoir

## 4.6 Dredging

Dredging is a mechanical method used to recover lost storage due to sedimentation in small reservoirs as well as for localized applications such as clearing of intakes. The total costfor creating reservoirs (per cubic meters) has been assessed lower than the cost of dredging. Besides, there remains the problem of dumping the dredged material. Dredging cannot thus be the standard solution. However, the option should not be overlooked, for instance the use of hydro suction in small irrigation reservoirs and large purpose-made dredging equipment for large hydroelectric schemes.

For small irrigation dams, dredging costs are reduced by avoiding pumping equipment when the reservoir head may be used up to 8 or 9 m. At places, where the labour cost is low, the cost per $m^3$ of sediment removal may turn out to be acceptable, comprising mainly the cost of pipes and small pontoons in calm water. The efficiency may be improved by special pipe inlets. There are however some possible limitations such as the pipe lengths, the length of reservoir to be desilted, the sediment depth and the water loss. The latter may be a factor as the sediment concentration in pipes is usually under 10%. Dredging shall be the last option after evaluating all other sediment control measures.

For reservoirs with annual or longer storage, consideration for conserving the live storage at the tail end of the reservoir can be through selected excavation and removal of silt. This option needs serious investigation as many reservoir capacities can be managed on long-term basis through this measure.

Dredging involves serious issues of water loss from the reservoir and hence has to be considered with caution especially for peninsular reservoirs.

Management of silt in the barrages pose special problem as the limited pondage capacity with shallow depths require management with manipulation of main gates and maintenance of approach channel for the intake structures.

The measures outlined above for managing reservoir sediment are for illustrative purposes only. Also, the number of listed is not exhaustive. The stated measures are chosen because of their popularity in our country primarily because of low cost of implementation and ease of implementation. For details of sedimentation techniques available and practised worldwide reference may be made to “Reservoir Sedimentation Handbook” **[e].**

## 5. Desilting the discharges to power house

Currently, desilting structures, such as settling basins, are provided for avoiding silt or sand discharges to the power house. Corresponding huge structures, often underground, have been implemented. Most have been made by hopper chambers with permanent arrangement for flushing of sediments with reduced water velocities of about 0.2 m/s over a length of about 200 m and with the target of withdrawing particles greater than 0.2 mm in diameter. The key drawback of this arrangement is the fact that 0.1 mm diameter particles may also erode turbines and the water velocity necessary for a more efficient desilting structure to deal with those would be in the range of 0.05 m/s **[b]**. This would only appear cost effective, if the reservoir itself were to be used as a desilting structure and designed accordingly. Further, savings in turbines wear may be obtained by specific mechanical design and coating.

## 6. Numerical studies for studying the efficacy of reservoir as Desilting Basin

Computer aided simulations using various numerical models are being used to predict the rate of sediment deposition and their profile in the reservoir using different combination of sediment evacuation modes. However, no study is available correlating the numerical results obtained with the prototype behaviour to validate the results. Besides, there are no standard guidelines for carrying out the numerical studies and corroborating the results. In absence of such a framework, the usefulness of the numerical studies gets limited, reducing them to an academic exercise. Numerical studies however, need to be encouraged along with their validation with prototype measurement. This will help in calibrating the numerical studies and develop guidelines for their use.

Properly calibrated numerical studies are important as they can be used to evaluate many unforeseen and complex situations which cannot be replicated easily in the physical model studies.

# Part -II

## Structural Measures for Reservoir Sediment Management

There is no standard solution and various alternatives should be studied allowing for uncertainty in their evaluation. Associating several solutions may be the best choice. Some suggestions are given below for the likely scenarios.

## 7. Options to cope with hydro-abrasive erosion

### 7.1 Increasing the erosion resistance

One way to reduce hydro-abrasive erosion is to increase the erosion resistance of exposed parts. For hydraulic turbines, a martensitic stainless steel with 13 % chrome and 4 % nickel is mainly used. Such steel has a Mohs hardness of 4.5 to 5, i.e. it can be eroded by harder mineral particles such as quartz and feldspar. Other steel grades and alloys with higher erosion resistance are used for e.g. welded hard-facing layers in Pelton buckets or needles of Pelton injectors (e.g. steel-cobalt-alloys such as 'stellite').

Another option is to apply coatings on steel surfaces exposed to sediment-laden flow. Soft-coatings (based on polyurethane/epoxy resin) have been used in turbines at lower heads (e.g. Kaplan). In medium- and high-head turbines, thermally sprayed hard-coatings made of tungsten carbide, cobalt and chrome (WC-CoCr) have become state-of the art. Such coatings are approximately as hard as quartz. They reduce the extent of erosion and increase the times between overhauls, but can still be damaged. Coated runners have generally a smaller initial efficiency than uncoated ones due to higher roughness and potentially different hydraulic profiles, but the loss of turbine efficiency is slower, resulting in higher revenues depending on site conditions.

### 7.2 Reduction of the sediment loading

Another approach to reduce hydro-abrasive erosion on turbines is to reduce the factors contributing to the sediment "loading", i.e. the number of particles, their impact energy and angle of attack (mode of erosion). In the planning phase, a turbine can be designed to be less prone to hydro-abrasive erosion. To find a suitable combination of measures and a specific turbine design, turbine erosion needs to be addressed in an early stage of planning and meaningful sediment data are required. For existing HPPs, the head and the velocity inside the turbines cannot be generally reduced; and the hardness and shape of particles are properties of the river catchment.

The SSC and the median particle size can be reduced by investments in the design and construction of civil works for dealing with reservoir sedimentation and by suitable operation of HPPs.

# 8. Measures for preventing sediment ingress into Intakes and also for preserving live storage capacity

The primary structural measures adopted for managing reservoir sediment are through provision of large sized sluices. These sluices can be used for undertaking a number of hydraulic sediment evacuation techniques viz; drawdown flushing, sluicing, density venting, etc. The efficacy of these sluices in managing sediment depend upon their number, size, location, and elevation at which they are provided. The project layout has also great influence on managing sediment and also protecting intakes from sediment ingress in the case of hydro-electric projects. Generally, these sluices are assigned the dual functionality of flood and sediment management. Besides, they create an enabling environment for formation of large desilting basin which can be used for protecting sediment ingress into the intakes. If desired depth and length of reservoir can be made a quiet zone, then provision of desilting chambers can be considered for omission.

## 8.1 Elevation of the sluices

ICOLD Bulletin 115 states that the bottom outlets should be located low enough to enable draw-down flushing and should have sufficient discharging capacity. The ideal elevation of bottom outlets is at the original river-bed level, preferably not higher than the relative water depth 0.15 to 0.2 from the bed. The discharging capacities of the outlets should be greater than 1-in-5 to 1-in-10-year flood discharge.

## 8.2 Size of the outlets

The outlet cross-sectional area is related to the required discharge capacity. The experience about performance of small sized outlets (3m x 4m) provided in dams has not been very encouraging. They tend to get choked in no time. Besides, they have very limited area of influence.

The recent trend is to assign both the functionalities of flood discharge and sediment evacuation to the outlets. The outlets provided on this consideration shall have minimum cross-sectional area of 50 $m^2$ for each outlet. The outlets should preferably be of rectangular shape, with their minimum dimension of one side as 7.0m. These bottom outlets can be used for both sluicing and drawdown flushing.

The crest elevation/size of the outlet are related to each other by a parameter called “Gate Thrust”. Presently, sluice gates up to a thrust load of 8500t have been planned/designed (Subhansiri Lower Project); whereas gates up to a thrust load of 6000t (Three Gorges Project) have been provided.

## 8.3 Abrasion resistance of Outlets

The outlets should he protected against the highly abrasive action of discharged sediment. Some abrasion-resistant material should be used to cover the outlets. A study of abrasion-resistant materials has revealed that:

- ❖ epoxy resins and mortar yielded best results, but strict technological requirements limit its large-scale use
- ❖ steel plate and plain concrete have low abrasive resistance
- ❖ high-strength concrete (60 MPa) can be used at relatively low cost

The maximum allowable velocities to avoid severe abrasion are 10 m/s, 12 m/s and 25-30 m/s for steel plate, plain concrete and high-strength concrete respectively. Currently, M-80 grade High Performance Concrete has been successfully used in hydropower projects in India (Kol Dam Project, Tehri Dam Project).

When slabs, plates or blocks of abrasion-resistant material (natural, artificial, non-metal or metal) are used, the joints are often the weak link in determining the abrasive resistance.

## 8.4 Corrosion Resistance Reinforcing Bars

Generally, unless coated, steel will readily corrode. However, when steel is placed into concrete it develops a passive oxide film, due to the high pH of the concrete. This passive film prevents further corrosion of the steel and there are many examples where common reinforcing steel in concrete has remained uncorroded for over 100 years. Corrosion of reinforcing steel may occur if the pH of the concrete is decreased, either from chemical attack or from reaction of the concrete with $CO_2$ in the atmosphere. If steel corrodes in concrete it may cause cracking or spalling of the concrete.

There are many ways to reduce the risk of corrosion- related distress in concrete. The first layer of defence is the concrete, which should be dense and cracks should be minimized. Appropriate concrete cover should also be used. The other is using Reinforcing bars (Rebars) with improved corrosion resistance over traditional carbon steel rebars. Currently, corrosion resistant rebars are readily available. Considering the fact that the structural stability and also the general stability of dam blocks with large sized sluices depend to a large extent on health of rebars, which are subjected to hostile conditions during their operating period, it is imperative that corrosion resistant rebars are used for sluices, spillways, piers, trunnion beams, bridges or other hydraulic structures.

## 8.5 General layout of structures

The sediment management shall be the core issue while firming up the general layout of the various components of water resources structures, such as; water intake, bottom gates, spillways and even possibly for the choice of the dam site and of the overall river utilization. During the planning the following shall be kept in view:

i. The intakes shall be located at a minimum distance horizontally, across the flow direction, from the face of outermost outlet nearer to intake.

ii. The intakes shall be located at a minimum distance horizontally, along the flow direction, from the upstream face of the dam.

iii. Intakes shall, preferably, be located on the concave curve of the river, if they are to be located on bend. Generally locating dams on a curved bend shall be avoidedas the bend would reduce the flushing capacity of the sluices in terms of the length of the reservoir from where the sediment can be flushed out.

iv. The size of bottom outlets shall be fixed considering their usage both for sediment flushing and passing of floods.

v. The option of providing/omitting desilting basin in case of HEP shall be decided on the basis of reservoir sediment management provisions made in the project that would facilitate creation of a desanding basin in the reservoir itself. This aspect would be explored, in detail, under the topic - "***Structural Measures in Dams for managing sediment*".**

Well adapted hydraulic model tests may be very useful for optimising layouts and levels of gates and for studying reservoir management options.

The following paragraphs discuss the structural measures that need to be provided for reservoir sediment management of different dam heights for the purpose of

- Preserving live storage capacity of the reservoir on long term basis; and
- Creating a satisfactory desanding basin in the reservoir for omitting the provision of desilting basins.

# 9. Structural Measures in Dams for managing sediment

## 9.1 Low height dams (15-30m]

If the reservoir stores most of the annual flow, even with sediment ratios over the world average of 0.5 or 1 tonne per 1 000 $m^3$, the useful life of the reservoir may be well over 100 years. But for reservoirs storing 10 or 20% of the annual flow, the reservoir may be half siltated in few tens of years. In India, the floods, and most siltation, happen in just the few months of the flood season. Keeping the reservoir empty during the first part of the flood season may more than double the reservoir life. This requires, at the design/construction stage, the provision of bottom gates for sluicing.

The typical small hydropower schemes are made using a low gated dam (15-30m high), a headrace tunnel and a high head power house. The small dam reservoir is flushed for evacuating the bed load but the water diverted to the power plant often includes sand particles up to 1 or 2 mm which may cause severe damage to turbines and increase by up to 20% or more the overall cost per kWh.

Such schemes are normally provided with large underground desilting chambers with continuous flushing with a water velocity of 0.20 m/s along the length of 200 m for settling the particles diameter about 0.2 mm. Their efficiency has been often less than anticipated and particles of 0.1 mm may anyway be harmful, especially if a high quartz content is present.

It may be more cost efficient to use the main dam reservoir itself for desilting. A diversion tunnel can be constructed sufficiently upstream of the dam to bypass the water in excess of what is required for power generation through it for maintaining the desired velocities in the reservoir needed for settling the particles of size 0.1mm and above. To be more effective, a dam upstream of the current dam and downstream of the DT intake may be provided [**b**]. This would clearly delineate the desilting basin. The upstream cofferdam constructed at construction time can serve this purpose.

For instance, if the flow to the power house is 50 $m^3/s$, a natural desilting basin 750-1000 m long may be created in the river upstream of the gated dam. The cross section of the reservoir, for a water speed of 0.05 m/s would be at least 1000 $m^2$ (50/0.05), i.e. a reservoir close to 1 million m3 and a dam 15 to 30 m high. A diversion tunnel (DT) 500 to 1000 m length along the river with a cross section of about 50 $m^2$ would bypass the basin for discharges above 50 m3/s and would be controlled by an upstream gate. It would divert nearly all bed load and a large part of annual silt and sand. The sediments deposited in the basin should be flushed in a few days per year. For a few days per year when floods exceed the capacity of the diversion tunnel, the diversion tunnel and the head race to the power house could be closed and the floods sluiced through the basin.

Summarizing the above, desilting basins can be omitted for such low height dams, if the following conditions are met/ provided:

a) Low level outlets (preferably at the river bed level) are provided for managing both flood and sediment.
b) A dedicated desanding basin is created in the reservoir for bypassing discharges in excess of those needed for power generation purposes.

However, in case the river flows during the monsoon periods are very high and contain high sediment concentration, which cannot be bypassed economically or managed otherwise (shutting of power house, preventing damage to turbines using coatings, etc.), then provision of dedicated desilting basin cannot be dispensed with.

### 9.1.1 Barrages

Barrages, generally of height of 15-30m, should invariably be provided with desilting basin.

## 9.2 Projects having dam height between 30-50m

Dam falling this category can be designed following the provisions of paragraph 9.1 or 9.3. To preserve live storage capacity, the sluices shall be placed at the lowest possible level, preferably near the bed level. As regards desilting basin, its omission shall only be considered if provisions of para 9.3 are complied with.

## 9.3 Projects having Dam height between 50-100m

Most of the large hydropower projects (including irrigation or storage schemes too) have dams 50 to 100 m high on large river and a power house using heads more than 100 m with a large discharge. If the reservoir stores less than 10% of an annual flow of several billion $m^3$ the reservoir may be siltated in a few dozen years or less. The scheme is likely to be designed for operating full time for a few months of the monsoon season and for supplying mainly daily peak power during the dry season. To preclude sediment ingress into the turbines large artificial desilting basins are provided to retain sediment particles greater than 0.2 mm.

In such schemes, it may be possible to utilize reservoir as a desilting chamber. The reservoir based desilting basins should be designed to remove sediment particle size up to 0.1mm. Using about 1 to 2 km of the downstream part of the reservoir as a desilting basin, with cross sections in the range of 10,000-15000 $m^2$, say for instance 40-60 m deep below MDDL (Minimum Drawdown Level) and 250 m wide, may be cost effective as compared to artificial desilting chambers. Flushing by spillway outlets with their crest kept at 25 to 30 m below the intake invert level may be efficient for maintaining this desilting basin and preventing sediment ingress into the intakes and also for keeping enough storage for peaking capacity. (***For dams with height between 50 to 75m, the vertical distance between spillway crest and intake invert may be adopted as 25m; whereas for dams having height above 75m but less than 100m, this distance may be kept as 30m***). Besides, intakes shall be located at a minimum distance horizontally from the face of outermost outlet nearer to intake.

The size of each outlet shall be as per provisions of paragraph 8.2. The outlets provided should have discharge capacity equal to or bigger than the design flood discharge for the Full Reservoir level (FRL).The outlet may be placed at a level lower than what has been suggested above if the site conditions permit. This will allow adoption of a combination of sedimentation management techniques. In the case of storage schemes, the level of sluices will be governed by the long-term live storage capacity that is required to be preserved.

Such schemes could also feature specifically designed dredging equipment. Associating dredging and exceptional flushing can be an option.

There can be situations where it may not be possible to provide such level differences between spillway crest and intake invert, particularly for dams in the height range of 50-60m height. For such cases the sluices may be provided at the lowest possible level feasible in accordance with site conditions coupled with provision of desilting chambers in case of HPPs.

Run-of-the-River HPPs are generally constructed in narrow gorges. At such sites width of 250m is generally not available. For such sites, it shall be ensured that at least 100m width of gorge is available for desanding basin. To compensate for the reduced width, longer length of reservoir may have to be created for settling of sediment. To enable this, following measures can be adopted:

- Sluices are provided at the lowest possible level. The vertical distance between intake invert and sluice crest may exceed the suggested difference of 25-30m.
- Sufficient straight reach is made available (3 to 5 km) upstream of the dam axis.

## 9.4 Projects having Dam height between 101-150m

Such dams will most likely have reservoir lengths in excess of 15-20 KMs. Sluices in such dams may be provided at an elevation, evaluated to be lower, based on the following criteria:

- 30m below intake invert
- 50-60m below MDDL (Minimum Drawdown Level)

## 9.5 Projects having Dam height between 150-200m

Such dams will most likely have reservoir lengths extending tens of kilometres upstream of dam axis. Sluices in such dams may be provided at an elevation, evaluated to be lower, based on the following criteria:

- 40m below intake invert
- 60m below MDDL (Minimum Drawdown Level)

It would be appropriate if sluices at two or more levels are provided for dams of these heights (150m-200m) on the consideration of preserving live storage and protecting intakes from sediment ingress. Drawdown flushing, by emptying the reservoir up to the level of sluices, would be difficult to implement in these projects on economic considerations. Pressure flushing with limited drawdown, sluicing, density venting, etc would be the dominant operations that would be adopted in such projects for hydraulic sediment evacuation.

Taking into account the gate thrust limits that have been achieved till date (these limits can be easily exceeded with proper design), a row of sluices of 50 $m^2$ area each can be safely provided at an elevation 100-125m below FRL. For managing higher gate thrusts, the number of trunnions is increased to 3 or 4 numbers from the conventional 2 numbers. (In Lower Subhansiri Project, 4 trunnions for each gate have been provided). With this modification, a bigger sized sluice can be provided at much lower levels. The following levels are suggested for two tier sluice arrangement, wherever feasible, for such dam heights.

- First (Lowest) row of sluices at 100-125m below FRL
- Second row at 50-75m below FRL.

Additional rows of sluices can also be provided in case of dams higher than 175m. The level of the sluices shall be governed by the live storage capacity that needs to be preserved on long term basis.

## 9.6 Projects having Dam height above 200m or having very large reservoir capacity

Projects having dam heights greater than 200m or having very large reservoir capacity and are generally storage projects. Here the implementation of drawdown flushing would be difficult because of huge loss of water. To manage sediment, rows of outlets, having high discharging capacity, may have to be provided at different levels (preferably ≥ 3 rows) to facilitate implementation of different types of hydraulic sediment evacuation techniques such as sluicing, density venting, limited drawdown flushing, etc. Dredging can also be implemented on limited scale to unsettle the consolidated sediment and thereafter hydraulically flushing it out of the reservoir. The guidelines given in paragraph 9.4 for dam heights, 150m-200m, are equally applicable for such dams with suitable modifications.

Sanmenxia Dam Project (Height- 106m; Reservoir Capacity- 16.2 BCM; Reservoir length – 246 km) is a classic case of successful reservoir sediment management through large sized bottom outlets. Here the bottom outlets were remodelled twice for enhancing their capacity. A combination of sediment management techniques – sluicing, draw down flushing, etc. are being employed for managing reservoir sediment.

**Note:** ***The dam height referred to in the above paragraphs is the height of dam above deepest river bed level.***

**Fig.2:** ***Sanmenxia Dam Project***

## 10. Sediment Management of projects governed by Indus Water Treaty

The hydropower/Storage projects located on river Indus, Chenab, and Jhelum are governed by the provisions of Indus Water Treaty (IWT). The Annexures-D&E of the IWT lists out the conditions to be fulfilled by these projects. The treaty lists out the following, inter-alia, conditions for sediment management, Intake & Spillway crest elevations:

a) There shall be no outlets below the Dead Storage Level, unless necessary for sediment control or any other technical purpose; any such outlet shall be of the minimum size, and located at the highest level, consistent with sound and economical design and with satisfactory operation of the works.

b) If the conditions at the site of a Plant make a gated spillway necessary, the bottom level of the gates in normal closed position shall be located at the highest level consistent with sound and economical design and satisfactory construction andoperation of the works.

c) The intakes for the turbines shall be located at the highest level consistent with satisfactory and economical construction and operation of the Plant as a Run-of-RiverPlant and with customary and accepted practice of design for the designated range ofthe Plant's operation.

Like all other Himalayan rivers, the three Indus basin western rivers carry huge sediment. This is apparent from the fact that the Salal reservoir of 450 MCM got filled up in a span of 5-6 years. Provision of structural measures for undertaking sediment management in projects located on these rivers is necessary for their satisfactory operation on long term basis. The guidelines given in paragraph-9 of this document are equally applicable for these projects. The elevations of sluices and intakes suggested shall be taken as the highest level possible for their provision for satisfactory operation of the project. The low level sluices will help in evacuating sediment using pressure sluicing and dredging for cases where flushing (draw down) cannot be used.

## 11. Frequency of Flushing

Effective flushing requires:

- Excess water
- Suitably large low-level outlets
- A steep, narrow reservoir basin
- Judicious operation

Flushing operation requires excess water to be effective and, in most cases, this means a reduction in water yield. Reservoir conservation by using flushing or sluicing are therefore in direct conflict with the water demands such as irrigation or hydropower. The effect of a reservoir conservation measure such as flushing also varies depending on the hydrology and sediment yield.

For most of the run-of-the-river hydropower schemes, where live storage capacity is a few MCM (million cubic meter), the following approach for reservoir sediment management using drawdown flushing can be adopted:

a. Maintain reservoir at MDDL during flood season to preclude sediment deposition in live capacity zone of reservoir.

b. Undertake first drawdown flushing at the onset of flood season. This will flush out all the sediment deposited during the non-monsoon period or carried by floods initial to flushing period.

c. Undertake second drawdown flushing during the receding phase of flood season. This will flush out all the sediment deposited in the reservoir during the flood season.

d. Intermittent flushing depending upon water availability may be undertaken in addition to the above two flushing.

e. Sluicing may be undertaken using excess water during flood season.

For storage schemes, firm water yield/mean annual runoff (MAR) vis-à-vis reservoir capacity has to be worked out for determining excess water for flushing. (Firm yield is the maximum draft on the reservoir for the demand on the reservoir to fail at a risk, say 1 in 50 years.)

## 12. Conclusions

The planning and management of hydro power schemes should incorporate structural measures to manage reservoir sedimentation and prevent sediment ingress into the intakes in order toensure the long-term viability of a project.It is also necessary at the planning level to incorporate costs for the control of reservoir sedimentation. In all of the hydraulic measures of reservoir sedimentation control, it is very important that sediment transport is accurately predicted. Calibration with field data is recommended and the processes of non-uniform and non-equilibrium sediment transport (for fine sediments) should be incorporated.

Beyond economic optimisation, long term sustainability requirements favour mitigation measures. They may vary significantly with dam site, purpose and reservoir operation. The sedimentation management may impact not only the design of the structures but also the choice of dam site and even the general layout. The studies should take care of uncertainties involved in the evaluation of the siltation.

Permanent diversion tunnels, flushing, sluicing and/or dredging may be cost efficient according to specific local conditions. Desilting the water inflow to power houses deserves an analysis of the true efficiency of existing structures. Using the reservoir itself for desilting may be cost efficient. Combining solutions is often suitable. A long-term sustainability analysis is advisable even if the risk is rather low. It may justify early small investments, such as bottom gates increased capacities, pipes through dams for future dredging, intakes for possible tunnels, etc. All these will considerably reduce future investments by adjusting siltation treatment to the actually measured siltation. The current trend of providing large sized outlets/sluices that are assigned the dual functionality of flood discharge and sediment management has given successful results, based on limited dataset available, in managing both reservoir sediment and flood. Dredging of reservoirs for storage recovery should only be carried out after evaluating all other control measures.

Progress in siltation mitigation will improve by obtaining more data and information on the true cost and efficiency of various worldwide solutions that have been used successfully and even more from difficulties and relevant changes and modifications that have had to be made to permanent works.

The sediment in dams is critical. Leaving sediment management as it is may lead to not only reduction but full loss of reservoir functions. With proper treatment of sediment, it is possible to maintain its function economically along centuries.

Since the progress of sedimentation is slow in general, part of solutions may possibly be delayed but the long-term possible solutions should be analysed initially and partly implemented from the beginning as they may thus impact the full design

The above guidelines are applicable for irrigation dams also where the level of sluices will be governed by the long-term live storage capacity that is required to be maintained.

## References


a) ICOLD Bulletin 115, Dealing with Reservoir Sedimentation – Guidelines and case studies.

b) ICOLD Bulletin 144, Cost Savings in Dams.

c) ICOLD Bulletin 152, Cost of Savings in Dam Construction.

d) The World Bank, Reservoir Conservation – The RESCON Approach, Vol. I & II.

e) Reservoir Sedimentation Handbook, Gregory L. Morris & Jiahua Fan, McGraw Hill.


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