Reservoir Sediment Management & Analysis for Engineers

Overview of Reservoir Management Methods

University of Kansas
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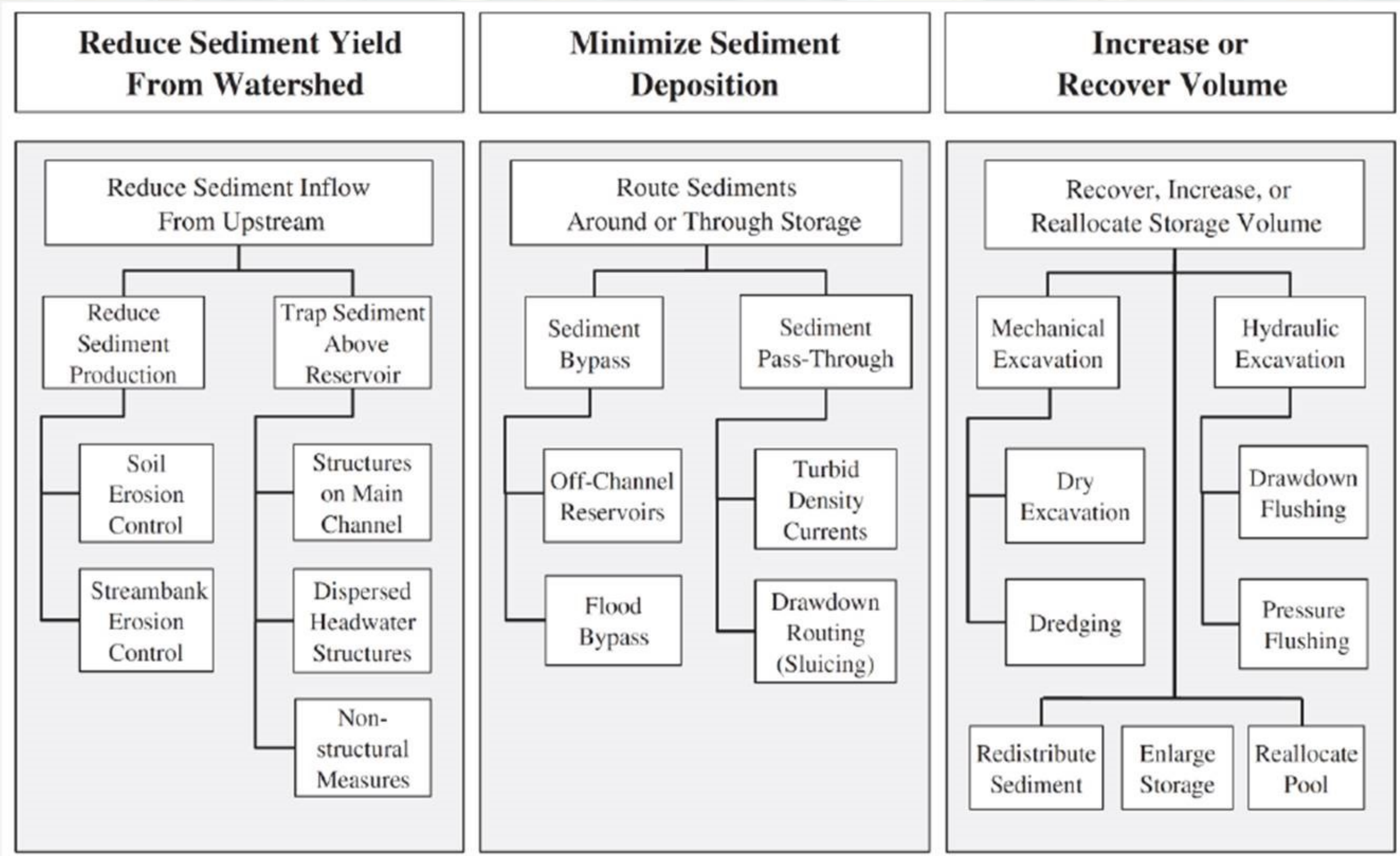
ERDC
Engineer Research and Development Center

Introduction

- In this lecture, we will discuss both active and passive reservoir sediment management technologies and methods, to include;
  - ▶ Background
  - ▶ Description
  - ▶ How it works
  - ▶ Where has it been used before (maturity)
  - ▶ What to remember when planning

Background



From: Kondolf et al., 2013

Background

- The objective of sediment management is to manipulate the river-reservoir system to achieve sediment balance while retaining as much beneficial storage as possible and minimizing environmental impacts and socioeconomic costs.
- Morris et al., 2007 divide reservoir sediment strategies among five basic approaches:
  1. Sediment Yield Reduction
  2. Sediment Storage
  3. Sediment Routing
  4. Sediment Removal
  5. Sediment Focusing

Background

- *Sediment Yield Reduction:* Apply erosion-control and bank stabilization techniques to reduce incoming sediment yields from upstream watersheds.
  - Soil Stabilization and Revegetation
- *Sediment Storage:* Provide sediment storage volume adequate for the anticipated sediment yield over a “long” period of time either in the reservoir itself or in upstream impoundments or debris basins

Background

- *Sediment Routing:* Pass sediments around or through the storage pool to minimize sediment trapping by employing techniques such as off stream storage, temporary reservoir drawdown for sediment pass-through, and release of turbid density currents.
- *Sediment Removal:* Remove deposited sediment by dredging or hydraulic flushing.

Background

- *Sediment Focusing:* These techniques are designed to tactically rearrange sediments within the impoundment to solve localized problems such as impacts from delta deposition. Any erosion of sediment from the reservoir that may occur is incidental to the primary objective.

Background

- Reservoir Sediment Management Methods:
  - Bypass Tunnels
  - Drawdown by Rule Curve
  - Empty Flushing
  - Flushing During High Sediment-laden Flows
  - Hydraulic Suction Dredge
  - Modifying Reservoir Geometry to Maximize Pass-through
  - Off-stream Reservoir to Bypass Sediment
  - Pass-Through by Hydrograph Prediction
  - Raising Dam Elevation
  - Sediment Bypass around an On-Stream Reservoir
  - Sediment Routing by Reservoir Drawdown
  - Turbid Density Current Venting
  - Upstream Check Structures (Debris Dams)

Bypass Tunnels

- Bypass tunnels are sediment routing tunnels used to route the sediments either around or through the reservoir.
- **How it works:** During floods sediment is routed through the tunnels into the tailwater. As a result the accumulation of sediment on the reservoir bed and within suspension decreases (Swiss Federal Institute of Technology, Laboratory of Hydraulics, Hydrology and Glaciology, 2013)

Bypass Tunnels

- **Where has it been used before:** The number of these tunnels are few worldwide due to the high investment, maintenance cost, and geographic conditions.
  - **Asahi Dam, Japan** – was built in 1978 with the bypass system built in 1998, and has been successful in reducing sediment deposition. Designed to bypass suspended load and bedload, with a maximum discharge of 4,940 cfs. Performed approximately 16 times each year from 1998 to 2002, transporting 80 – 90% of the annual inflow sediment downstream.

Bypass Tunnels

- **What to remember when planning:** bypass tunnels are prone to abrasion damages, especially along the invert. In Switzerland, tunnels are lined with steel, granite, or basalt to help prevent abrasion. The terrain is also important for bypass tunnels. Narrow reservoirs located on steep channels likely are better candidates for successful application of the technology.

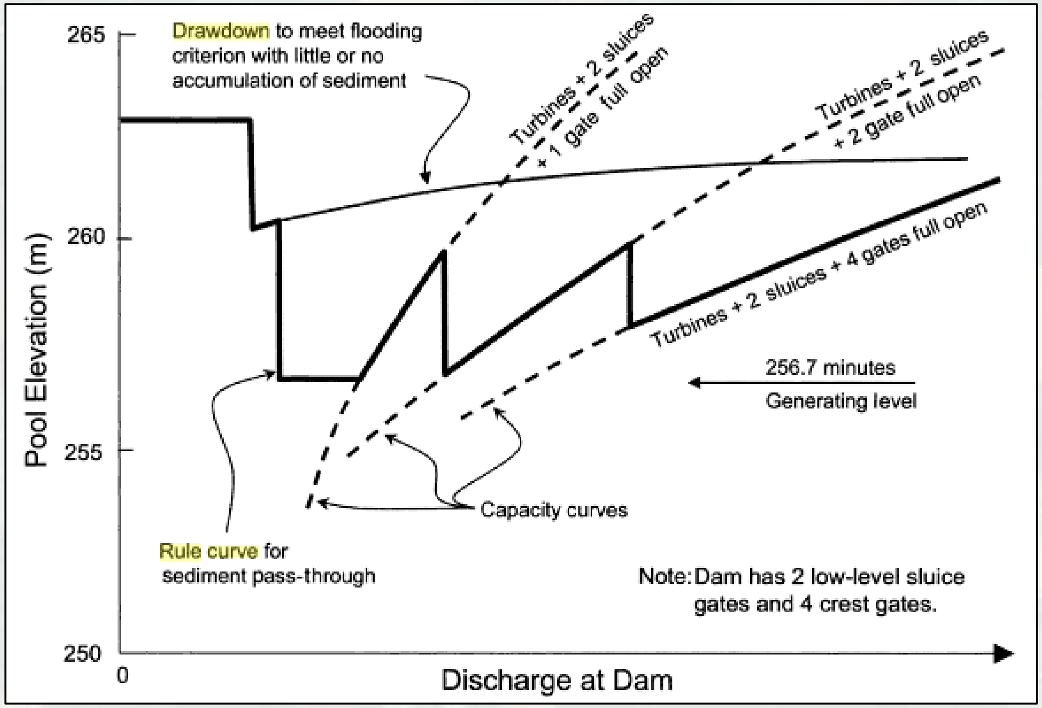
Invert abrasion in Palagnedra sediment bypass tunnel in Ticino, Switzerland.

Drawdown by Rule Curve

- This is a sediment pass-through method that focuses on maximizing flow velocity to pass sediment without, or before, deposition. Involves lowering water levels or changing operation of gates only during flood events.
- **How it works:** Flood drawdown lowers the pool level in an effort to discharge as much sediment as possible. In this particular method gate operation is governed by a rule curve and discharge measurements either at the dam or at an upstream gage. This method can be designed to achieve whatever outcomes are needed.

Drawdown by Rule Curve

- **Where has it been used before:** Used at Cowlitz Falls Dam in Washington – the reservoir is hydrologically small and has a capacity to inflow ratio of 0.3 percent. Has also been utilized at the Rock Creek and Cresta hydropower reservoir on the North Fork Feather River, California. This approach also regulates the filling and lowering of Enid Lake in North Mississippi.



Example rule curve for sediment pass-through at Cowlitz Falls Dam, Washington (modified from Locher and Wang, 1995).

Drawdown by Rule Curve

- **What to remember when planning:** is effective for very small reservoirs (Garcia, 2008). Lower-level and longer period drawdowns will induce sediment transport and the grain size transport to increase.

Hydraulic Suction Dredge

- Most commonly used reservoir dredge, the dredge consists of a rotating cutter head at the tip of a suction line, a submerged ladder pump (if depths > 33 feet), a dredge pump, and a pipeline to transport the slurry.
- **How it works:** The blades of the cutter head dislodges sediment that is collected by a suction line. The dredge pump or submerged ladder pump then forces out the sediment, and the material travels through the discharge pipeline to a diked containment areas or into the river downstream of the dam.

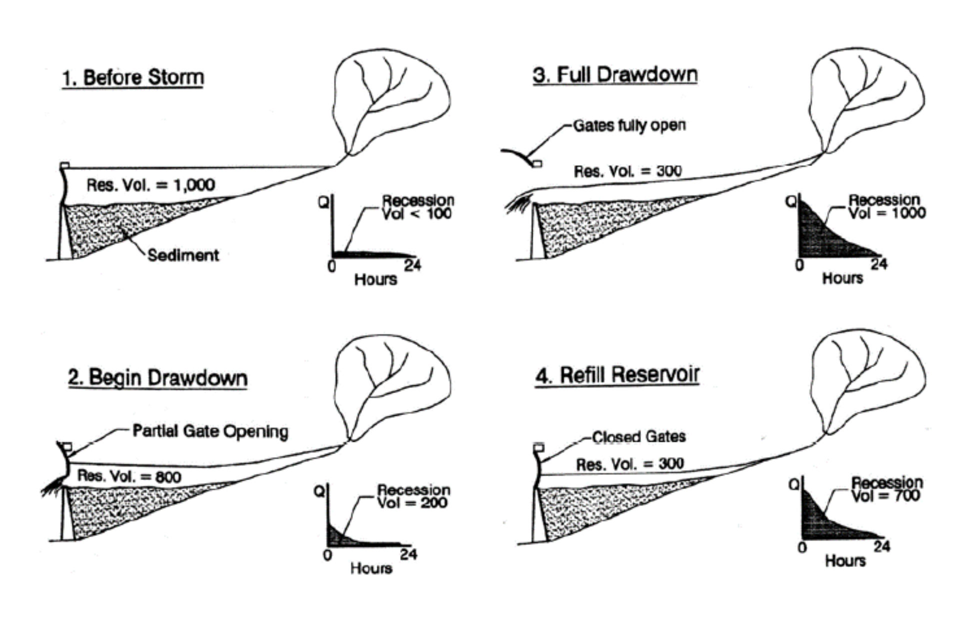
Hydraulic Suction Dredge

- **Where has it been used before:** In 1997, the Loíza reservoir in Puerto Rico, removing 212 million cubic feet of sediment. The project cost was approximately $10 per 33 ft^3 which included the dredging cost, land acquisition and construction of three sediment-disposals sites, engineering, permitting, and environmental protection (Garcia, 2008).
- **What to remember when planning:** Works well in reservoirs without disrupting normal impounding processes. Dredging can efficiently control sedimentation if the process can be repeated for an indefinite period. However, if the main disposal site becomes full after the initial dredging, the next disposal site will become more costly. Dredging on a large scale may prove to be costly and limited due to limited access to upland disposal sites.

Hydraulic Suction Dredge

Pass-Through by Hydrograph Prediction

- This is a sediment pass-through technique that focuses on maximizing flow velocity to pass sediment through without, or before, deposition.
- **How it works:** It involves lowering water levels or a change in the operation of gates only during flood events. Pass-through by hydrograph prediction draws down the pool in anticipation of flood arrival, releases sediment-laden water during the hydrograph's rising limb, and then refills the reservoir with the storm hydrograph's recession limb (Morris and Fan 1998; Garcia, 2008).



Pass-Through by Hydrograph Prediction

- **Where has it been used before:** Loíza Reservoir in Puerto Rico was a site where pass-through by hydro-graph prediction was studied (Garcia, 2008). Simulations of this method showed the rate of reservoir sedimentation would decrease by 50% (Gregory L. Morris Engineering, 2013). The method is now the Loíza Reservior's prospective management strategy. Before, the reser-voir was always kept at highest water level to guarantee a source of wa-ter. However, opening the reservoir's gates during major storms showed how effective sediment pass-through by hydrograph prediction was in minimizing sediment loads (Morris and Fan, 1998).

Pass-Through by Hydrograph Prediction

- **What to remember when planning:** Pass-through by hydrograph prediction works for hydrologically small reservoirs on rivers without extended, predictable high flow periods (Garcia, 2008). It also works for those with significant storage or limited discharge capacity (Morris and Fan, 1998). Antecedent and real-time hydrologic data and calibration data sets are required for hydrograph prediction (Morris and Fan, 1998). A safety factor, ensuring a high probability that the reservoir will refill, should be included in this technique because a refilling failure causes a serious condition. The safety factor should be updated as model accuracy increases due to the availability of data from re-calibration events (Morris and Fan, 1998).

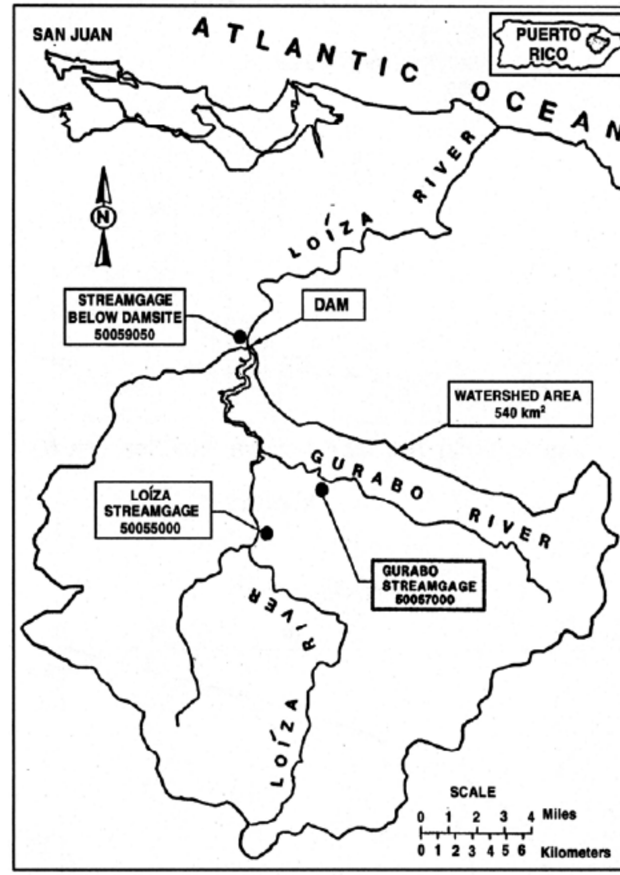


FIGURE 20.5 Location map of Loíza watershed USGS, gage stations, and reservoir.

Raising Dam Elevation

- Raising the elevation of a dam increases storage volume of a reservoir in response to storage loss by reservoir sedimentation (Tiğrek and Aras, 2012).
- **How it works:** By raising the height of a dam, the increased storage volume of the reservoir compensates for the loss of storage by reservoir sedimentation (Tiğrek and Aras, 2012).

Raising Dam Elevation

- **Where has it been used before:** The US Army Corps of Engineers proposed to raise the spillway of Toutle River's sediment-retaining dam by ten feet so that the dam would regain its trapping efficiency and prevent volcanic silt from traveling downstream and causing floods (Stepankowsky, 2011). By slowing the river, the dam is supposed to collect sediment. However, because the storage area has become full, the spillway needs to be raised to increase storage area (US Army Corps of Engineers, Portland District, 2012). On the other hand, the Cowlitz Indian tribe opposed the proposal in fear that the Corps works to raise the spillway up to 30 feet as part of their long-range plan.

Raising Dam Elevation

- **What to remember when planning:** Although raising the height of the dam is cost-effective, it is not a long-term solution for reservoir sedimentation. Instead, it only allows an increase in water storage (Tiğrek and Aras, 2012). This technique for lost storage replacement needs careful engineering (Tiğrek and Aras, 2012). Problems can result from raising the dam. For example, socio-economic and political issues arise from resettling people. Water losses increase from evaporation and seepage, and the cost of raising the dam could become high due to dam safety aspects (Tiğrek and Aras, 2012).

Raising Dam Elevation

Sediment retention structure (SRS) and upstream sediment plain on North Fork Toutle River (1990 photo).

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Questions