Reservoir Dredging:
from Puerto Rico to Pakistan

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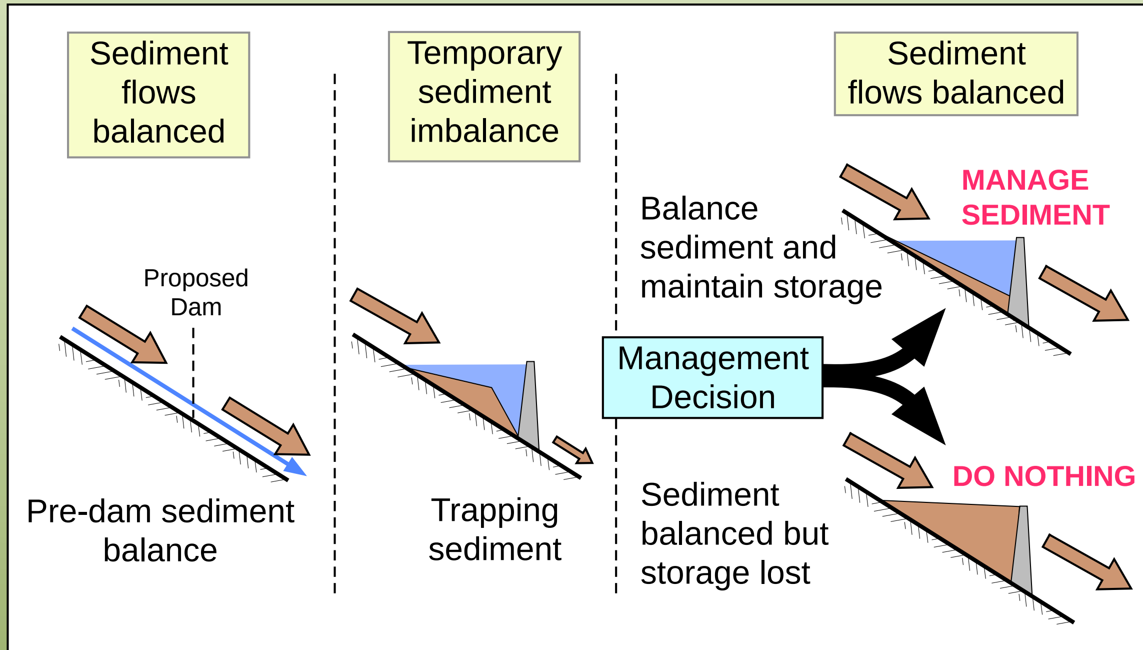
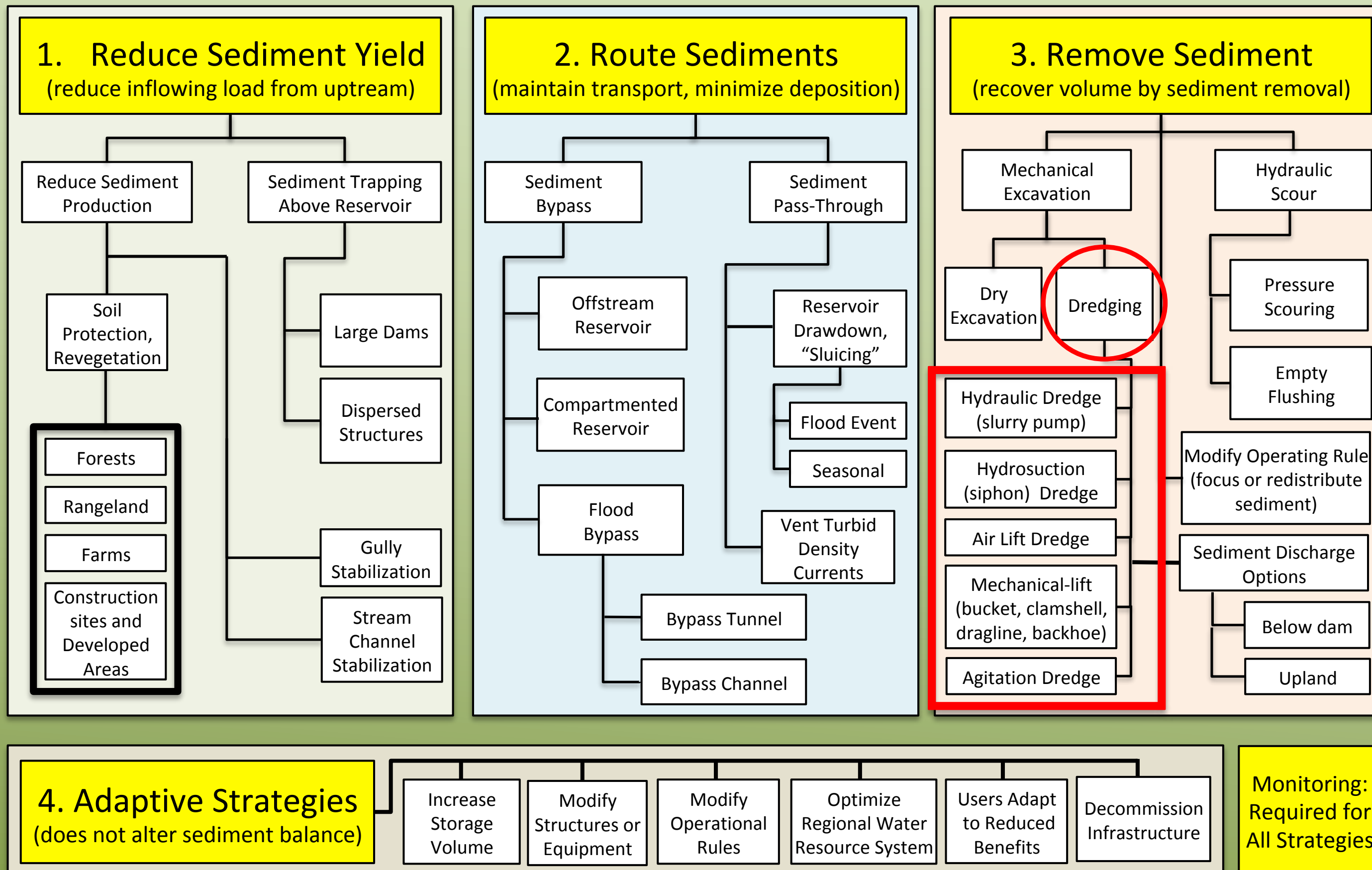
Without sediment management, all reservoir storage is a non-sustainable resource

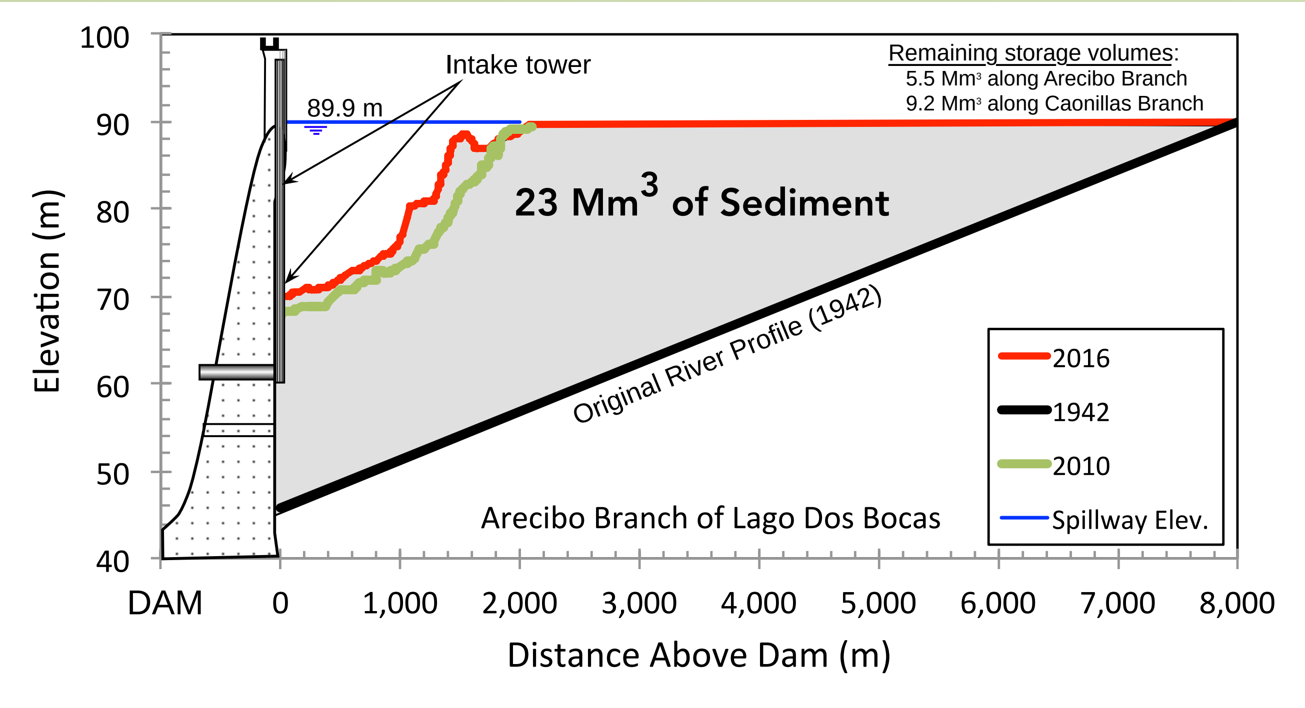


Sustainable reservoir management → Bring sediment inflow and outflow into a long-term balance. Preserve as much usable storage as possible while minimizing environmental harm.

Dredging is one of many sediment management strategies in reservoirs

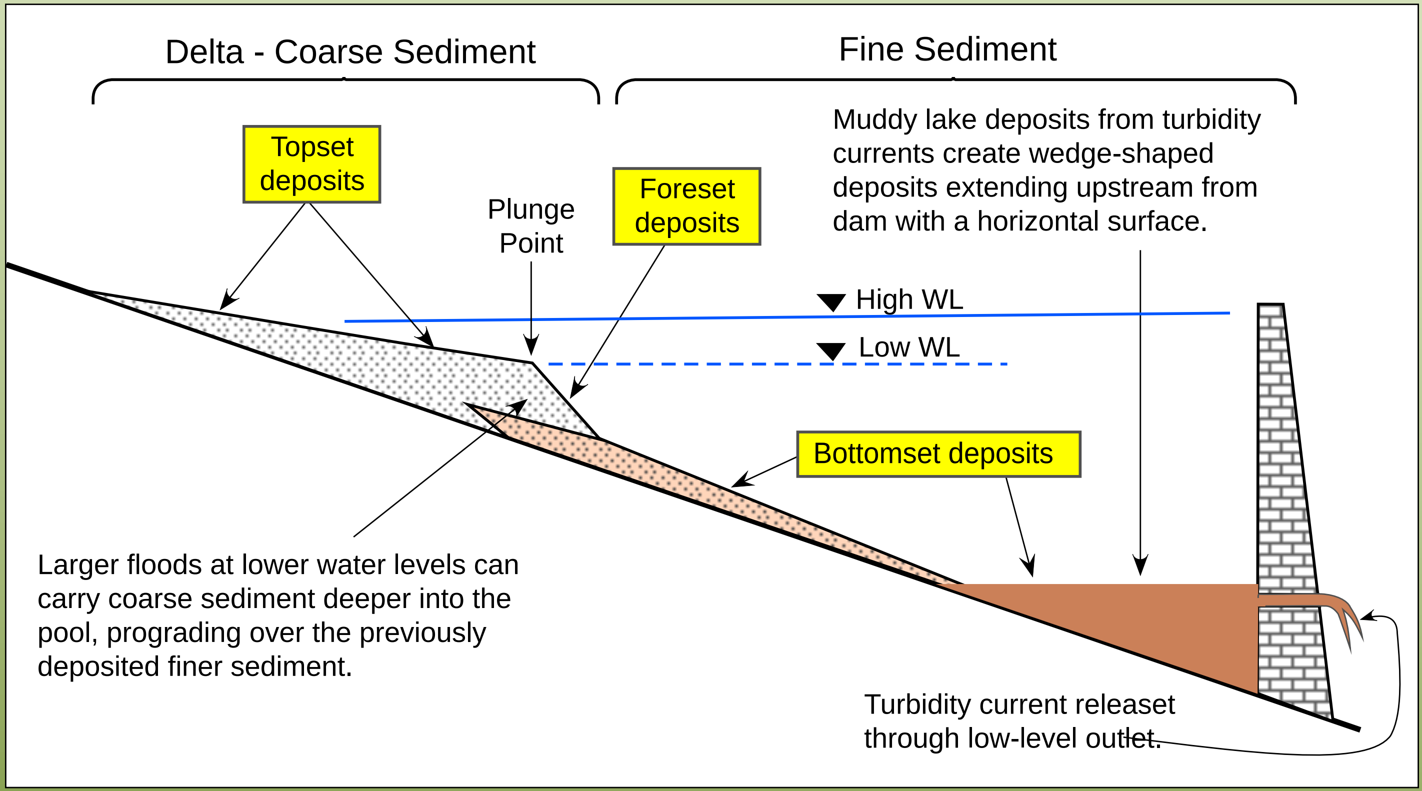


How will dredging complement other management methods?



- Sediment volumes are huge.
- Can't afford to rely on dredging to address sediment problems.
- Where will you put all the sediment?
- How can dredging be used together with other strategies to preserve long-term capacity?

Sedimentation Patterns in Reservoirs




Playas, Colombia
Delta with silt and fine sand
Tarbela, Pakistan
Gravel-dominated delta
Yeso dam, Chile

Sediment Variability

- **Longitudinal variability**, primarily due to the advancing delta (fine sediment downstream, coarse upstream)
- **Vertical variability,** primarily consists of coarse sediment being deposited on top of layers of fines as the reservoir's delta advances downstream.
- **Lateral variability**, most apparent in the delta, particularly in reservoirs with annual drawdown. Examples of lateral variability (during reservoir drawdown) are shown in the air photos below.

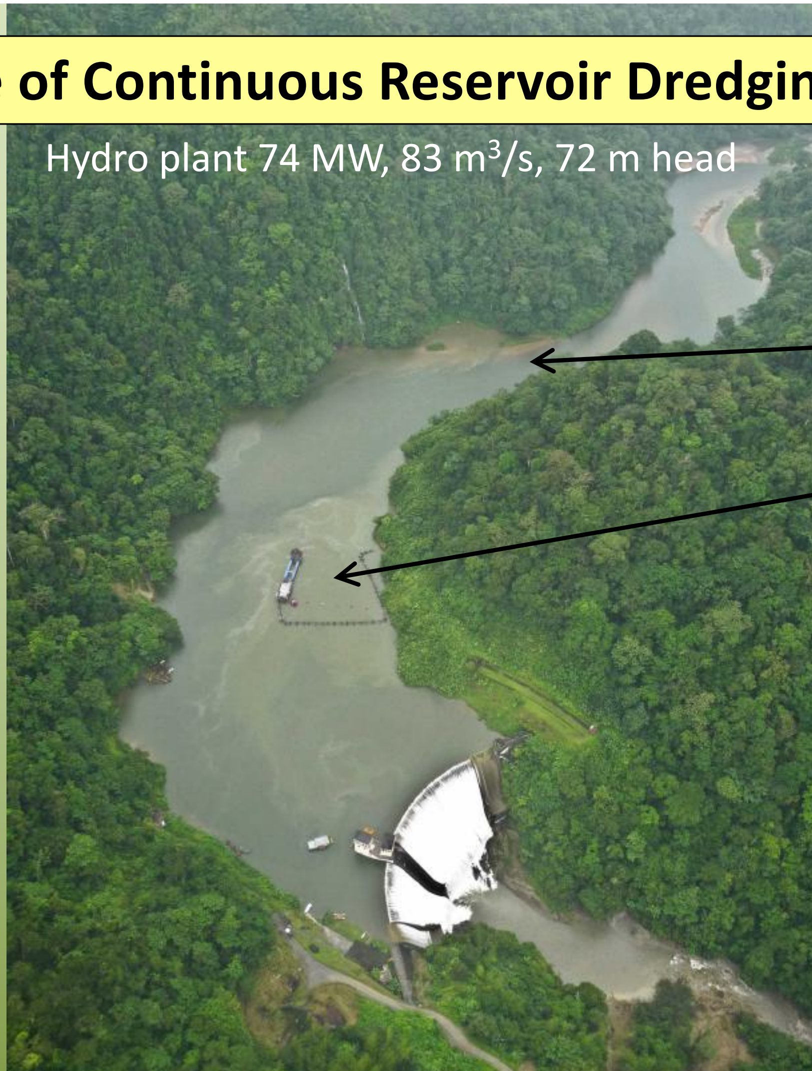
Sampling Sediment with Vibracore

Chivor, Colombia

Loíza, Puerto Rico

Strontia Springs, Colorado

Example of Continuous Reservoir Dredging



Dredging has been performed since 1962 at Bajo Anchicayá hydropower reservoir, Colombia, to maintain intake free of sediment

Sauerman dragline

Electric cutter suction dredge

Dry Excavation at Baihe Reservoir, Taiwan (2019)

Reservoir Dredging in Puerto Rico

- 2 Mm^3 (2.6 Mcy) currently underway at Loíza water supply reservoir, 3 containment areas, max. pumping distance 16 km.
- Dredging plans being prepared for 10 more reservoirs, for smaller volumes than above.
- The 10 additional reservoirs have are located in mountainous areas and present extreme challenges.

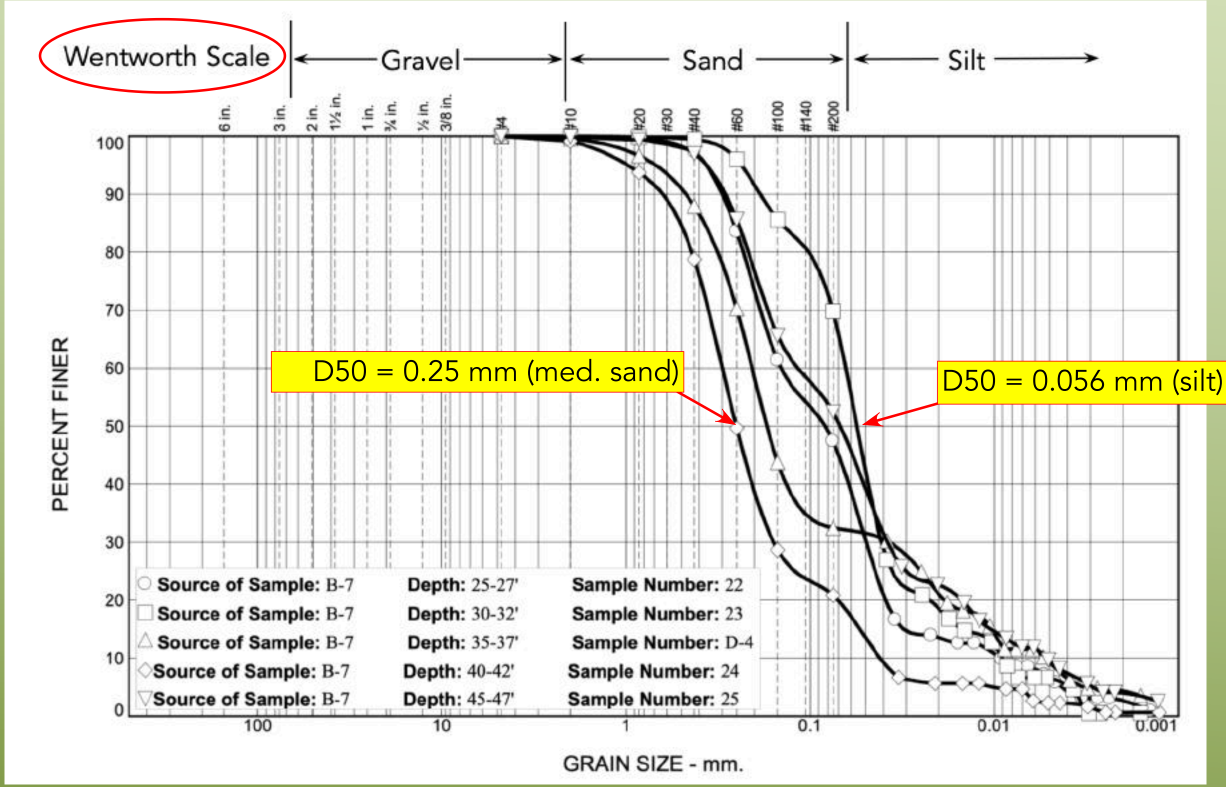
Caonillas Reservoir:

- 56 Mm^3 original 1948 capacity, now reduced by 30% due to sedimentation.
- Entire perimeter is steep mountainous land.
- Steep slopes resent problems for both staging and disposal areas.
- Split staging area: remote site for stockpile and lakeside for assembly.
- Containment dike proposed as a tailings dam.

Site Access

- Access is a huge problem due to narrow roads, sharp curves.
- Limits the size of equipment that can be mobilized to the site.
- Limits access to disposal site by haul trucks, if reuse is intended.
- This problem is certainly not unique to reservoirs in Puerto Rico.

Grain size can change significantly with depth due to delta advancing and burying finer sediments



- Be aware of the basis for specifying grain size: USCS scale used by geotechnical engineers is different from the Wentworth scale used by USGS.

How are debris going to handled contractually?

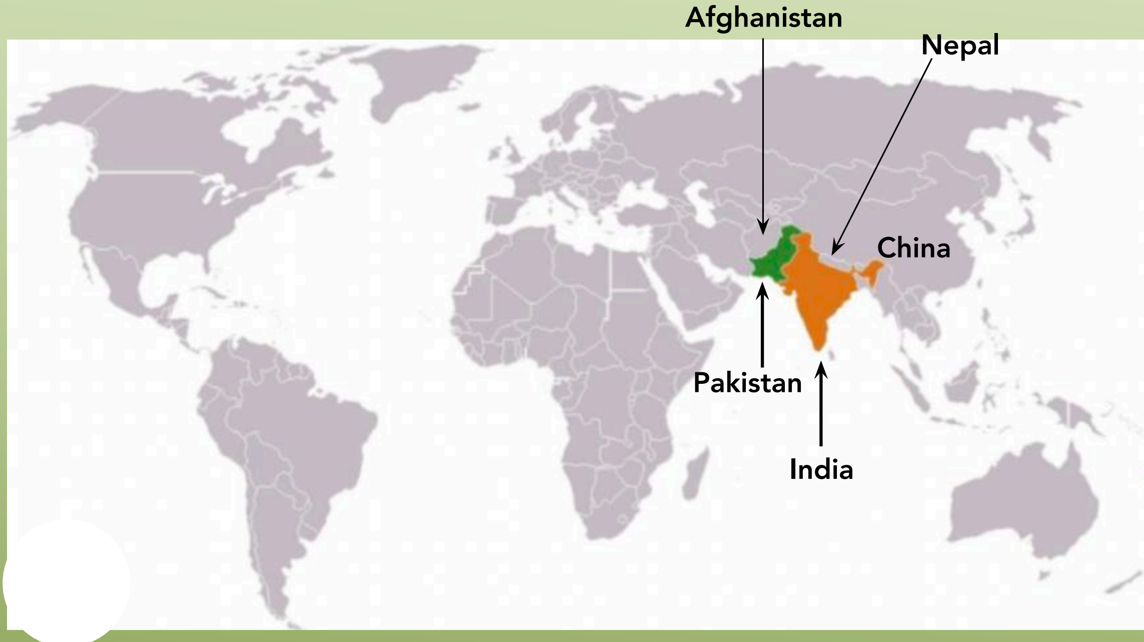
- May tend to collect against the dam, or in side channels with little flow velocity.
- Has an appropriate dredging method been selected?
- Who carries the risk, owner or contractor?
- Is there a method to quantify a threshold for any additional compensation?

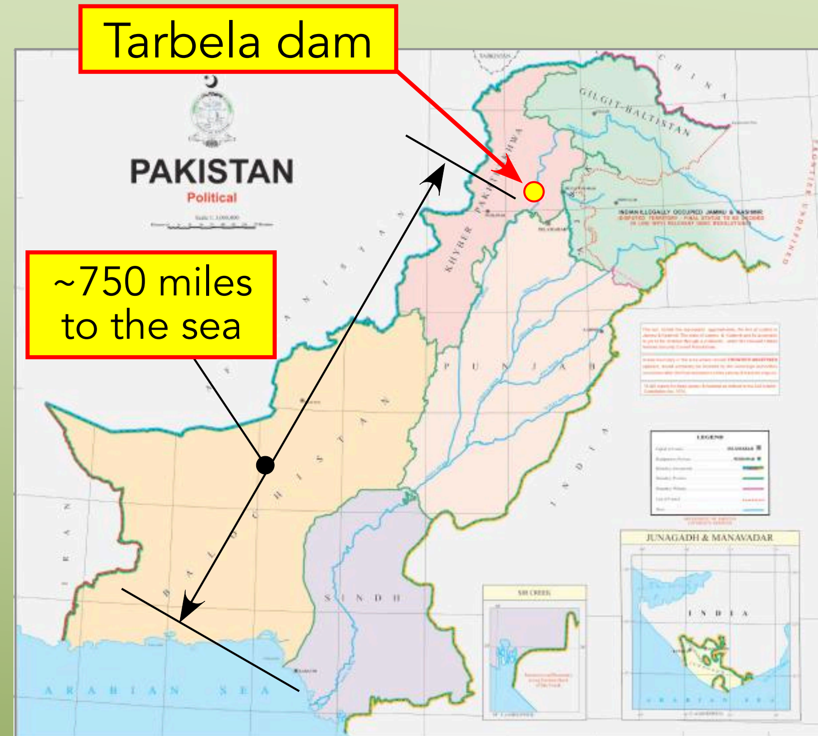
Lake Lure, NC, hurricane Helene

Some Additional Considerations:

- Selection of dredging area. In reservoir dredging, it is typically desired to maximize extraction within a given elevation range (e.g. the live pool), without dredging beyond the original bottom.
- Depth highly variable. Delta may include dry land with trees, yet sediments at dam may be over 100 feet deep
- Where is the bottom? Many reservoirs were built over 70 years ago, and the topography of the original will probably not be known with precision. Ensure the contract allows flexibility to adjust the dredging prism to accommodate uncertain subsurface geometry.
- Grain size scale. Be aware of the basis for specifying grain size: USCS scale used by geotechnical engineers is different from the Wentworth scale used by USGS and many others.
  - Example, 3 mm diameter is called “gravel” on the Wentworth scale but “sand “ on the USGS scale.
- Pay volumes. Compute pay volumes by monthly measurements. A large flood can deliver new sediment or re-work existing deposits to partially refills previously dredged areas.
- Water quality. Reservoirs or streams downstream of the containment area discharge may be used for drinking supply, and there may not be much dilution water available. This makes water quality control particularly critical for parameters including turbidity and dissolved oxygen.
- Sediment quality. Reuse options may be constrained by industrial and agricultural contaminants. The grain size and contaminant load will vary within the reservoir.

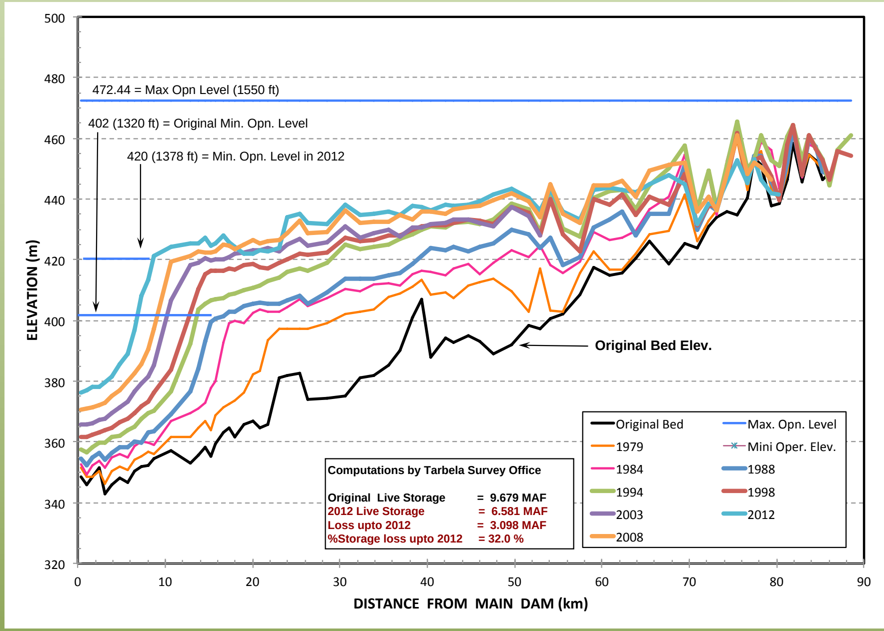
Location Map for Tarbela dam in Pakistan

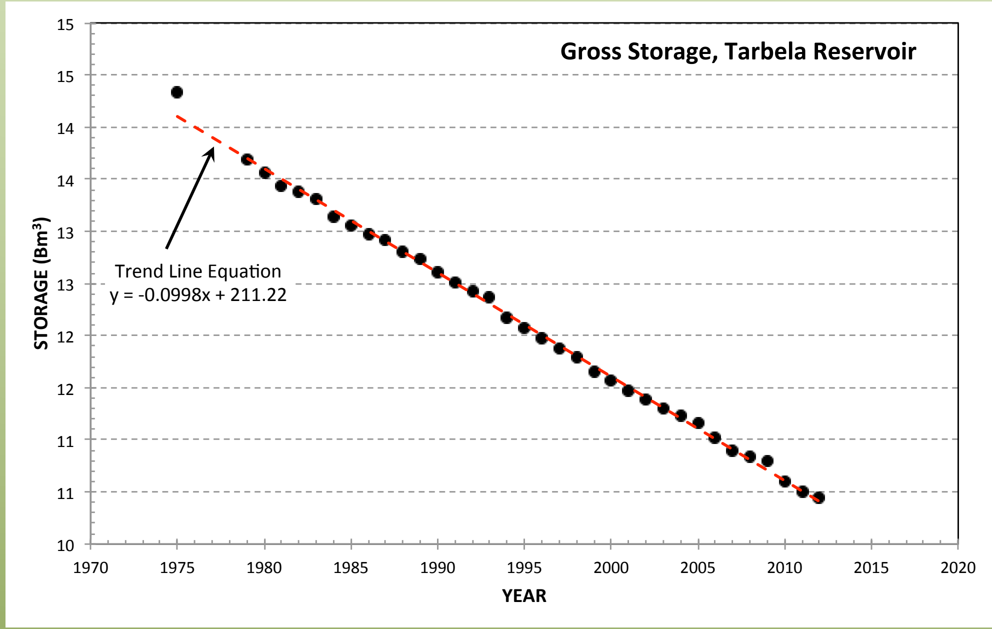




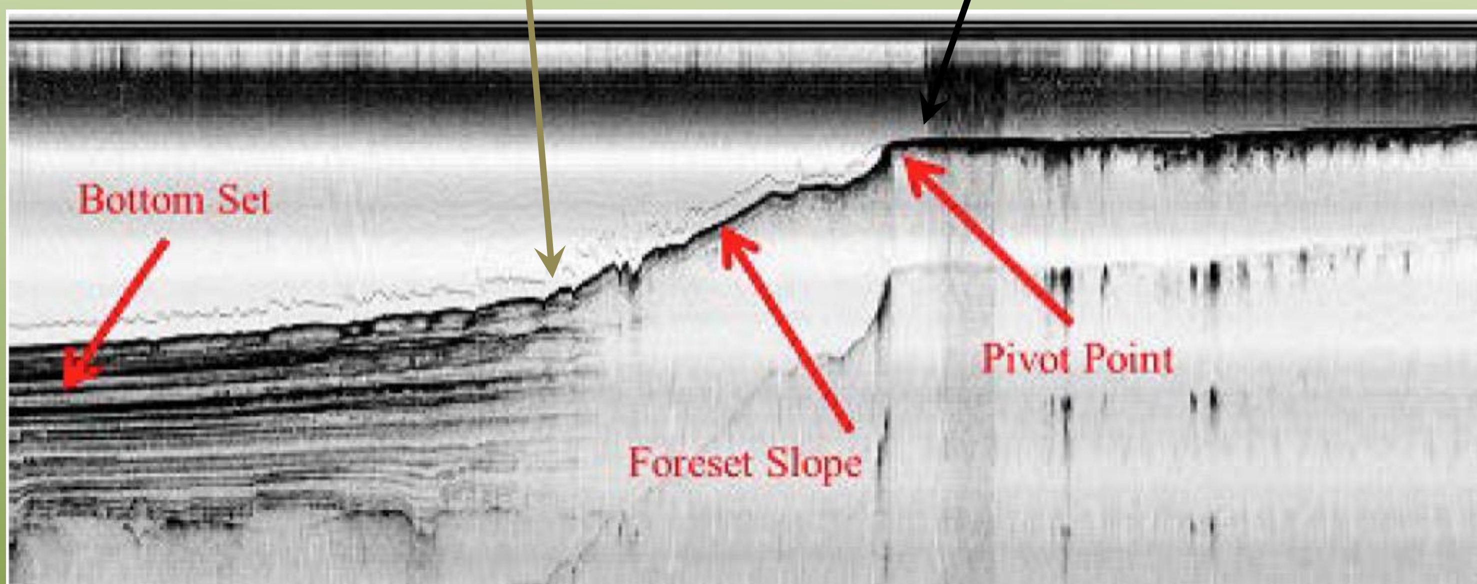
Tarbela Sediment Imbalance

- Tarbela storage loss ≈ 123 Mm^3/year (almost 1% per year)





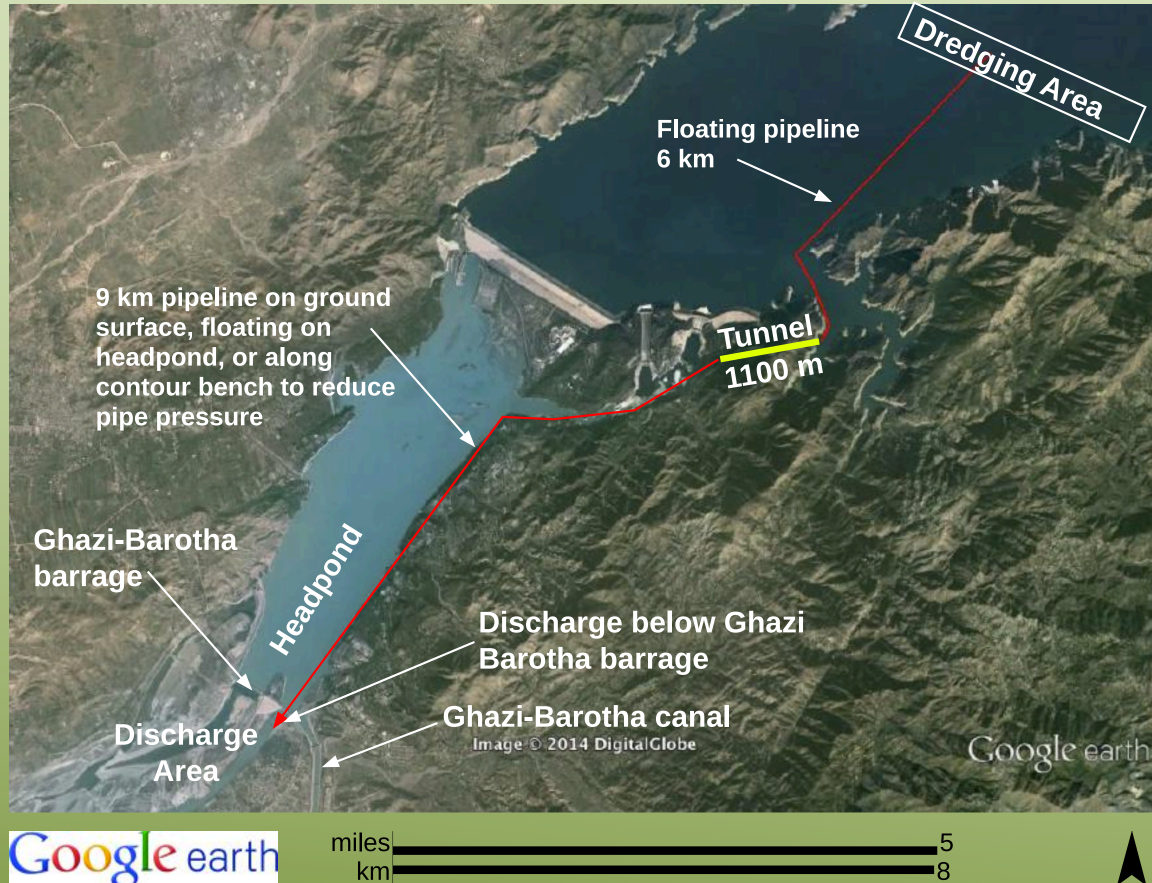
Longitudinal View of Advancing Delta



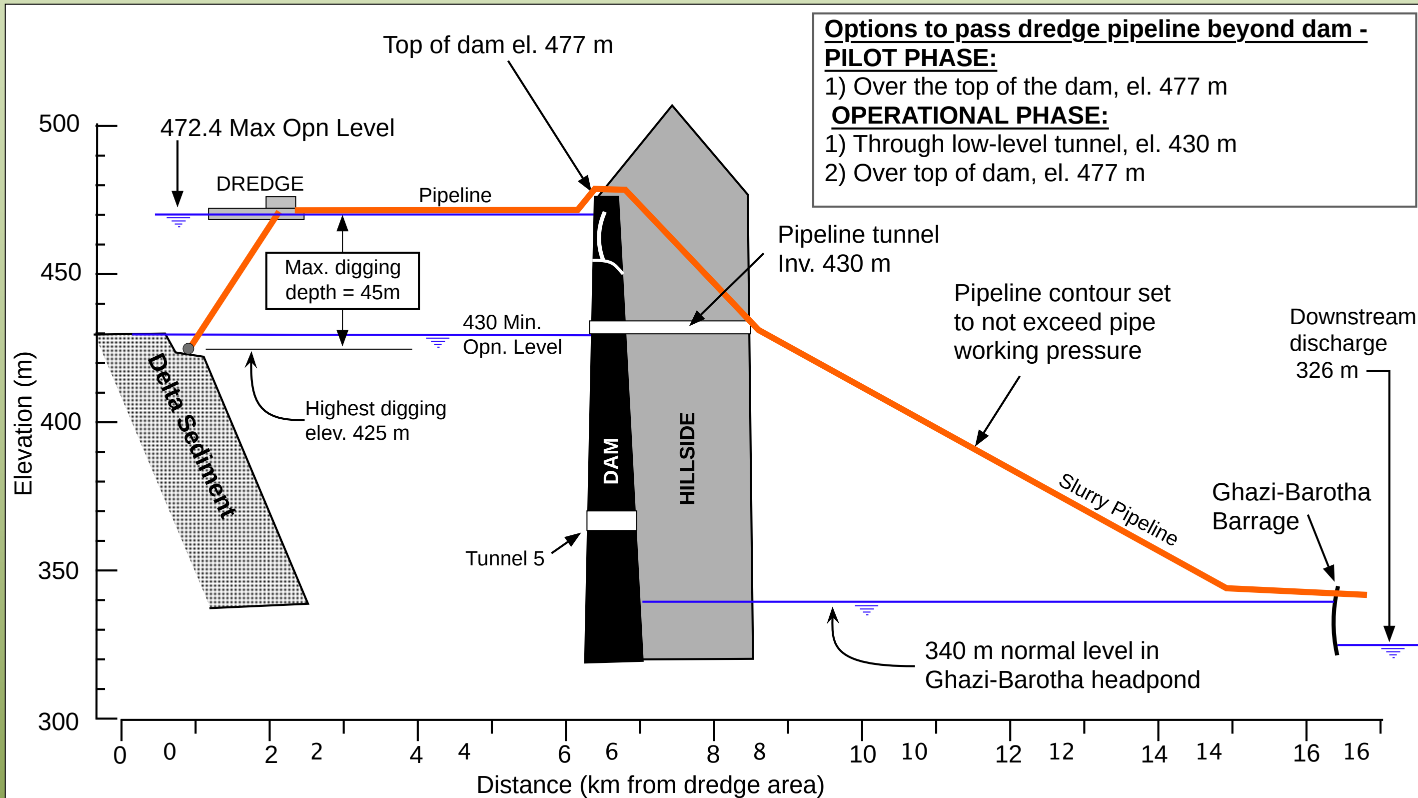
Sediment balance at Tarbela will be achieved by one of 4 methods

1. Allow reservoir to fill and pass sediment over the spillways (sand abrasion will destroy spillways)
2. Pass sediment through turbines (sand will destroy turbines)
3. Construct 10 new tunnels each 10 m diameter, and use for annual flushing (must turn off 6400 MW power plant for a month, replacement power would cost >USD $500 M/year, no control of downstream sediment release rate, uncertain technical feasibility)
4. Continuous dredging (the least cost option, controlled release rate)

Layout of Tarbela continuous dredging project



Conceptual Longitudinal Profile



- Power production cost at Tarbela is about $0.01/kWh
- A $500 M/yr dredging project would increase power production cost to about $0.02/kWh.

Factors Favoring Reservoir Dredging

- A well-developed technology
- Can exactly control the amount of sediment removed
- Can be scaled to any size (using multiple dredges)
- Uses relatively small amount of water
- Does not require reservoir operation to be changed (as in sluicing or flushing)
- Clean way to transport sediment (no trucks)
- At hydropower sites, <u>may</u> be able to use self-supplied energy.
- Can be used when other methods won't work (strategy of last-resort)

Factors Limiting Reservoir Dredging

- High cost
- Energy-intensive
- Not sustainable in the long term if disposal sites are limited.
  - Strictly speaking, it is only sustainable if the sediment is discharged back into the river and can be transported to the sea.
- Environmental impacts (highly variable and site specific)

CLOSING THOUGHTS

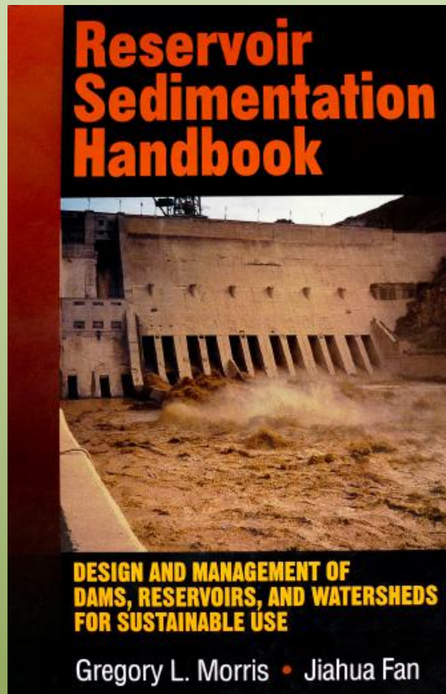
20th century = reservoir construction

21st century = manage sedimentation

- Multiple strategies need to be used – there is no silver bullet.
- Dredging will be a big part of the picture.
- Where will the sediment be placed?
  - Much sediment will need to go downstream, restoring sediment continuity along rivers.
    - **Today we have the opportunity to identify and select the "<u>best" </u>option**
    - **Tomorrow we will have to settle for "<u>the only option remaining"</u>**

Technical resources – available without cost on the Internet

www.reservoirsedimentation.com

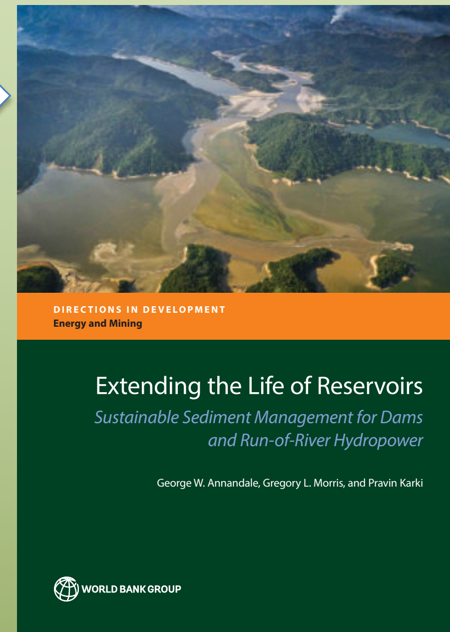


748 page PDF

Extending the Life of Reservoirs
World Bank, Washington, DC

Reservoir Sedimentation Handbook
McGraw-Hill Book Co., New York

World Bank Publication



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