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Conowingo Infill Influence on Chesapeake Bay
Chesapeake Research Consortium Workshop
Annapolis, MD

Sedimentation Dynamics of Reservoirs


River channel crossing delta deposit, Peligre reservoir, Haiti

13 January 2016
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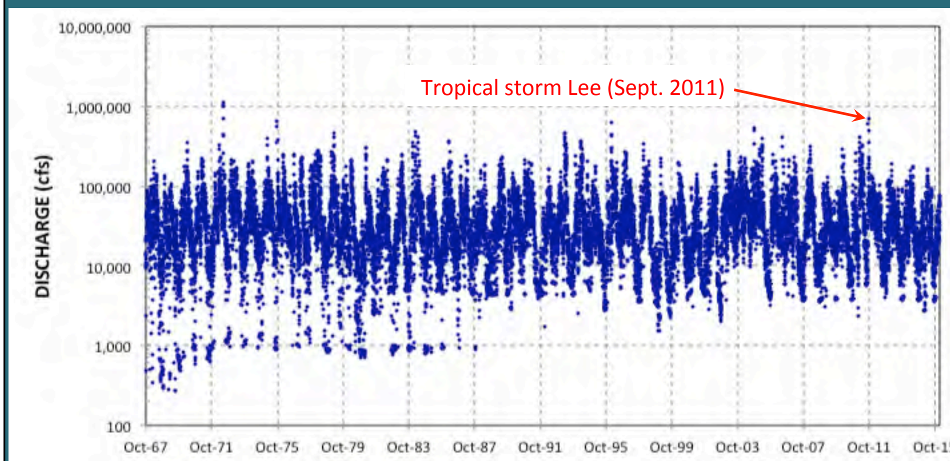
Main Concepts

1. Variability of sediment transport over time
2. Geomorphic evolution of reservoirs
3. Deposition patterns – change in reservoir geometry
4. Management options for sediment

Daily Discharge – Susquehanna at Conowingo



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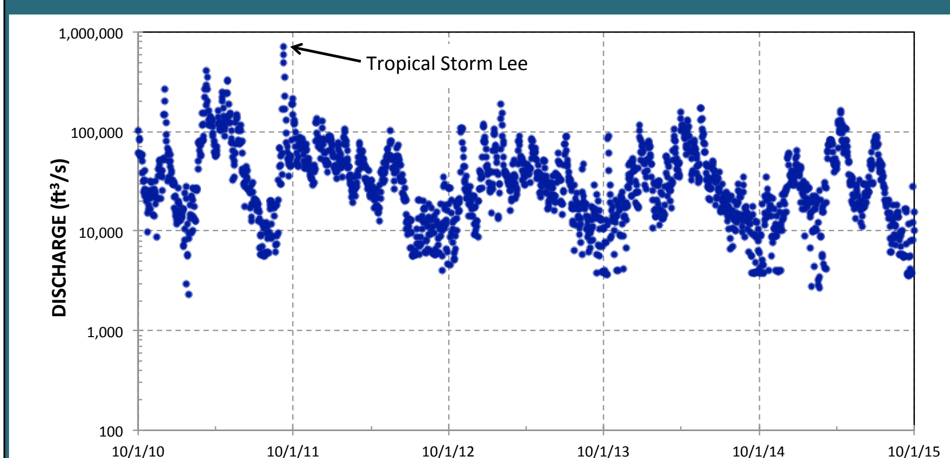
Daily Discharge – Susquehanna at Conowingo



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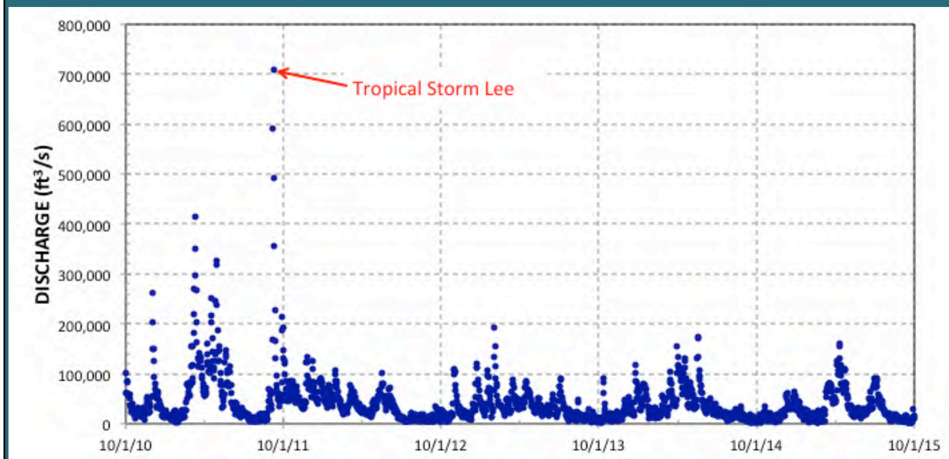

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Example of Extreme Variability of Sediment Yield

San Carlos watershed
Antióquia (Medellín), Colombia

Headwater zone of Río San Carlos

Calderas powerhouse
(supplied by tunnel from adjacent Calderas watershed)

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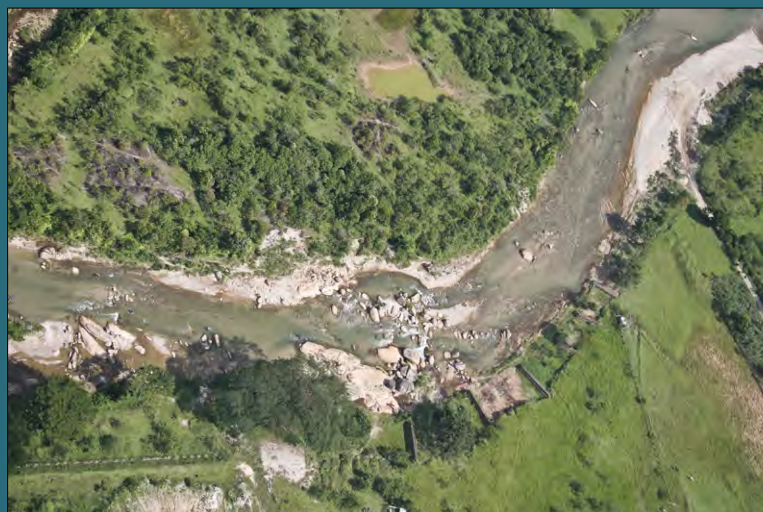
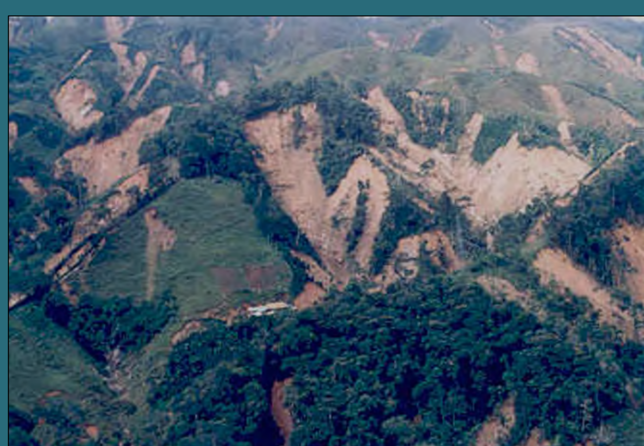
Although the watershed is well vegetated, the streambed contains rocks too large to be transported by the normal flow regime.



Extreme rainfall produced extensive landslides and debris flows across the watershed



Antioquia, Colombia

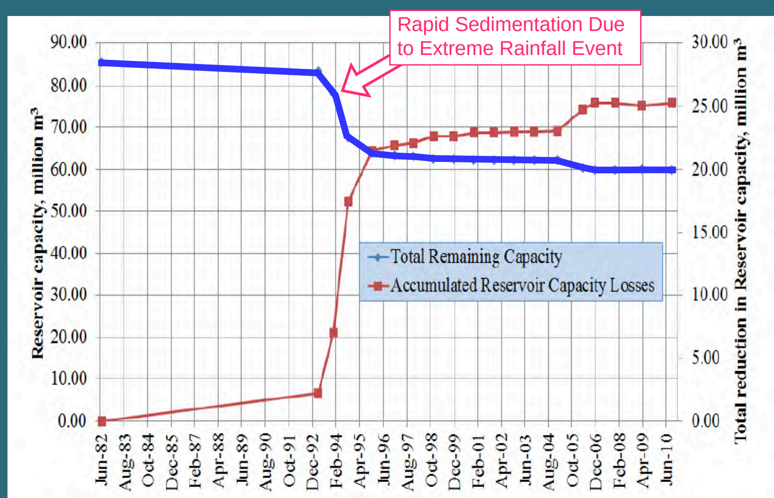
A robust design must consider these extreme events

Calderas Powerhouse

Boulders INSIDE the powerhouse

Impact of Large Events on Sediment Yield

Storage loss at Kulekhani reservoir, Nepal. (Shrestha 2012)

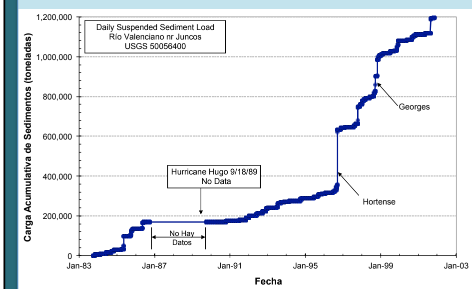


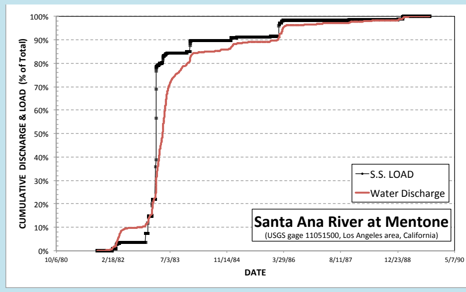
Sediment Load is highly variable over time:

- Graph of CUMULATIVE LOAD clearly shows that most sediments are transported by the highest flows
- In many areas, 2 - 4 days/yr contribute over half the sediment.
- Year-to-year sed. Load may vary by factor of 10x

Cumulative suspended sediment load during 9 years.
Río Valenciano, Puerto Rico

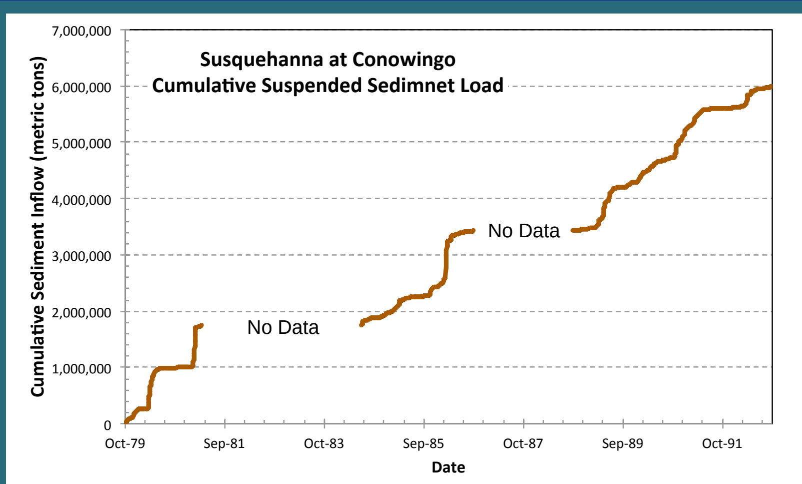
Cumulative suspended sediment load during 8 years.
Río Santa Ana, área de Los Angeles, California.





Cumulative Suspended Sediment Load over Time:

Susquehanna R. Below Conowingo Dam,
showing importance of individual storm events (1979-1992)



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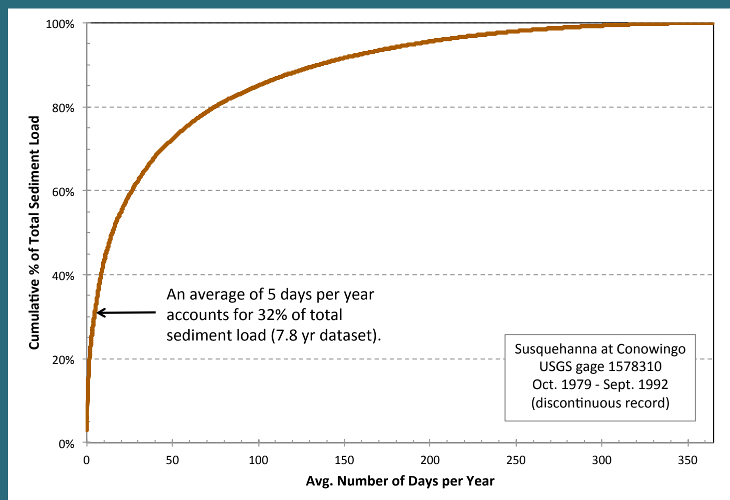
Suspended Sediment Discharge below Conowingo dam is concentrated in time (1979-1991 data)



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Variable Inflows Produces Sediment Layering

(Folsom reservoir, California)

Fine Sediment

Sand (transported by flood)

Fine Sediment

Embalse Folsom, California

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Plunging turbidity current, Porce-2 reservoir
(Río Medellín, Colombia)

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View of top of delta, Porce II, Río Medellín

Embalse Folsom, California

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Sediment Layering (Porce II reservoir, Río Medellín)

SAND (lying below silt and clay)

Silt and Clay deposited over sand

Embalse Folsom, California

Sediment sampling to monitor the advance of sand toward the intake.

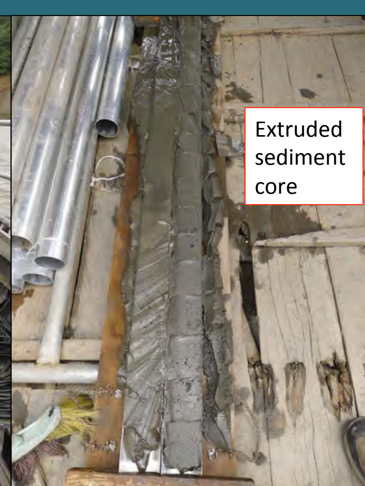
(Vibracore Sampling of Sediment Cores to 60 m depth, La Esmeralda, Colombia)

Winch

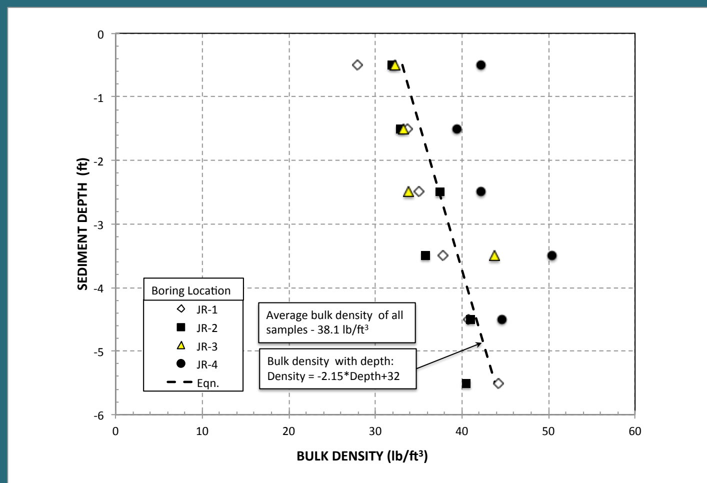
Core tube

Vibrating head

Floats to keep core vertical despite boat Movement.



Bulk density as a function of depth, John Redmond Reservoir (Juracek, 2010)



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QUESTION?

- Conowingo reservoir could be operated to discharge sediment and nutrients two ways:
  - Frequently, in smaller pulses
  - Infrequently, in large flood pulses
- Which is the preferred strategy?

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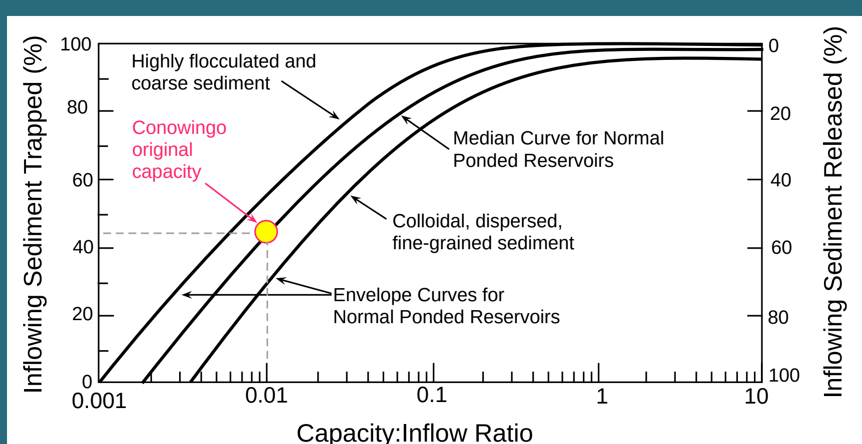
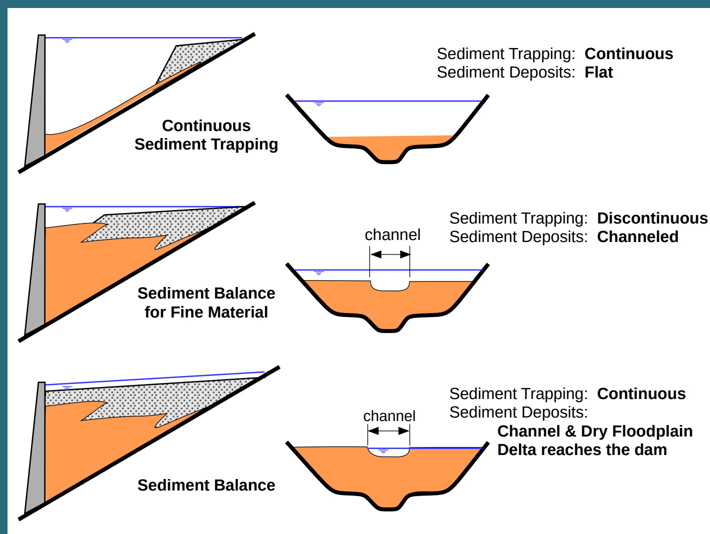
Conowingo never was a large reservoir: Original capacity:inflow ratio approx. 1%.

Brune Curve: rough estimate of a reservoir's average sediment trap efficiency



Long-term evolution of reservoirs
Without intervention, dams will simply become waterfalls



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Camaré reservoir, Venezuela:
Completely sedimented in 14 years. Notice the river channel in the background, flowing over fixed spillway crest

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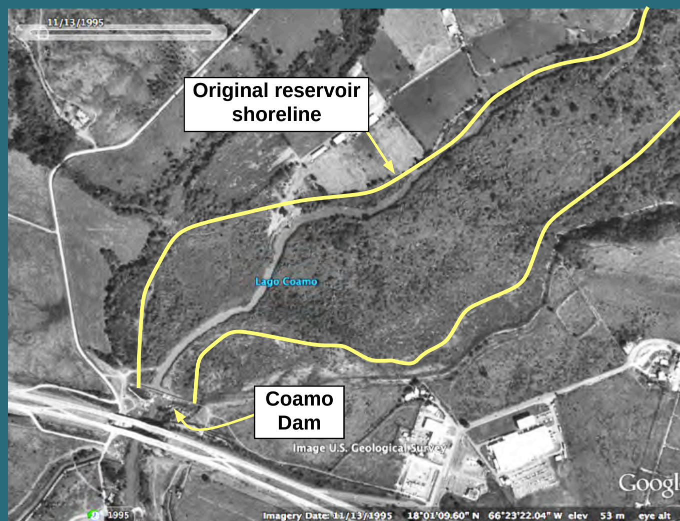
Coamo Reservoir, Puerto Rico: before and after sedimentation



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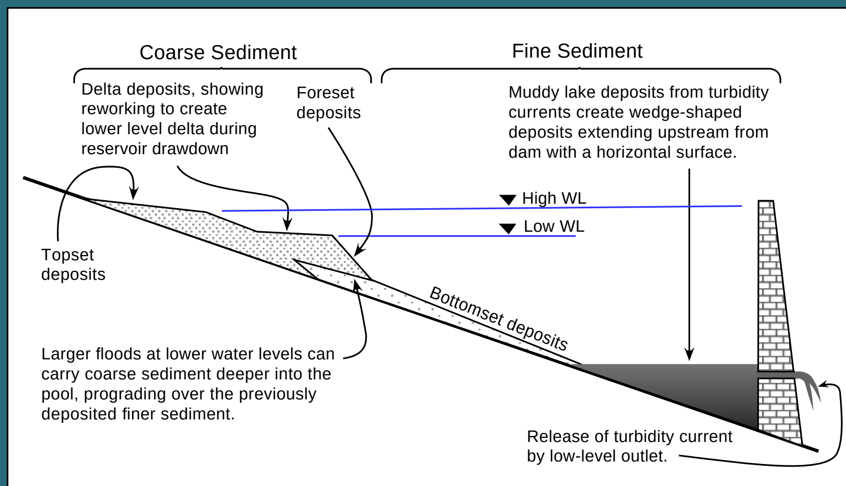
Longitudinal profiles probably provide the best conceptual "snapshot" of the sedimentation process.



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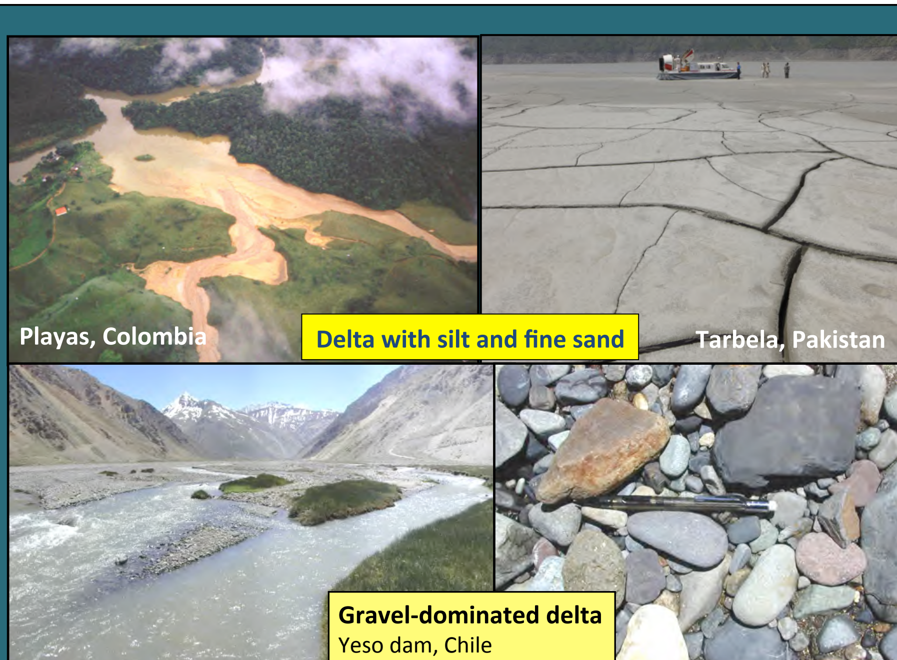

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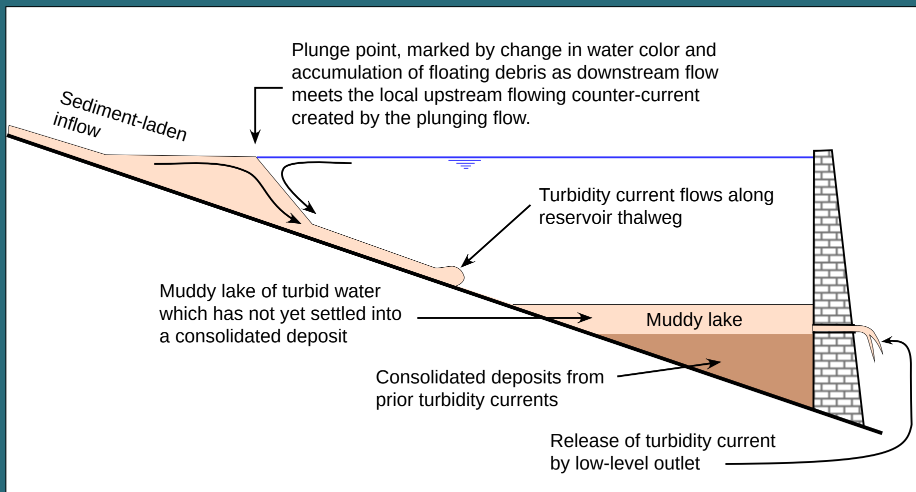
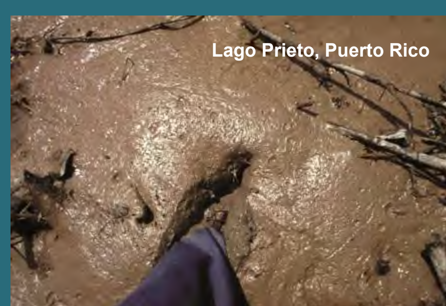
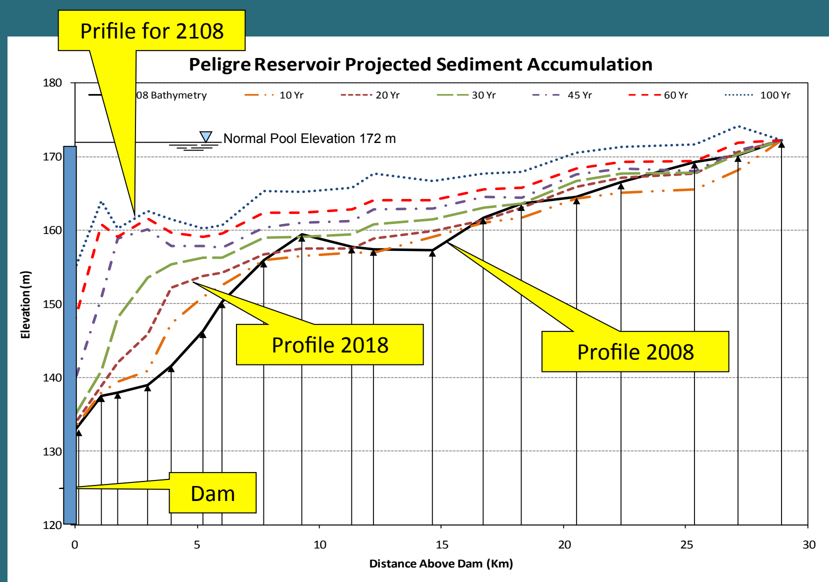
Turbidity currents are important in many reservoirs and may be used to release sediment through turbines



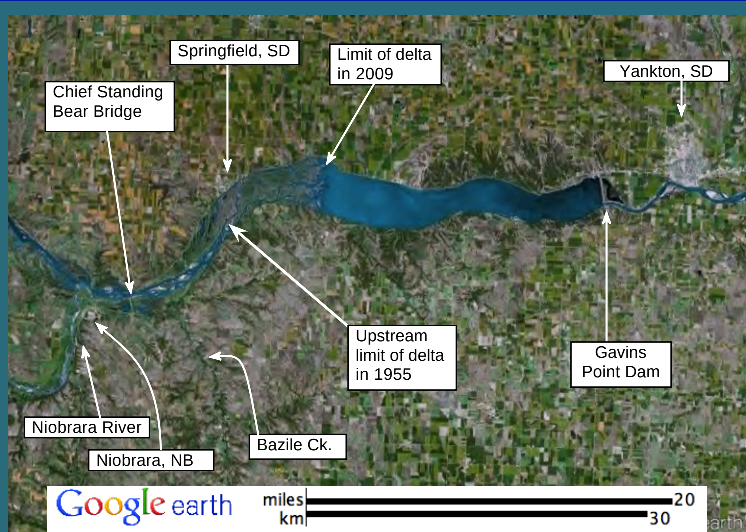
Fine sediment deposited downstream of the delta



Longitudinal Profiles from 100 year simulation.
(Peligre reservoir - SRH-1D software, USBR)



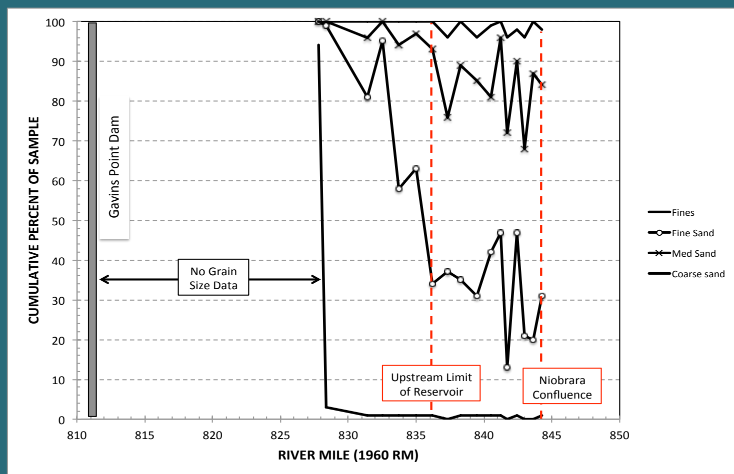
Grain size can vary along the length of the delta
(Lewis & Clark Reservoir, Missouri River at Yankton, South Dakota)



Grain size can vary along the length of the delta

(Lewis & Clark Reservoir, Missouri River at Yankton, South Dakota)

Grain size decreases moving downstream along the delta.



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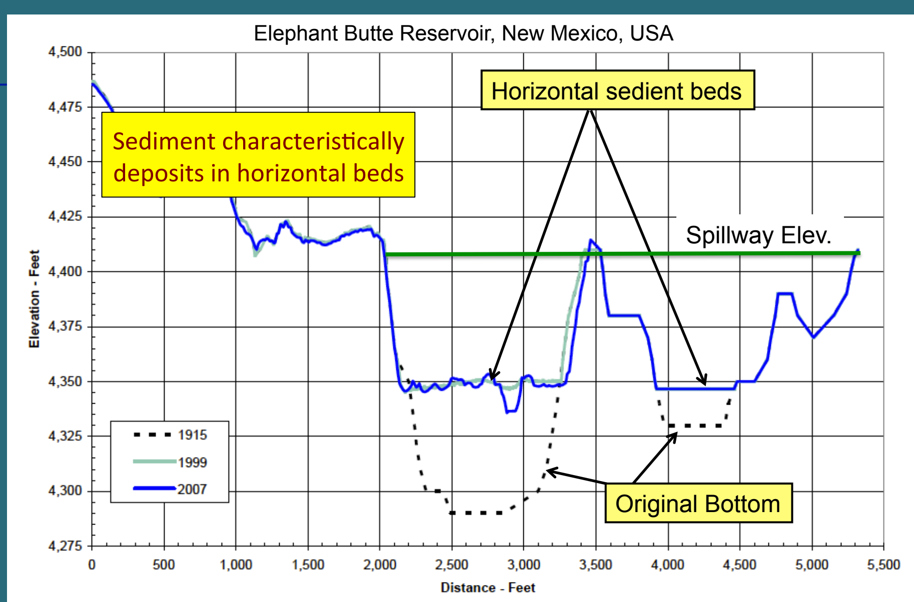

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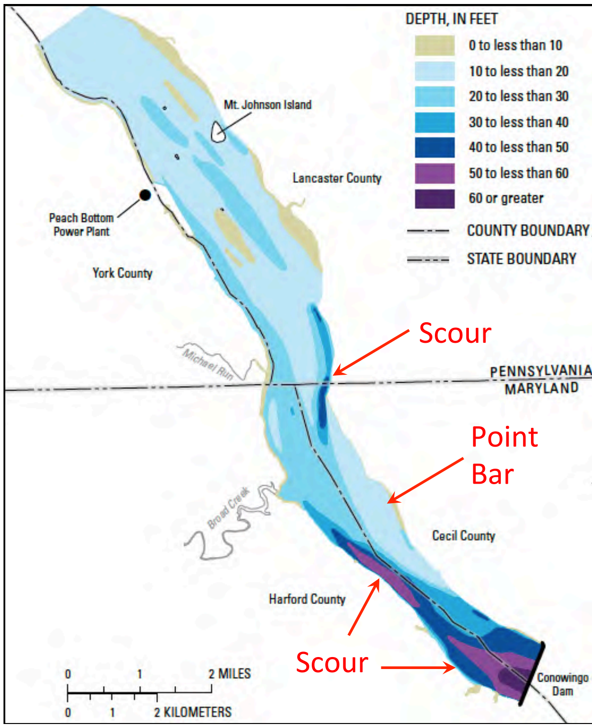
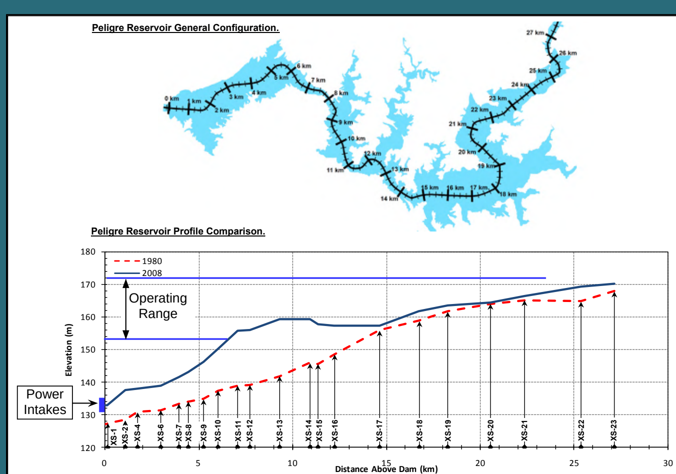


Scour features revealed in bathymetry for Conowingo reservoir

The reservoir is reverting into a river, with geomorphic patterns characteristic of an alluvial river

With annual drawdown, vertical growth of the delta may be limited; most sediment deposited on the delta face as it advances toward the dam (Peligre Haiti)



Peligre Reservoir, Haiti: river channel flowing across a silty delta

At high water level, delta is submerged.

People cross the river by boat for lack of a bridge.

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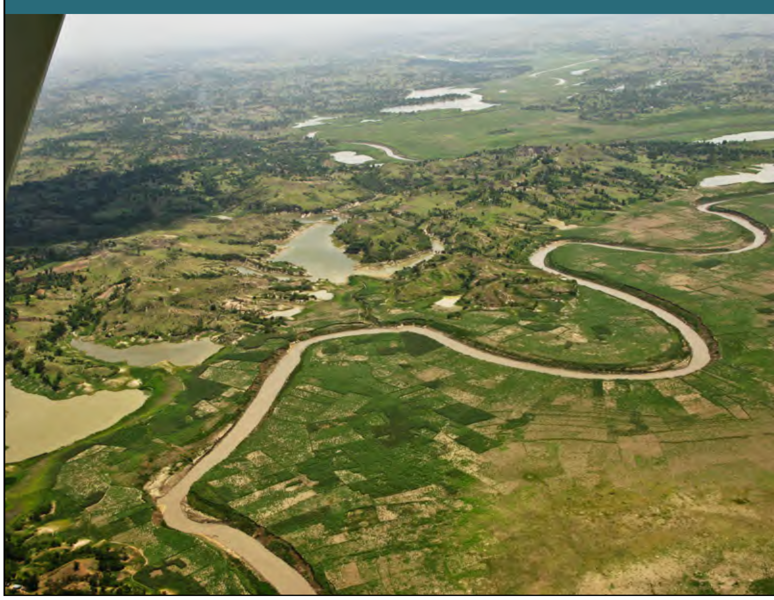
During annual drawdown for power production, the delta is used for crop production



Pattern of delta deposition is not uniform:

Notice that a natural levee has built up (coarser sediment) on river banks, while further off-channel there is ponding and much finer and softer sediment

Slower rate of deposition, and finer sediment.

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Bathymetric survey during drawdown: this photo also shows general appearance of delta

Delta is predomnately silt.

River is sand bed.

$50k of equipment in a dugout canoe. No motorized boat available.

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Key Points

- Longitudinal sorting of sediment by grain size.
- Typically a definitive transition occurs from delta (coarse sediment) to fine sediment.
- Layering of sediment and grain size variation across width of the reservoir.
- Reservoir will convert into a river, absent management to actively scour sediment
  - Shallow off-channel areas will continue to trap sediment and may eventually become vegetated.

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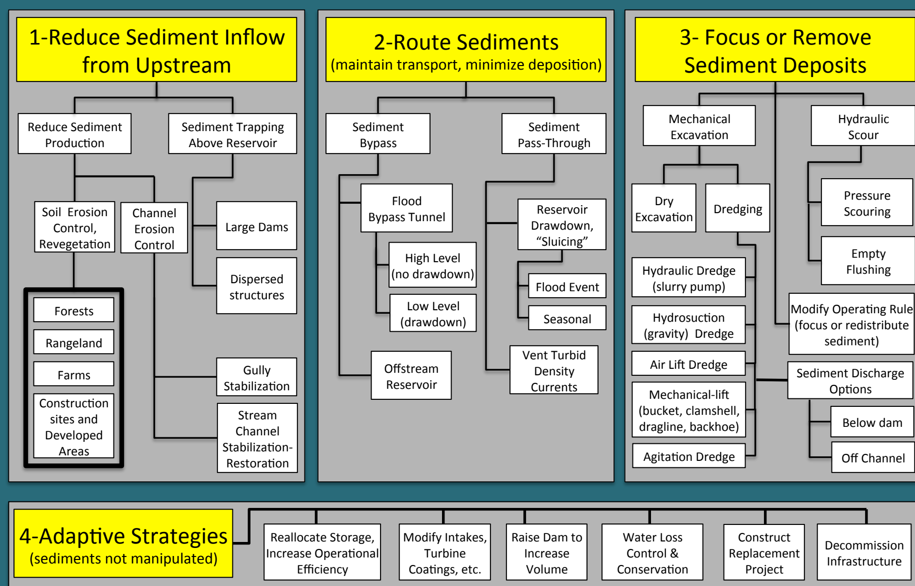
Classification of Sediment Management Strategies for Reservoirs



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1- Reduce Sediment Yield

- Erosion control
  - Costly, may involve many thousands of land users, slow and uncertain implementation and downstream response
- Upstream Sediment Trapping
  - Small check dams have little capacity and are subject to eventual failure, releasing stored sediment, but can be effective if installed in large numbers.
  - Large debris dams are costly.
  - Upstream dams built for hydro, irrigation or other benefits are typically the fastest and surest way to reduce watershed inputs, but these projects may not get built as planned.
- Upstream Sediment Release
  - Sedimented upstream reservoirs can change their operation to start releasing sediment.

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2 - Sediment Routing:
(Minimize Sediment Deposition)

- Sediment Bypass (offstream storage, bypass tunnel)
  - Highly effective, method of choice where feasible
  - Dramatically reduces but does not eliminate sedimentation
- Reservoir Drawdown (sluicing)
  - Reservior level is reduced during floods to maximize flow velocity through the reservoir and minimize sedimentation
  - Some sediment may be scoured (as in flushing), but this is not the primary objective
- Release Turbidity Currents
  - While most reservoirs have turbidity currents, not all of them transport a substantial amount of sediment to the dam
  - Requires low-level release
  - Minimum impact on operations

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Passing Sediment by Reservoir Drawdown
Sanmenxia Dam, Yellow River, China

First major reservoir successfully managed for control of sediment

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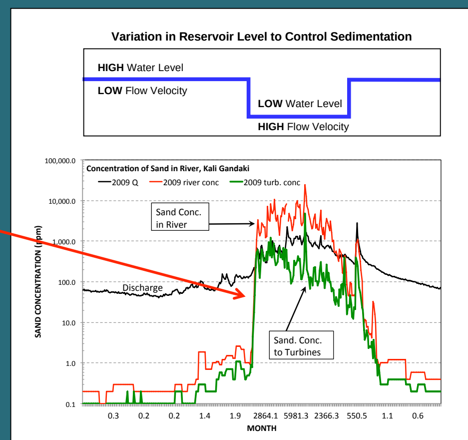
Monsoon hydrograph and drawdown sluicing

Reservoir operated in drawdown mode during monsoon to maximize flow velocity and control sedimentation. Without drawdown, the Kali Gandaki reservoir would fill with sand within a single monsoon season.

- As soon as the reservoir is drawn down for sluicing, the suspended sediment concentration in the river at the intake increases by 3 orders of magnitude
- Sedimentation basins are used during the drawdown period to reduce sand concentration delivered to turbines.



Kali Gandaki, Nepal
Reservoir during an emptying event

Although sediment is not managed at this reservoir by flushing (the sediment load is too high), this photo of the reservoir empty illustrates very clearly that the flushing channel scoured through a reservoir during emptying has a limited width, and large volumes of sediment may not be removed by flushing.

Coarse delta sediments can cause extreme damage to turbines:

- Catastrophic erosion can occurr when an inflowing flood scours sand from the delta and delivers it to the power intake.
- Extreme damage can occur in as little as 24 hours.
- Continuous monitoring and timely shut-down of power plant can prevent this type of damage.
- As reservoirs fill with sediment, it will also be necessary to gradually increase minimum operating level to prevent this type of damage.

Sand in delta deposits eroded during seasonal drawdown for power production

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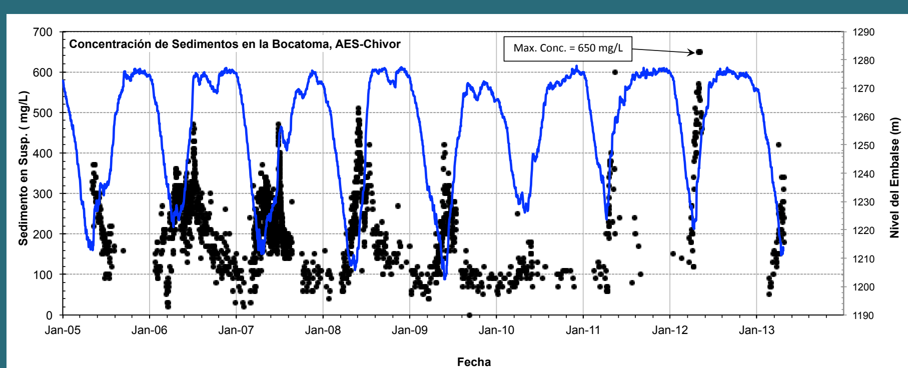
Sediment concentration in water delivered to turbines



- Low water levels scour sediment from delta and also provide less storage detention time for sedimentation.
- Turbidity currents may also contribute.

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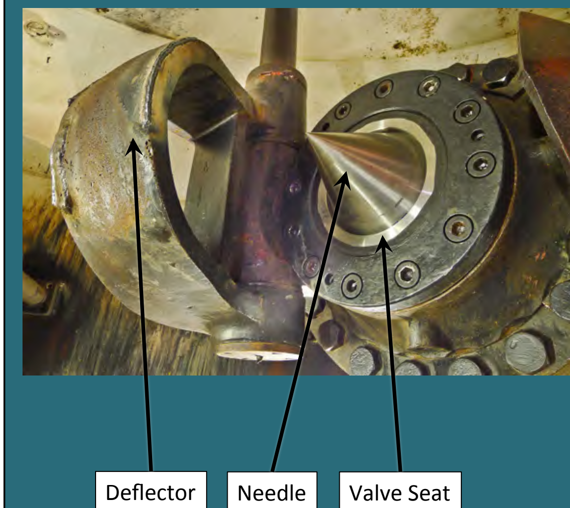
Pelton turbine:
Needle valve configuration



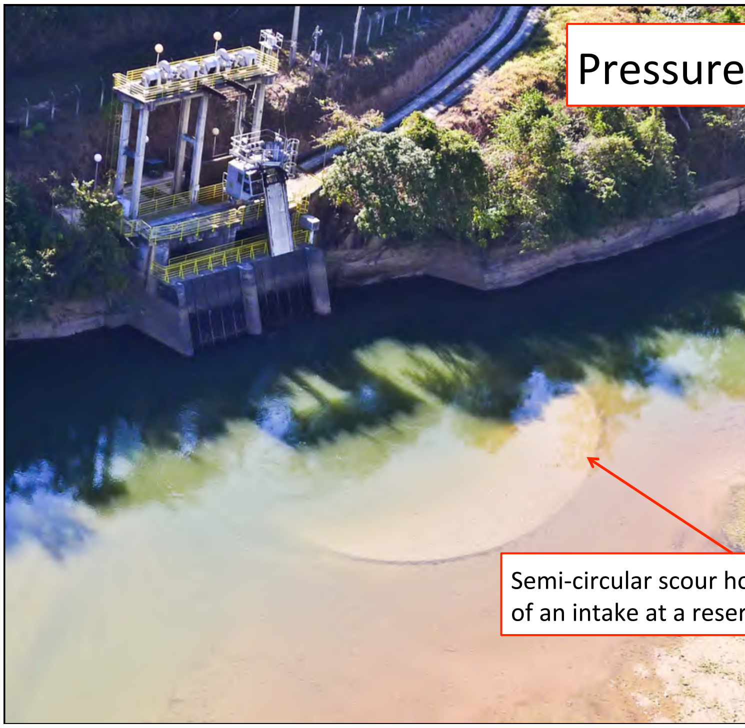
Risk of Catastrophic Damage to Valves & Runners

1000 MW power station, pelton needle valves under 800 m head
Extreme sand abrasion when reservoir drawdown coincided with flood event

10,000 hrs normal operation

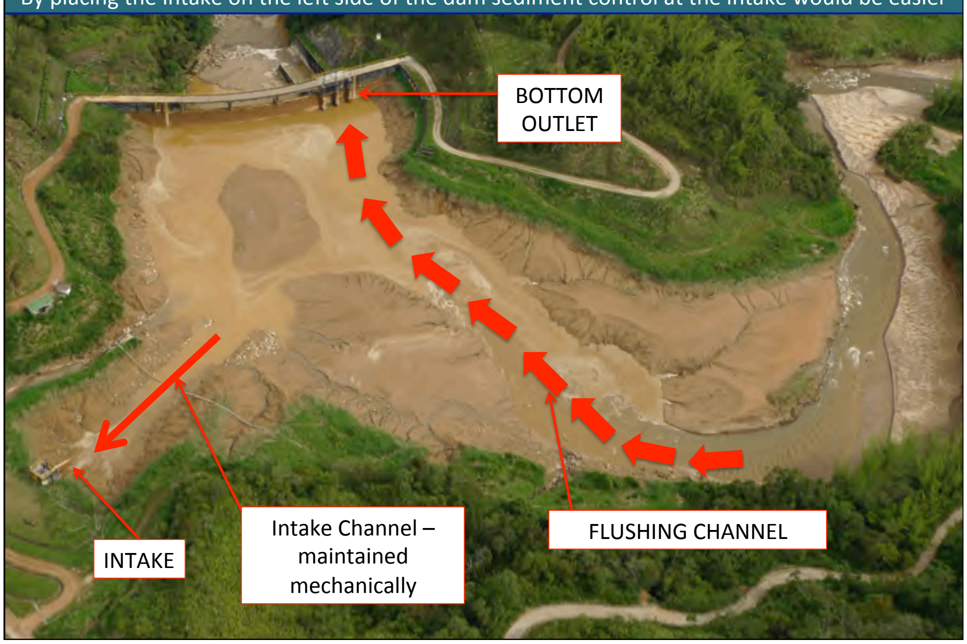
<24 hours passing sand

Pressure Flushing

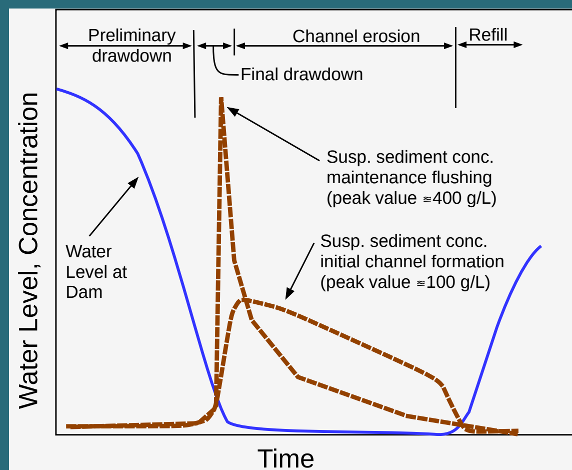


Empty Flushing: Channel and Intake Location

By placing the intake on the left side of the dam sediment control at the intake would be easier



Typical timewise variation in sediment concentration below dam during flushing



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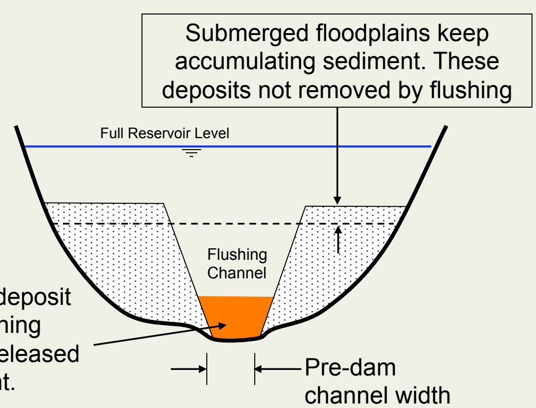
Flushing will only scour out a channel about as wide as the original aluvial river channel

- Because the discharge rate and transport capacity of the flushing release is limited by the low-level outlet capacity, it will typically not be possible to flush out all of the coarse sediment that enters the reservoir.

- Flushing channel helps sustain turbidity current movement to the dam.



Turbid density currents deposit fine sediment in the flushing channel, which can be released in the next flushing event.

QUESTION?

- Conowingo reservoir could be operated to discharge sediment and nutrients two ways:
  - Frequently, in smaller pulses as a result of gate operations.
  - Infrequently, in large flood pulses responding to large natural inflow events
- Which is the preferred strategy?

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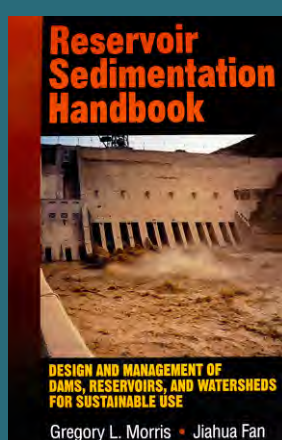

PDF of 748 page book
Reservoir Sedimentation Handbook
McGraw-Hill Book Co., New York

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