JORNADA “HACIA LA GESTIÓN INTEGRADA DE SEDIMENTOS DE EMBALSES”

RESERVOIR SEDIMENTATION MANAGEMENT: PROGRESS AND NEEDS

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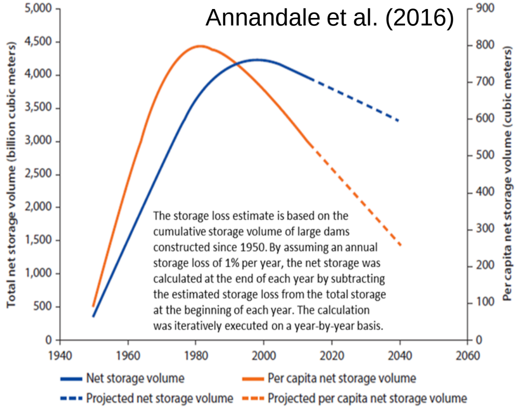
INTRODUCTION

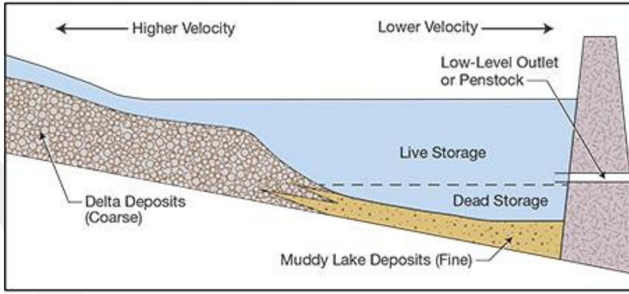
- Reservoirs formed by dams are a key part of sustainable water resources development for the water-energy-food nexus (UN, 2015).
- Rate of reservoir sedimentation: annual storage loss ranging from 2.3 % to 0.68% (average of 0.96% (ICOLD, 2009)).
- Global rate of storage loss due to sedimentation has outpaced the rate of new storage construction.
- Without further actions, one quarter of all reservoirs will lose their storage to sedimentation in the next 25 to 50 years.

Wujie Reservoir in 2018 (Taiwan). Courtesy Hsiao Wen Wang (National Cheng Kung University)



RESERVOIR DESIGN LIFE

- GIVEN selected site for a dam ➡ FIND elevation of lowest outlet.
- Design life: typically 50 or 100 years.
- Accepted practice was to design reservoirs to be filled with sediment.
  - Estimate the reservoir sedimentation volume and spatial distribution.
- Design the dam outlet to be above the reservoir sedimentation level over the design life.
- Future generations will take care and handle the consequences of sedimentation.



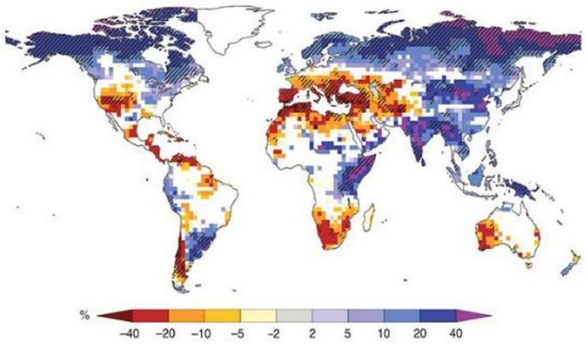
Reservoir Sedimentation Manual

Paonia Reservoir, CO (US Bureau of Reclamation)

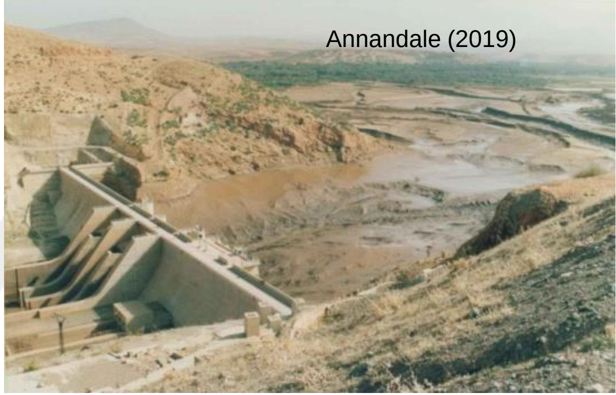
RESERVOIR DESIGN LIFE

- Global water use and hydropower increase with population and development.
- Climate Change: Hydrologic variability, deforestation, increasing sediment loads.
- Most reservoirs cannot be economically dredged to recover lost storage capacity.
- Sustainable sediment management is needed:
  - To preserve the reservoir benefits for future generations.
  - To reduce environmental impacts.

World Bank: "*The last century was used to build reservoirs. This one will be used to solve sediment problems.*"



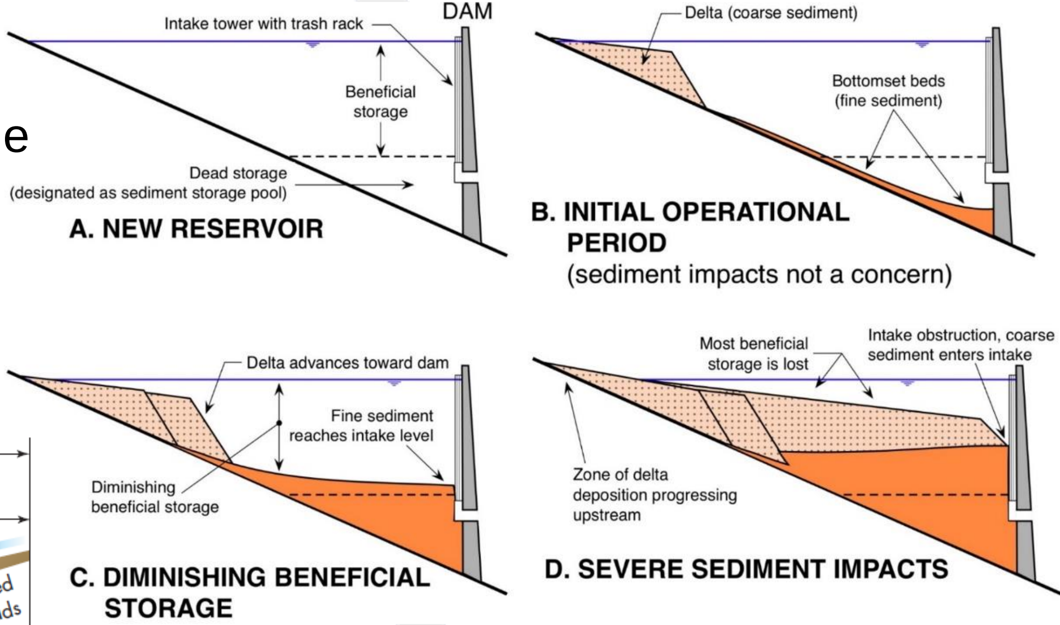
Climate change: Mean annual flow increase/decrease (Annandale, 2019)



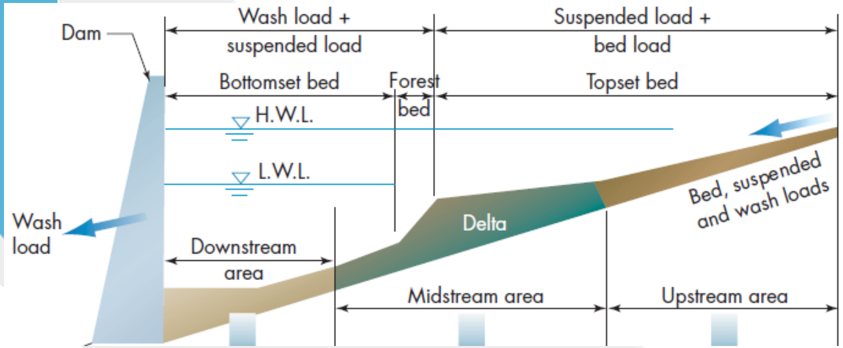
Annandale (2019)

RESERVOIR SEDIMENTATION

- Reservoir blocks downstream transport of sediment.
- Only very fine sediments pass the dam outlets.
- Coarse material trapped and advances toward dam.



Morris (2015)



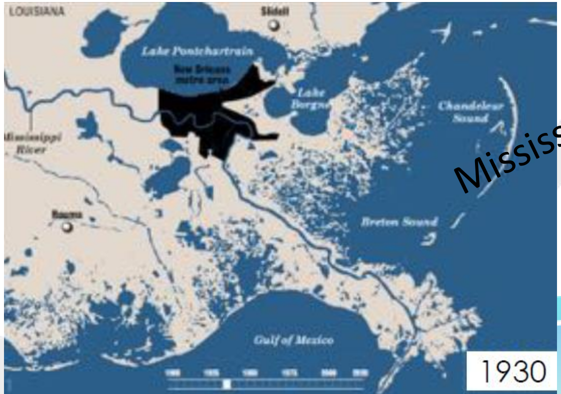
Kantoush et al. (2018)

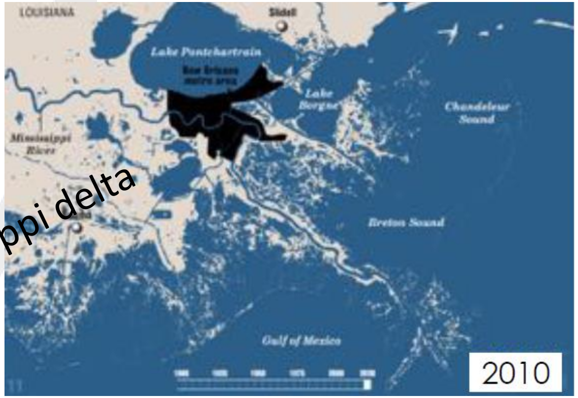
WITHOUT RESERVOIR SEDIMENT MANAGEMENT

- Lost storage capacity over time.
- Sediment discontinuity from upstream to downstream.
- Upstream aggradation and increase in flood stage.
- Buried or impaired dam outlets, water intakes, boat ramps.
- Ecosystem impacts.
- Downstream channel degradation, habitat loss.
- Coast Erosion.

Phragmites Established on Deposited Sediment in Lewis and Clark Lake

Annandale (2015)





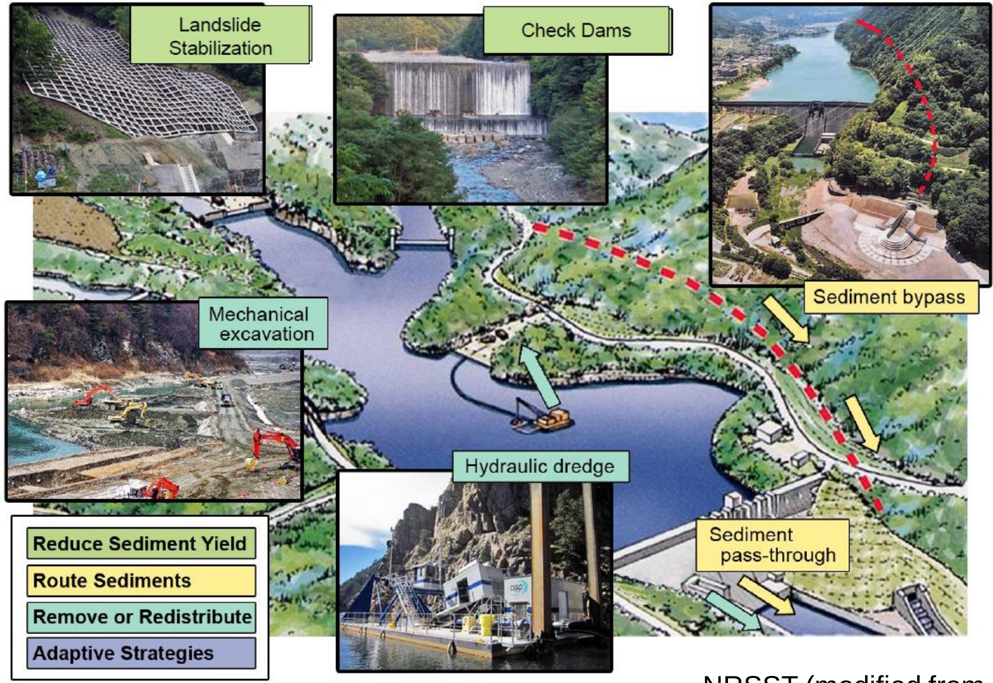
Mississippi delta

Don Swenson (2012)

SUSTAINABLE RESERVOIR SEDIMENT MANAGEMENT

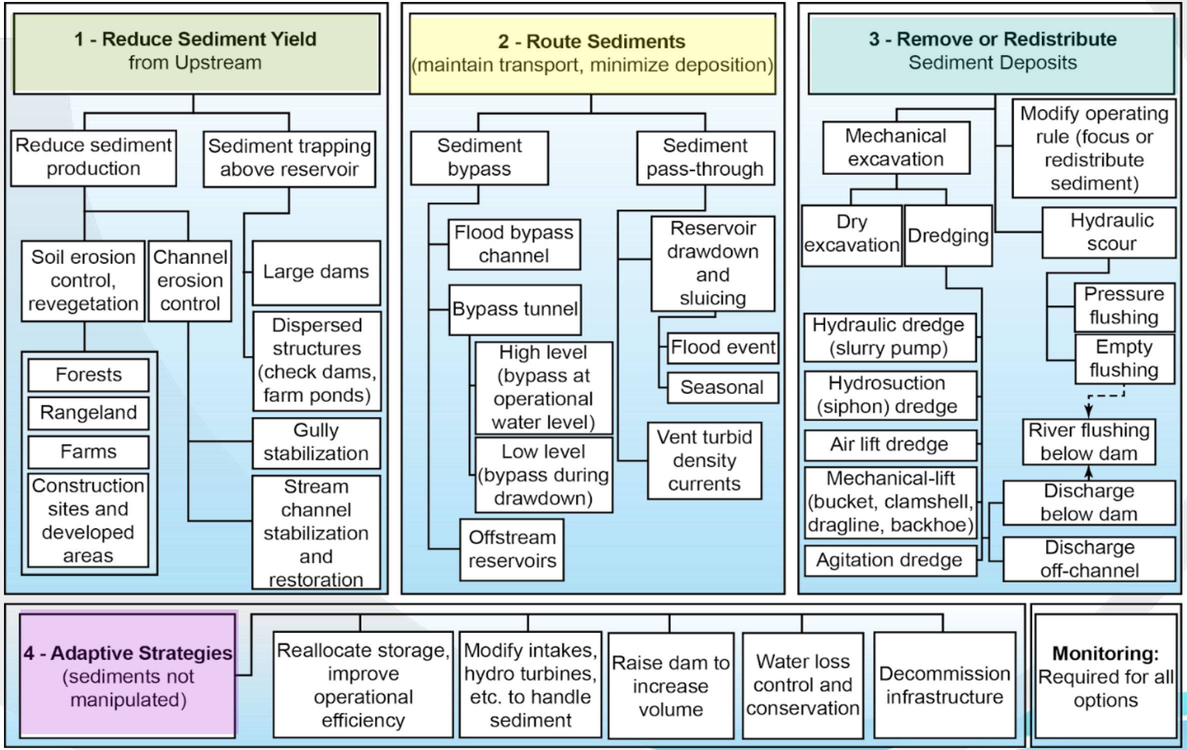
- Sustainable sediment management seeks to:
  - retard the rate of storage loss.
  - bring sediment inflow and outflow into balance.
  - maintain long-term reservoir capacity to maximize benefits from the reservoir.

While minimizing environmental harm



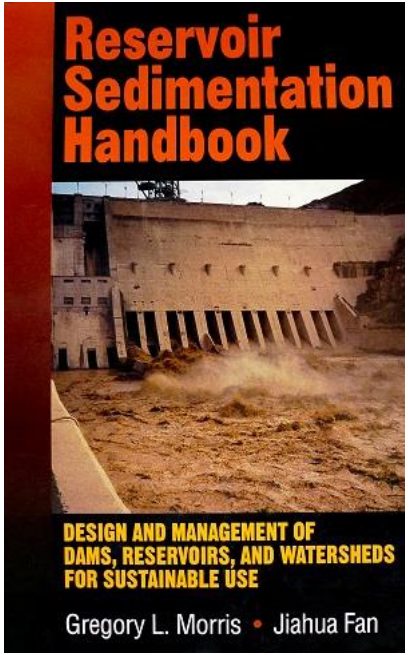
NRSST (modified from Sumi et al. 2017)

SUSTAINABLE RESERVOIR SEDIMENT MANAGEMENT



Technical resource –

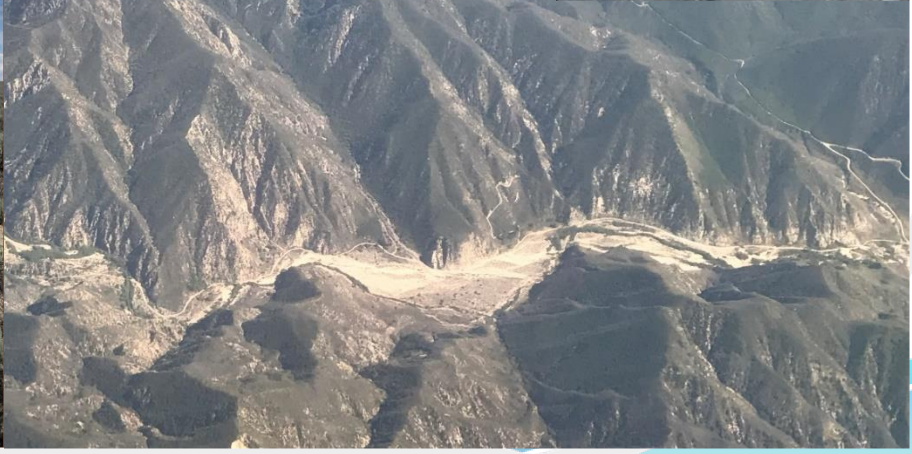
Freely available on Internet

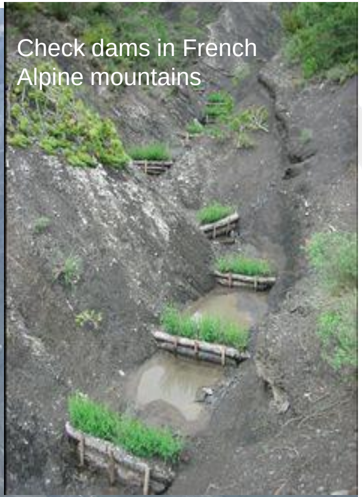


Morris (2015)

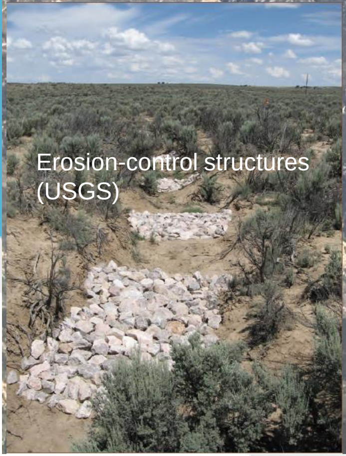
REDUCE SEDIMENT YIELD

- Reduce sediment production:
  - Soil erosion control and revegetation.
  - Landslide erosion control.
  - Channel erosion control.
- Sediment trapping above reservoir:
  - Large dams.
  - Small check dams and farm ponds.
  - Gully stabilization.
  - Stream channel stabilization and restoration.



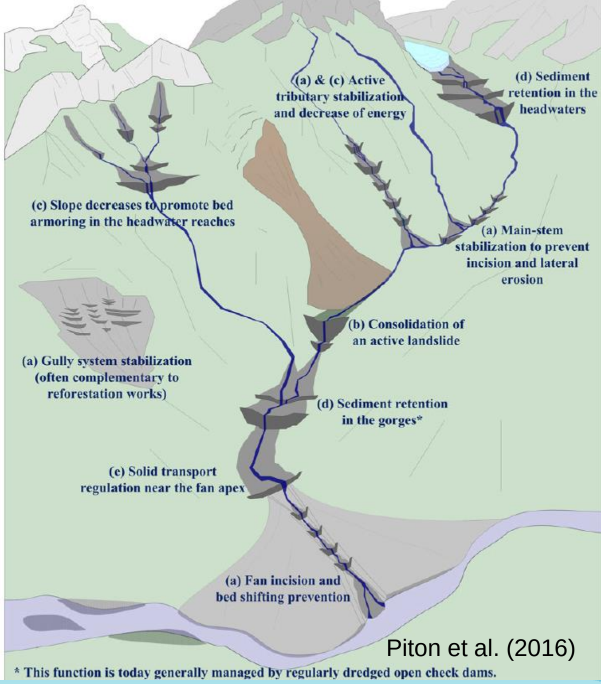


Check dams in French Alpine mountains



Erosion-control structures (USGS)

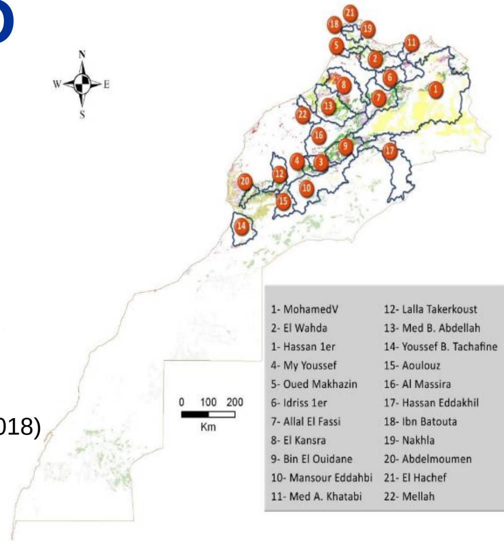
- Large scale implementation
- Decades of efforts to reach measurable reduction of the sediment yield
- Timetable cannot be assured



Piton et al. (2016)

REDUCE SEDIMENT YIELD

- Example of Morocco
  - Reservoir sedimentation: capacity loss nearly 75 Mm³/ year
  - Strong erosion rate: 2,000 t/km²/year.
  - Few dams equipped with bottom outlets.
  - Dredging operations are too expensive.
  - Constructions of 59 new dams by 2030.
  - Raising some highly silted reservoirs.
  - **A National Watershed Management Plan for implementing erosion control for 22 high-priority watersheds.**
    - Reforestation of catchments covering 1,500,000 ha at a rate of 75,000 ha/year.
    - Since 1996, 650,000 ha have been reforested in 18 watersheds.

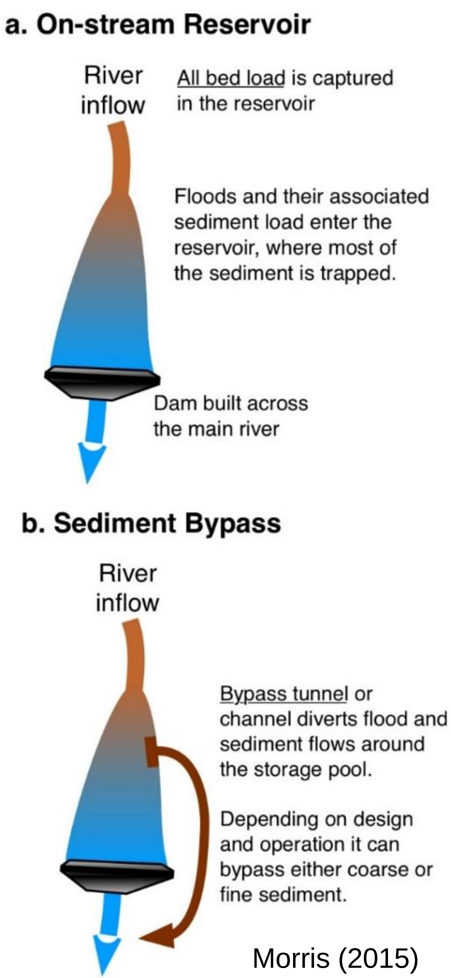


Loudyi et al. (2018)

Mohammed V Reservoir
Loss of capacity: 78%
Raising the dam hight from 63 m to 73 m (under work)

RESERVOIR SEDIMENT ROUTING BY BYPASS TUNNELS

- Bypass tunnels convey fine and coarse materials.
- Operated during natural flood events.
- Bypass tunnel design discharges currently in service or under construction range from 40 to 400 m^3/s (1000 m^3/s in Taiwan).
- Improvement of morphological and ecological status of downstream reaches.
- Under favorable conditions, the rate of sediment delivery into a reservoir may be reduced by over 90%.
- Used in Japan, Taiwan, Switzerland.



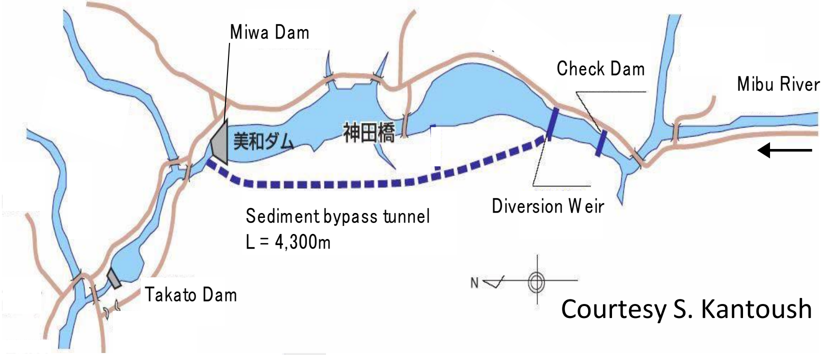
Morris (2015)

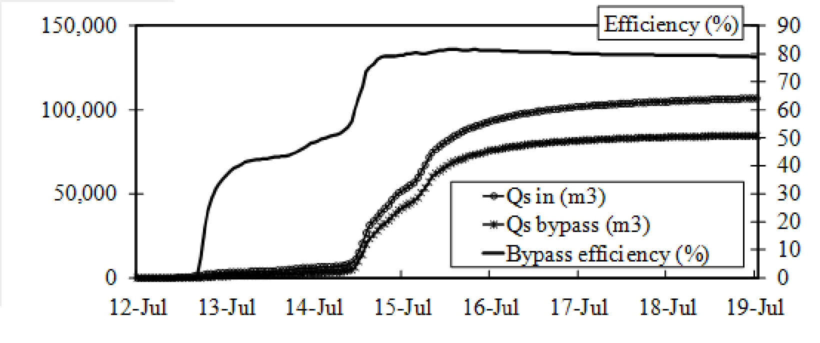
RESERVOIR SEDIMENT ROUTING BY BYPASS TUNNELS

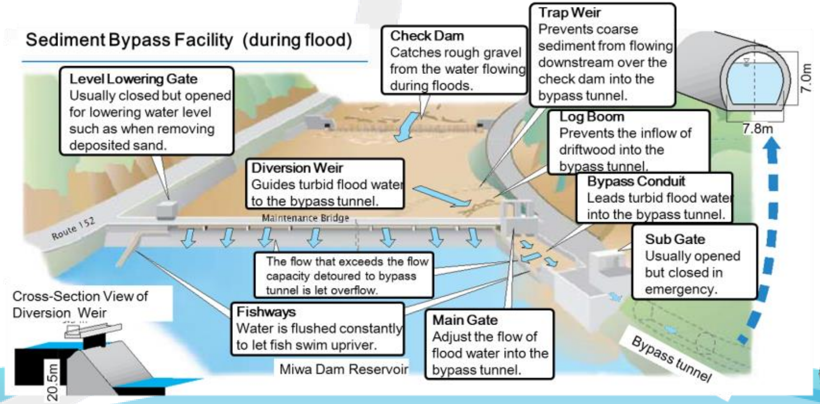
Courtesy S. Kantoush

RESERVOIR SEDIMENT ROUTING BY BYPASS TUNNELS

- Sediment Bypass Tunnel at Miwa Dam:
- Check dam (height: 10.2 m, sedimentation capacity: 200,000 m^3)
- Diversion weir (height: 20.5 m, sedimentation capacity: 520,000 m^3)
- Tunnel (length: 4,300 m, maximum flow rate: 300 m^3/s)







RESERVOIR SEDIMENT ROUTING BY BYPASS TUNNELS

- High construction costs.
- No guideline for the design (economic tunnel cross section, intake and outlet, invert material) and operation of sediment bypass tunnels is available (some guidelines are given in ICOLD 2022).
- Morphology and ecology should be monitored.
- Severe invert abrasion: high maintenance costs.
- Need validated abrasion models to be implemented in numerical models of flow and sediment in tunnels.
- Inspection of tunnels to check the invert and walls at the end of the flood season every year (Boes, 2022).

Asahi bypass tunnel (Japan, Source: Sumi)

Solis bypass tunnel (Switzerland, Source: Boes)

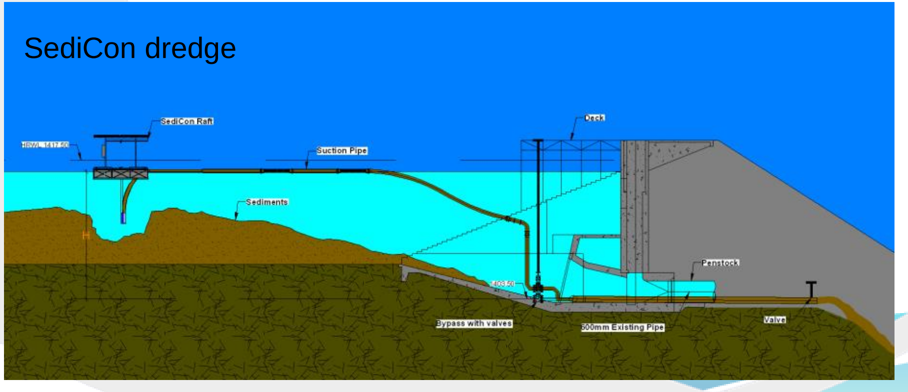
Auel (2022)

Palagnedra sediment bypass tunnel, Switzerland

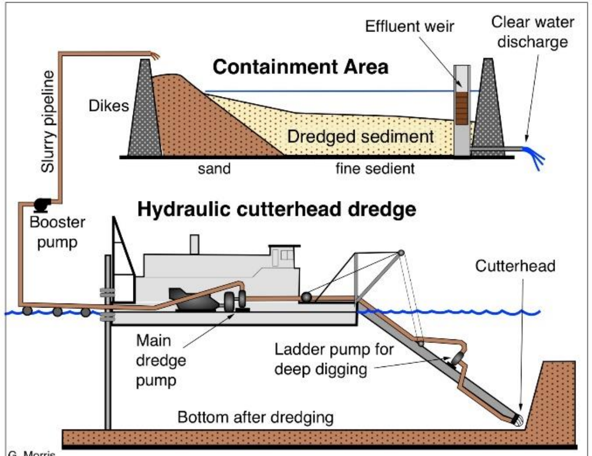
SEDIMENT REMOVAL BY EXCAVATION/DREDGING

- Dry excavation.
- Dredging uses cutterheads and pumps.
- Hydrosuction dredging uses gravity and suction.
- Transport by slurry pipeline, truck, or conveyor belt for discharge to the downstream river channel, disposal site, or beneficial use.


Dry exavation at Longefan Reservoir, France (EDF)



SediCon dredge



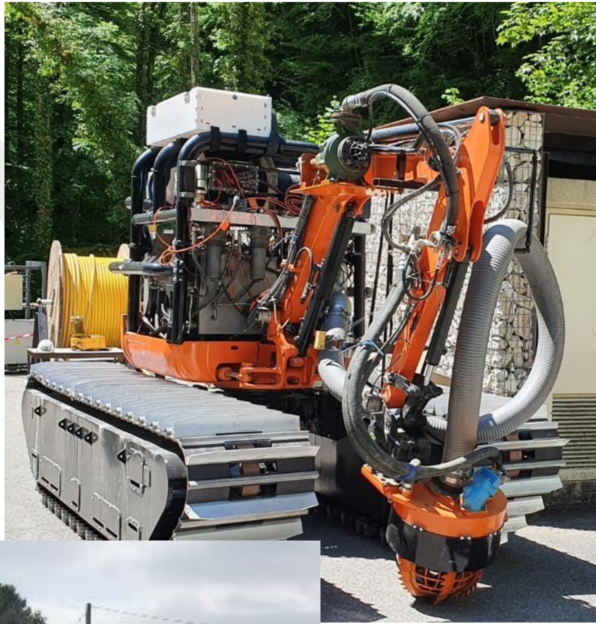
SEDIMENT REMOVAL BY DREDGING: NEW COST-EFFICIENT TECHNIQUES

- **LISIE** = Llight Subaquatic Innovative Excavator.
- **NESSIE** = New Environmental System for Sediment Innovative Evacuation.
- Both techniques are cost effective “by construction” (Low manpower input, Low mob/demob and launching cost, No indirect cost related to reservoir).
- NESSIE and LISIE are now used by EDF for dredging operations

NESSIE

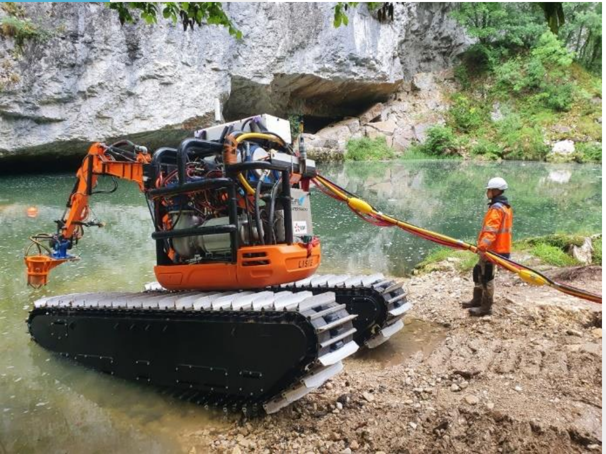
LISIE

SEDIMENT REMOVAL BY DREDGING: NEW COST EFFICIENT TECHNIQUES



- LISIE = LIight Subaquatic Innovative Excavator
  - For subaquatic works in confined environment up to 100 m depth
  - Dimensions: L max: 4.43m W: 1.66m H : 2.85m
  - Dry weight : 4.7 tonnes

WATERTRACKS

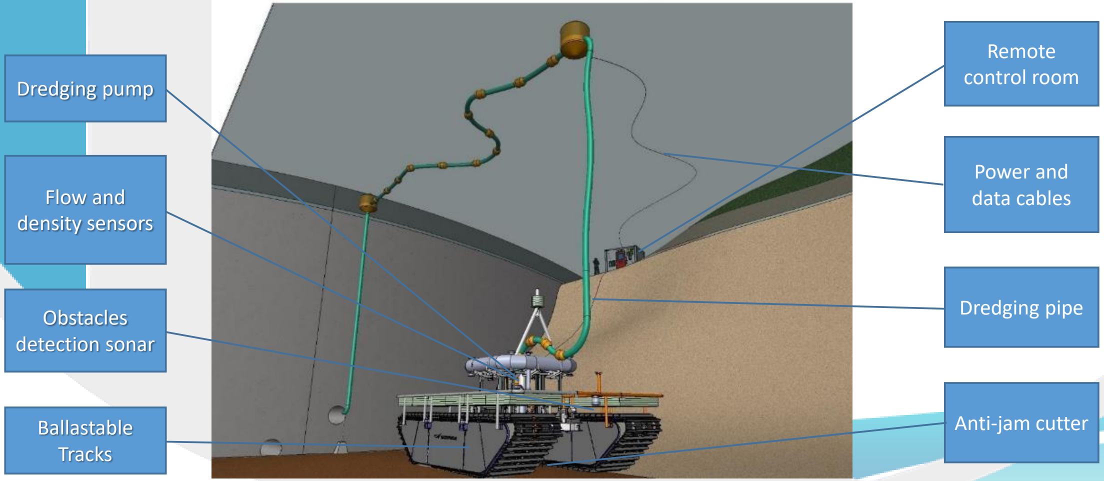


SEDIMENT REMOVAL BY DREDGING: NEW COST-EFFICIENT TECHNIQUES

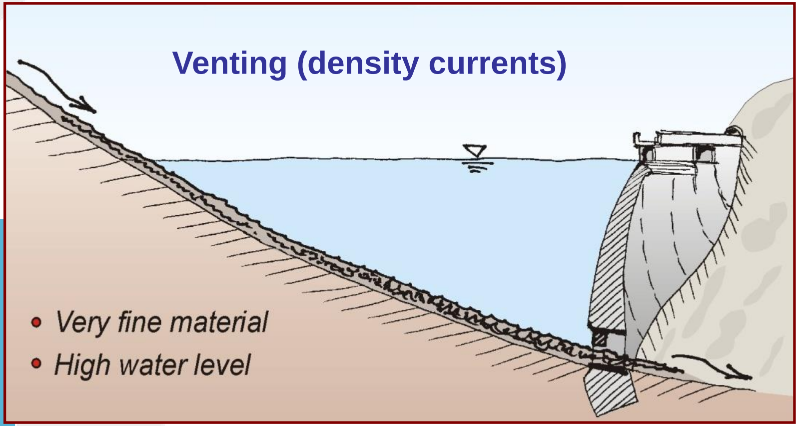
- NESSIE = New Environmental System for Sediment Innovative Evacuation
  - Can work 24/24,
  - Under 1 m to 300 m water depth
  - Equipped with a cutter for cohesive material;
  - Dredging discharge 1200 m^3 /h, i.e. > 100 t/h solid

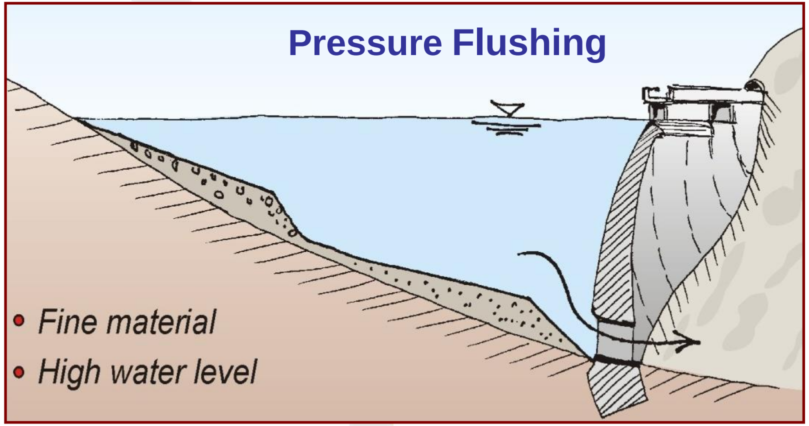
Cutter

WATERTRACKS

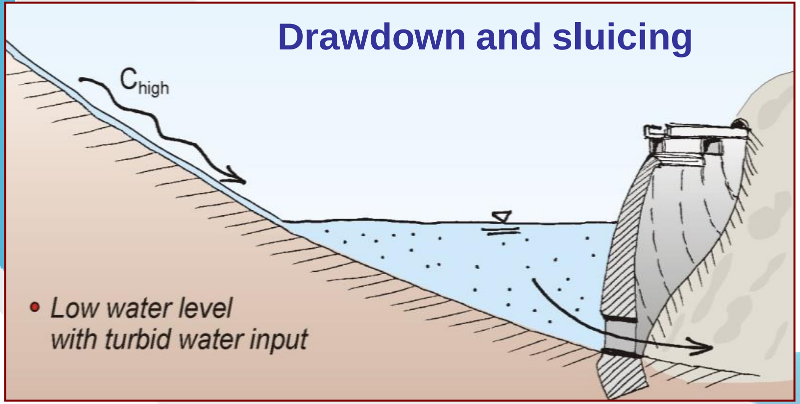


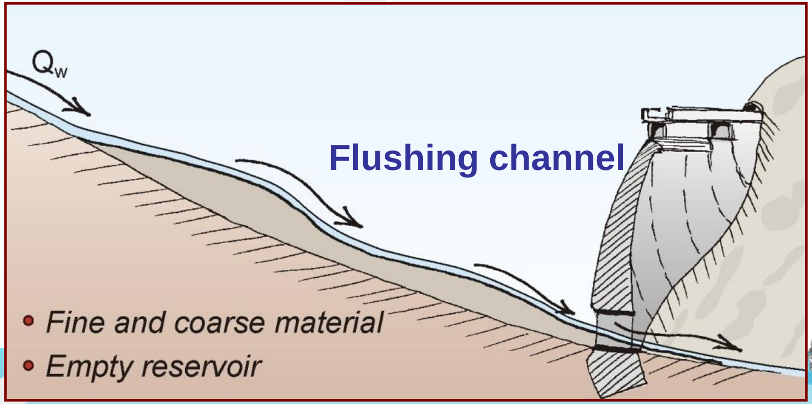
SEDIMENT REMOVAL BY SLUICING/FLUSHING





Di Silvio (2001)





SEDIMENT REMOVAL BY SLUICING/FLUSHING

- Obtaining permits to initiate flushing can be difficult due to concerns with downstream water quality
- Flushing operations release water with high suspended sediment load of adverse chemical properties
- Numerical models are used for simulating the sluicing/flushing operations
- Continuous monitoring is necessary


Gebidem Reservoir, Switzerland

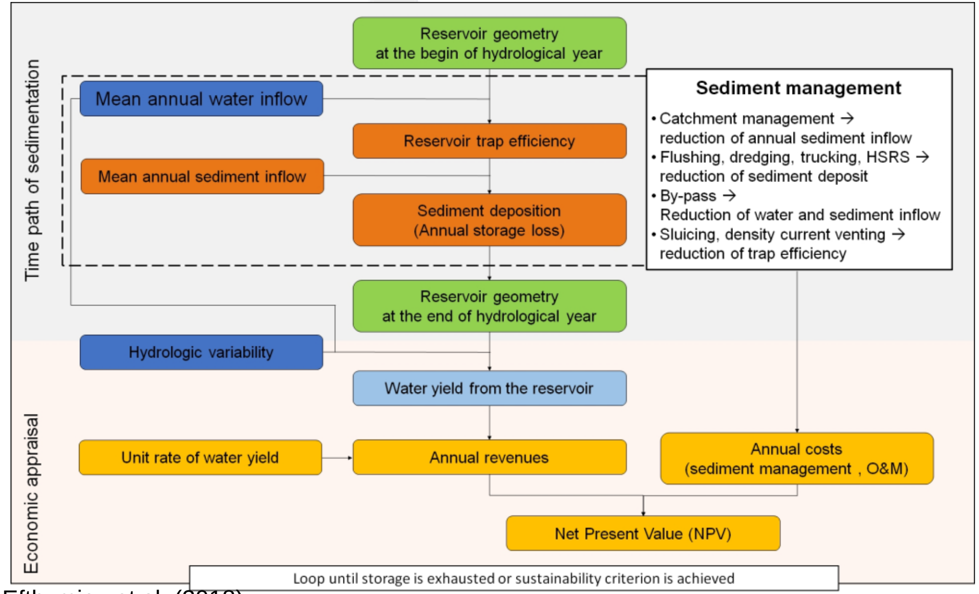

Courtesy S. Kantoush

Flushing channel in reservoir during operation

Fish mortality following a drawdown operation in an Italian reservoir. (Courtesy: S. Bastasi)

HOW TO ASSESS FEASIBILITY OF MANAGEMENT TECHNIQUES

- Technical, environmental, legal, social, and economic feasibility.
- **Reservoir Conservation Model RESCON 2**
  - **https://www.hydropower.org/sediment-management-resources/tool-reservoir-conservation-model-rescon-2-beta**
- Compare consequences of alternatives to the consequences from the eventual retirement of the reservoir and the need to construct a new reservoir elsewhere.



Efthymiou et al. (2018)

Flow chart of RESCON 2 analysis for the assessment of reservoir performance. O&M: Operation & Maintenance

NEED FOR SEDIMENT MONITORING

- The first obvious signs of a sediment problem may be the plugging of a dam outlet or reservoir water intake with wood and sediment.
- Reservoir surveys are periodically needed to monitor & forecast problems and avoid crisis management.

$$Frequency = \frac{Projected\ Reservoir\ Age}{10\ Surveys}$$

Frequency = survey frequency in years per survey,
Projected Reservoir Age = Age of reservoir, in years, when sedimentation has reached the dam’s lowest outlet or other important dam or reservoir facility

- Monitoring is now more important because most reservoirs are in the 2nd half of their sediment-design life.

CONCLUSIONS

- Focus on managing recent or future sedimentation rather than past sedimentation.
- Types of feasible strategies will vary from site to site, and over time.
  - Compare strategies: use of the free tool RESCON 2 for example.
- Management strategies must be assed not only in terms of volume of sediment removed or routed, but also in terms of effects on fauna and flora
- Monitoring of flow and sediment transport in reservoirs and during operations of sediment /removal
- Sediment bypass tunnels
  - Efficient but very expensive.
  - Maintenance and refurbishment of tunnels is necessary because of abrasion.
  - Some progress in terms of recommendations for cross-section profile, bed slope, invert material (see guidelines from ICOLD (2022).
  - Prediction of abrasion of the tunnel invert: need of validated models of abrasion.

CONCLUSIONS

- New dredging techniques are now available:
  - Competitive in terms of direct costs (cheaper than classic techniques), environmentally friendly operations.
  - Work under operational difficulties (trees, leaves heterogeneous sediment, stones).
- Sluicing and Flushing operations
  - Use of numerical models for preparing the sluicing/flushing operations: pre-check of efficiency.
  - Real time monitoring is necessary
- Both quantity and quality of the routed or removed sediment should be studied:
  - How much sediment should be supplied to downstream ?
  - What kind of grain size is Environmentally accepted ?
  - Both quantity and quality of the supplied sediment should be studied
  - What about contaminated sediments?

IAHR Group Reservoir Sedimentation

Join us ☺

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IAHR Worlds Congress 21-25 August 2023, Vienna, Austria

Special session: Reservoir Sedimentation and Sustainable Management

Short course : Assessing and managing reservoir sedimentation with RESCON2 and Delft3D-FM

Acknowledgements

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National Reservoir Sedimentation and Sustainability Team (NRSST)

- https://acwi.gov/sos/nrsst/

Gracias por su atención

Thank you for your attention

Merci de votre attention