RESERVOIR SUSTAINABILITY WORKSHOP AND NATIONAL RESERVOIR SEDIMENTATION TEAM

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ABSTRACT

A Reservoir Sustainability Workshop with national and international specialists was convened in Lakewood, Colorado, July 10-12, 2012 to develop and describe practical solutions for managing sediment for long-term reservoir sustainability. The workshop was sponsored by the Federal Advisory Committee on Water Information, Subcommittee on Sedimentation and the U.S. Society on Dams.

One of the recommendations made during the workshop was to form the National Reservoir Sedimentation Team. The Subcommittee on Sedimentation adopted this recommendation and formed this new team to provide short-course training on reservoir sedimentation and sustainability, provide web-based resources for agencies and the public, recommend interagency protocols for web-based storage and retrieval of reservoir survey datasets, encourage storage of reservoir capacity and sedimentation data in the national reservoir database RESSED, and formulate a white paper on reservoir sedimentation and sustainability.

INTRODUCTION

All rivers transport sediment of various sizes (e.g., clay, silt, sand, gravel, cobbles) and rates. Therefore, reservoirs located on a stream channel accumulate sediment over time unless sediments are trapped by an upstream reservoir. Coarser sediments (sand, gravel, and cobble) entering the reservoir deposit first and often form a delta at the upstream end of the reservoir (Figure 1). The formation of a reservoir delta depends on a significant supply of coarse sediment and the reservoir operating level (Morris and Fan, 1998). Finer sediments (clay and silt) deposit farther downstream along the reservoir bottom. Sediment often accumulates at all elevations of the reservoir. Outlets at most federal dams were typically designed to remain above the sediment accumulation during the first 50 or 100 years of operation (sediment design life). The rate of sediment accumulation depends on the upstream sediment supply and the trap efficiency of the reservoir.

RESERVOIR SEDIMENTATION IMPACTS

One of the most obvious impacts from reservoir sedimentation is the loss of water storage capacity (Figure 2), which will eventually lead to the reduced reliability of water supply and power. Reduced reliability will have the largest impact in regions exposed to multiple-year droughts, which may be exacerbated by the effects of climate change. Other serious impacts often occur long before the reservoir completely fills with sediment:

- Burial of dam outlets, water intakes, boat marinas, and boat ramps (Figure 3).
- Reduction in surface area for recreation (Figure 4).
- Increased dam safety risks from sediment loads against the dam, abrasion of outlets and spillways, and loss of functioning outlets (Figure 5).
- Degradation of the downstream channel bed and stream-bank erosion (Figure 6).
- Alteration of downstream channel and riparian habitat (Figure 7).
- Aggradation of upstream channels, which can lead to reduced conveyance capacity, increased flooding stage, and increased ground water table (which can cause waterlogging and soil salinization).

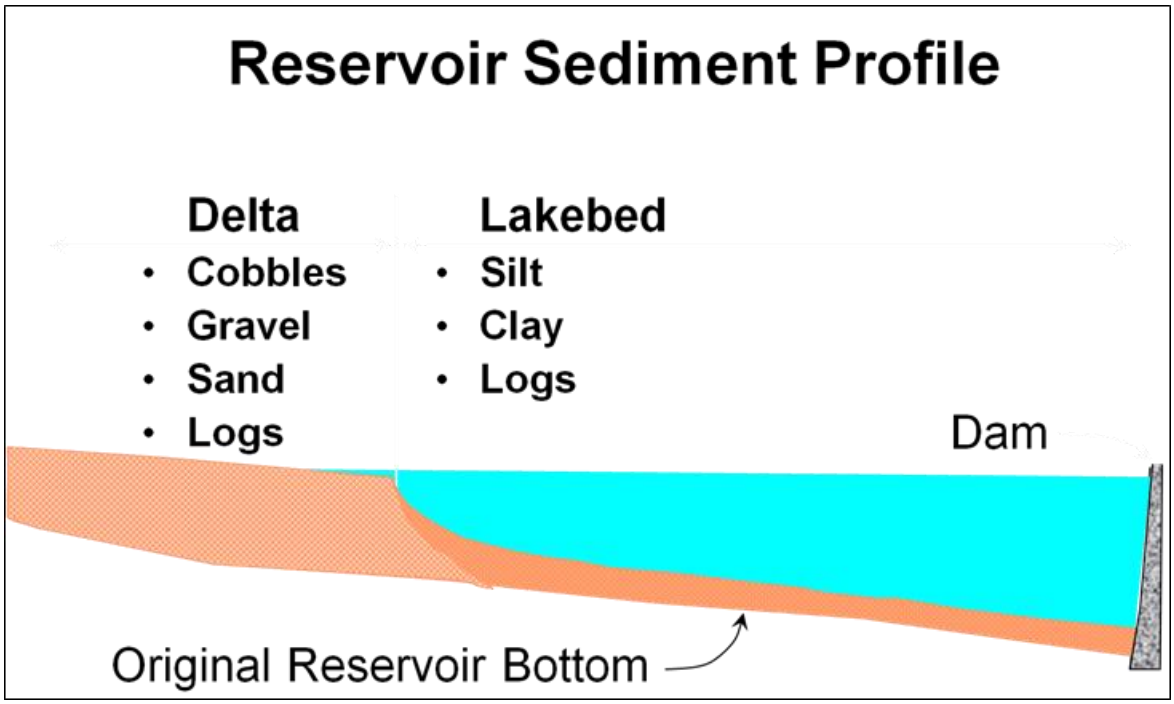

Figure 1 Typical longitudinal profile of a reservoir with a delta and lake bottom sediment deposits.

RESERVOIR SUSTAINABILITY WORKSHOP

The future project benefits of the nation's reservoirs are threatened by continued sedimentation. Therefore, a workshop of national and some international specialists was convened in Lakewood, Colorado, July 10-12, 2012 to discuss potential solutions to reservoir sedimentation (Randle and Collins, 2013). The workshop objective was to develop and describe practical options for managing sediment for long-term reservoir sustainability in the United States. The workshop was organized and sponsored by the Federal Advisory Committee on Water Information, Subcommittee on Sedimentation (SOS) and the U.S. Society on Dams, Hydraulics of Dams Committee. The Subcommittee on Sedimentation provided some financial support for the workshop.

The three-day workshop consisted of a series of sessions. Each session began with an invited lecturer (Figure 8) followed by four separate and concurrent small-group discussions that focused on specific questions. The small groups gave everyone an opportunity to provide input and allowed different groups to concurrently address different questions (Figure 9). Afterward, all participants reconvened for a summary of the four small group discussions. The questions that the small groups focused on are listed below:

- What are impacts associated with reservoir sedimentation?
- What are useful categories of reservoir sedimentation?
- What are the reservoir sediment monitoring recommendations?
- What are the effective reservoir sustainability methods?
- When are specific sustainability methods most applicable?
- What are the environmental effects of reservoir sediment management?
- What further research is needed and what are the priorities?

Figure 2 Sedimentation has almost completely filled the reservoir behind Matilija Dam near Ventura, California.

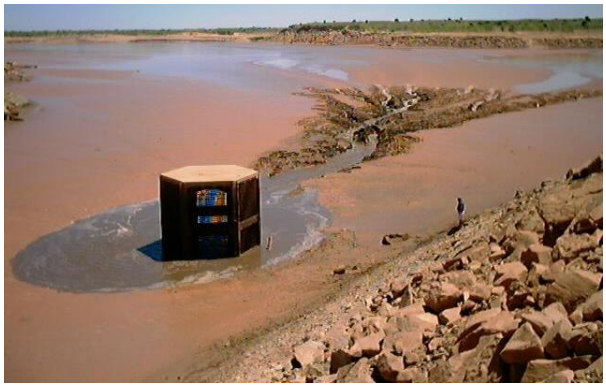

Figure 3 Reservoir sedimentation has impaired the outlet at Sumner Dam near Fort Sumner, New Mexico.

Figure 4 The reservoir delta has reduced the surface area available for recreation at Lake Powell near Hite, Utah.

Figure 5 Sand has abraded the spillway at the Milburn Diversion Dam near Sargent, Nebraska.

Figure 6 Channel degradation downstream from Sumner Dam near Fort Sumner, New Mexico.

Figure 7 Channel Degradation and narrowing of the Platte River near North Platte, Nebraska.

Figure 8 Invited lecturers help to introduce each workshop topic.

Figure 9 Small group breakout sessions were used to concurrently discuss different aspects of each workshop topic.

The workshop was kept to a manageable size by inviting the following organizations with expertise in managing reservoirs and sedimentation:

- Subcommittee on Sedimentation Member Organizations
  - U.S. Army Corps of Engineers (Meg Jonas, Dan Pridal, John Remus, Jerry Webb)
  - U.S. Department of Agriculture
    - Agricultural Research Service (Matt Römkens)
    - Natural Resources Conservation Service (Kerry Robinson)
  - U.S. Department of the Interior
    - Bureau of Land Management (Robert Boyd, Andrew Moss, Dan Staton)
    - Bureau of Reclamation (Michael Beus, Kurt Brown, Kent Collins, Ron Ferrari, Blair Greimann, David Harpman, Victor Huang, Sean Kimbrel, Cassie Klumpp, Yon Lai, Jan Oliver, Tim Randle)
    - Geological Survey (John Gray, Kyle Juracek)
    - National Park Service (Patrick Mangan)
  - Environmental Protection Agency (Gina Christiano)
  - American Society of Civil Engineers (Tim Randle)
  - Colorado Water Resources Institute (Amanda Cox)
- U.S. Society on Dams, Hydraulics on Dams Committee (Marty Teal)
- North Fork Water Conservancy District (Tom Alvey, Trey Denison, Bruce Marvin)
- Los Angeles County Flood Control District (Chris Stone)
- Universities
  - Brigham Young University (Rollin Hotchkiss)
  - Colorado State University (Amanda Cox)
  - Kyoto University (Tetsuya Sumi)
  - Oregon State University (Desirée Tullos)
  - Stanford University (Tom Zigterman)
  - University of South Carolina (Enrica Viparelli)
- Consultants
  - Golder Associates Inc. (George Annandale)
  - Gregory L. Morris Engineering (Greg Morris)
  - WEST Consultants, Inc. (Marty Teal)

The following lectures were provided to introduce each workshop session and stimulate subsequent discussions among the small breakout groups:

- Reservoir Sedimentation Keynote Lecture (Gregory Morris, GLM Engineering)
- Sustainable Water Supply: Policy Implications (George Annandale, Golder Associates)
- Reservoir Sedimentation Categories (Kent Collins, Reclamation)
- Frequency and Extent of Reservoir Sediment Monitoring and the REServoir SEDimentation (RESSED) database (John Gray, USGS)
- Data Collection Technologies (Ron Ferrari, Reclamation)
- Reservoir Sustainability Options (Tetsuya Sumi, Kyoto University)
- Applicability and Cost of Reservoir Sediment Management Options (Rollin Hotchkiss, Brigham Young University)
- Elwha River Restoration Sediment Management (Tim Randle, Reclamation)
- Environmental Effects of Reservoir Sediment Management Options (Kyle Juracek, USGS)
- Modeling Turbidity Currents (Yong Lai, Reclamation)

RESERVOIR SUSTAINABILITY SOLUTIONS

Several categories of reservoir sustainability solutions exist. Combinations of reservoir sediment management methods may be needed to achieve sustainability:

- Watershed land-use practices can reduce the sediment yield entering a reservoir. A wide range of methods can be employed that reduce landslides (Figure 10), soil erosion, and stream-bank erosion.

- Sediment bypass around the reservoir would keep sediments from entering the reservoir. For example, an upstream diversion weir could be constructed to divert river flows with high sediment concentrations into a tunnel or pipe that conveys the sediment around the reservoir and past the dam (Figure 11).
- Passing inflowing sediments through the reservoir also would limit sediment deposition. The venting of turbidity currents through a low-level outlet in the dam (Figure 12) or drawing the reservoir down during periods of high sediment inflow would pass sediment through the reservoir.
- Sluicing of sediment during partial reservoir drawdown would help evacuate sediments near the sluice gates.
- Flushing of sediments previously deposited in the reservoir would help recover storage capacity. Emptying the reservoir is necessary to increase the flow velocity and sediment transport capacity through the reservoir (Figure 13). Downstream sediment concentrations can be very high during flushing.

Figure 10 Landslide stabilization in Japan reduces the watershed sediment yield.

Figure 11 A tunnel was constructed along the Miwa Reservoir in Japan to bypass river flows with high sediment concentration.

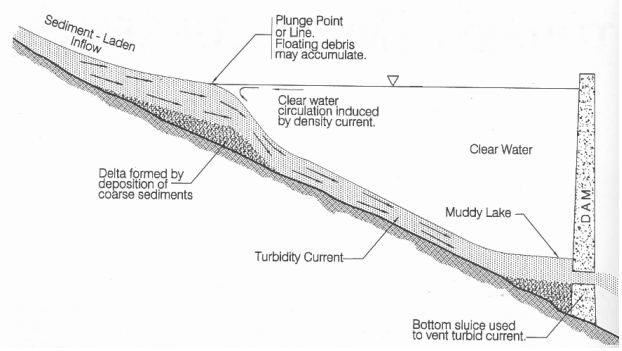

Figure 12 Sediment laden inflows can form a turbidity current along the reservoir bottom and it may be possible to vent this high sediment concentration through a low-level outlet in the dam (Morris and Fan, 1998)

Figure 13 Lowering the reservoir can result in the erosion and downstream flushing of sediments (Lake Aldwell behind Elwha Dam, Washington).

- Sediment removal also would help recover storage capacity. Sediment can be removed by hydraulic dredging (Figure 14), mechanical dredging (Figure 15), and dry excavation. Sediments can be conveyed from the reservoir by sediment slurry pipeline, truck transport, or conveyor belt. Removed sediments can be discharged into the downstream river channel or delivered to a disposal site.

Some sediment management methods would affect reservoir storage operations:

- Flushing that is implemented during the non-flood season by complete reservoir drawdown.
- Sluicing that is implemented during the flood season with partial or full reservoir drawdown.
- Dry excavation, which requires emptying reservoir and using conventional excavation equipment to remove sediment.

Figure 14 Hydraulic dredging of reservoir sediments for transport through a sediment slurry pipeline (Strontia Springs Reservoir, Colorado).

Figure 15. Mechanical dredging of reservoir sediments and transport by truck (Japan).

Other sediment management methods would have much less effect on reservoir storage operations:

- Upstream check dams.
- Bypassing sediment through or around the reservoir.
- Density current venting.
- Hydraulic dredging.
- Barge-based mechanical dredging.
- Hydrosuction sediment removal systems.
- Pressure sluicing under a full reservoir to remove sediment near the outlet.

WORKSHOP FINDINGS

Overview Findings:

- Continued reservoir sedimentation will eventually eliminate or substantially reduce the benefits for which the reservoirs were authorized, designed, and constructed. Sediment management alternatives exist to achieve sustainable reservoir management. The cost of these alternatives is not well known, but failure to manage reservoir sediment will eventually result in substantial dam decommissioning costs and either the loss of project benefits or increased costs of future water storage.
- Federal reservoirs are functioning as originally authorized and designed, which also means they trap sediment that is naturally transported by all rivers and streams. Policy makers likely are not aware that the numerous benefits provided by the nation's reservoirs are not sustainable over the long term without sediment management.
- Population increases over time will result in increased demand for water supply while reservoir storage capacity is being reduced due to sedimentation.
- In some regions, climate change may lead to increased hydrologic variability. Increased variability will reduce water supply reliability during droughts and increase rates of reservoir sedimentation during floods, which also reduces reservoir reliability.
- The present course of reservoir sedimentation will result in lost opportunities for future generations, force them to pay for dam decommissioning, and force them to choose more expensive water storage alternatives than those that were available to previous generations.

- Economic analysis of reservoir sediment management needs to account for inter-generational equity, the future value of reservoir storage, and the eventual dam decommissioning cost if no action is taken. A life-cycle design approach for reservoirs would promote sustainability over the traditional design-life approach.
- A great deal is known about reservoir sedimentation processes. More research is still needed, but enough is known to start addressing the problem.

Reservoir Sediment Monitoring:

- Reservoir sediment monitoring and reporting is needed to track and forecast sedimentation. A publicly available and updatable reservoir sedimentation database is also needed Reservoirs should be surveyed at minimum intervals based on the rates of sedimentation. Reservoirs should also be surveyed after significant inflow floods (e.g., after 10-year flood peak or greater).
- Reservoir sediment survey costs have substantially decreased over the past few decades while the quantity and precision of the data have greatly improved.
- Capabilities to continuously measure sediment transport through surrogate technologies (e.g., hydro-acoustics, turbidity) have also improved over time.

Reservoir Sustainability Solutions:

- Each reservoir sediment management method has a range of applicability. Guidelines are needed to help determine the most applicable sediment management method (or combination of methods) for a given reservoir.
- For each reservoir, eventually develop a plan for either long-term sustainability or decommissioning. Watershed and reservoir demonstration sites are needed to collect data, and test methods and models.
- Reservoir sediment monitoring data are needed to measure sedimentation rates and determine management priorities. Sediment monitoring data should include the volume and spatial distribution within the reservoir, grain size, bulk density, chemical composition, and cohesive properties.
- Environmental problems associated with reservoir sediment can be managed or mitigated with sufficient investigation and understanding of physical, chemical, and biological processes. Lack of understanding will result in unintended consequences.

Sediment Management Research Needs:

- Develop techniques or methods to reduce sediment measurement costs and improve the efficiency of measurements for sediment inflow and thickness within the reservoir, grain size, bulk density, and chemical characteristics.
- Develop methods or models to assess the effectiveness of watershed land-use practices.
- Develop reservoir sediment models to simulate turbulence and sediment entrainment, turbidity currents, and downstream effects.
- Develop improved design methods for dam outlets and bypass tunnels or pipes. Important topics would include the entrainment of sediment into outlets, controlling abrasion, and allowing for maximum reservoir drawdown.
- Develop improved methods for the treatment of contaminated sediment both in situ and at off-site locations.
- Develop improved understanding of how various species of fish or other aquatic organisms respond to periods of high sediment concentration.
- Develop economic analysis methods that account for intergenerational equity and the future value of water storage.
- Explore financial opportunities to pay for reservoir sediment monitoring and management.

NATIONAL RESERVOIR SEDIMENTATION TEAM

Based on the recommendations from the Reservoir Sustainability Workshop, the Subcommittee on Sedimentation has formed the National Reservoir Sedimentation Team (NRST), which is comprised of representatives from the Bureau of Reclamation, U.S. Army Corps of Engineers, other SOS-member organizations, universities, and consultants (Table 1 and Figure 16).

The Objectives and Mission of the NRST are listed below:

- Provide training on reservoir sedimentation and sustainability.
- Provide publically available web-based resources.
- Develop interagency protocols for web-based storage and retrieval of reservoir survey datasets.
- Encourage storage of sediment survey data in the national reservoir database RESSED.
- Formulate a white paper on reservoir sedimentation and sustainability.

Table 1 Founding members of the National Reservoir Sedimentation Team.

Name		Title	Organization
Mustafa	Altinakar	Director and Research Professor, National Center for Computational Hydroscience and Engineering	University of Mississippi
Paul	Boyd	Hydraulic Engineer, River and Reservoir Engineering Section	U.S. Army Corps of Engineers
Kent	Collins	Civil Engineer (Hydraulics), Sedimentation and River Hydraulics Group	Bureau of Reclamation
Deborah	Cooper	Research Hydraulic Engineer, River Engineering Branch	U.S. Army Corps of Engineers
Darrell	Eidson	Hydraulic Engineer, Hydrology and Hydraulics Branch	U.S. Army Corps of Engineers
Ron	Ferrari	Civil Engineer (Hydraulics), Sedimentation and River Hydraulics Group	Bureau of Reclamation
Rollin	Hotchkiss	Professor and Chair, Department of Civil and Environmental Engineering	Brigham Young University
Meg	Jonas	USACE	U.S. Army Corps of Engineers
Kyle	Juracek	Research Hydrologist, Kansas Water Science Center	U.S. Geological Survey
Sean	Kimbrel	Civil Engineer (Hydraulics), Sedimentation and River Hydraulics Group	Bureau of Reclamation
Matt	Kondolf	Dept Landscape Architecture and Environmental Planning	University of California, Berkeley
Greg	Morris	President	Gregory Morris Consultants
Peter	Nelson	Colorado Water Resources Research Institute (CWRRI)	Colorado State University
Tim	Randle	Reclamation Manager, Sedimentation and River Hydraulics Group	Bureau of Reclamation
Rene	Vermeeren	Chief, Hydrology and Hydraulics Branch	U.S. Army Corps of Engineers
Frank	Weirich	Iowa Institute of Hydraulic Research, Hydroscience and Engineering	University of Iowa

The NRST is currently focused on the first objective, which is training of reservoir sedimentation and sustainability provided through short courses or workshops, such as the Federal Interagency Sedimentation Conference and other times when possible. These short courses and workshops would be open to the public.

The next objective of the NRST is the development of web-based resources to be posted on the SOS website. These web-based resources would include the following types of information:

- Answers to frequently asked questions

- Protocols for answering new questions posed by the public
- Photo gallery
- Bibliography and publications

Figure 16 Photograph of National Reservoir Sedimentation Team members. Standing left to right are Rollin Hotchkiss, Deborah Cooper, Frank Weirich, Peter Nelson, Sean Kimbrel, Ron Ferrari, Meg Jonas, Tim Randle, Darrell Eidson, Paul Boyd, Kyle Juracek, Mustafa Altinakar, and Rene Vermeeren. Seated left to right are Greg Morris and Matt Kondolf.

The third objective of the NRST is to develop interagency requirements for web-based storage and retrieval of reservoir survey datasets. NRST members will brainstorm ideas to encourage the storage of sediment survey data in the national reservoir database RESSED.

As part of the fourth objective, the SOS website (http://ida.water.usgs.gov/ressed/) and RESSED database are excellent tools for acquiring, summarizing, and sharing information on reservoir sedimentation. Agencies and other organizations are also encouraged to make reservoir sedimentation data available to the public through RESSED. The NRST will be tasked with developing protocols for web-based storage and retrieval of reservoir survey datasets that would be hosted on individual agency web sites.

The last objective is to develop a white paper on reservoir sedimentation and sustainability to inform policy makers about the life-cycle approach to managing sediment in reservoirs.

SUMMARY AND CONCLUSION

The convening of the Reservoir Sustainability Workshop and the formation of the National Reservoir Sedimentation Team are key steps forward in the development of information and awareness about reservoir sedimentation and sustainability. The technical information and policy implications will be important for mangers of dams and reservoirs throughout the nation as they may seek to implement sustainable sediment management practices for the benefit of future generations.

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