

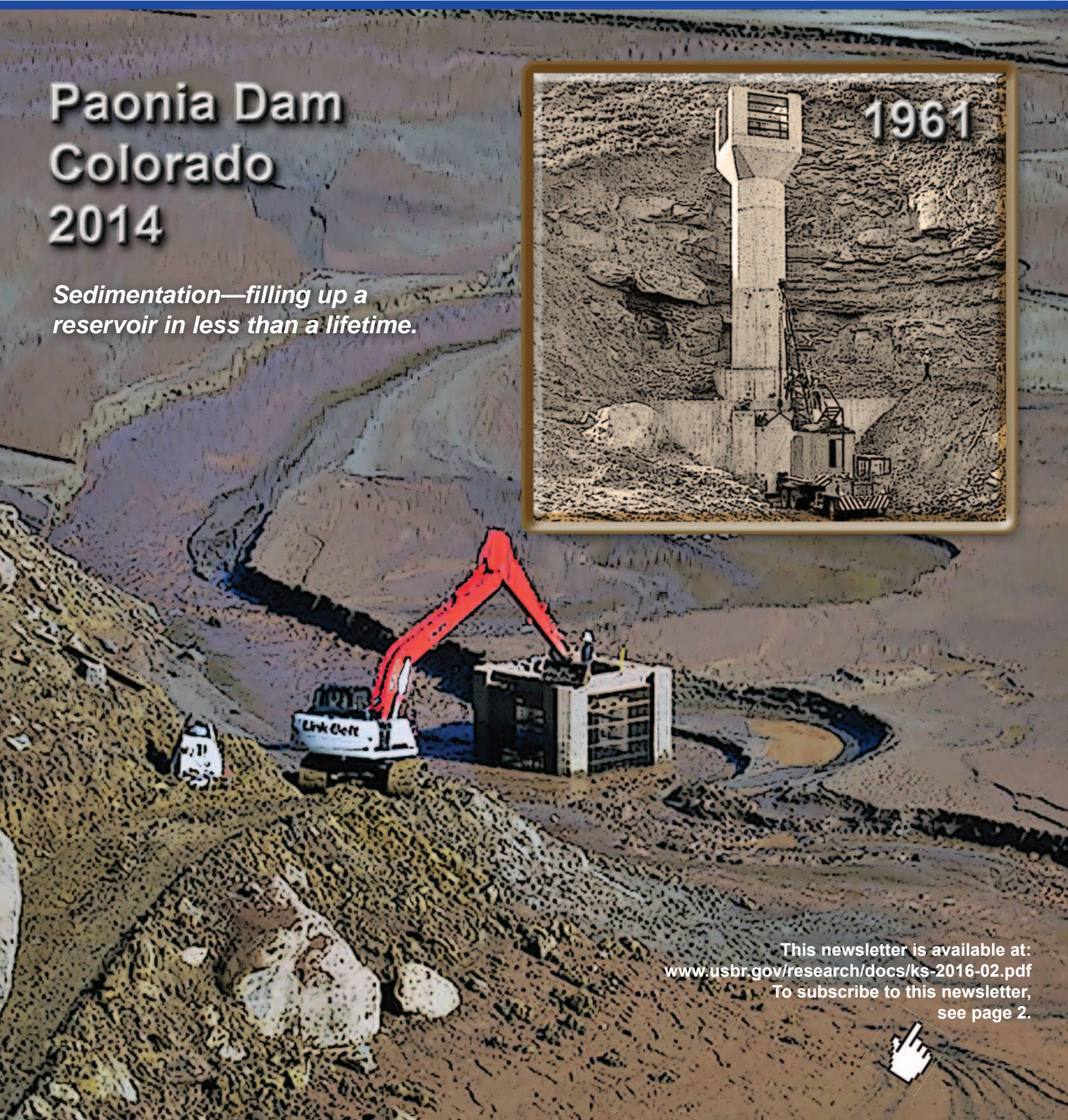
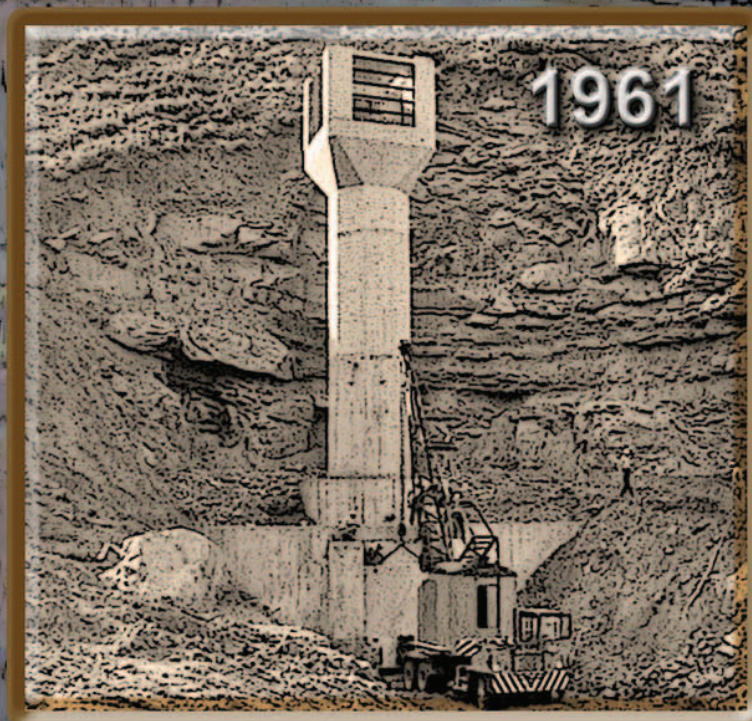
The Knowledge Stream

Spring 2016
Research and
Development Office
Newsletter 2016-02

Reservoir Sedimentation and Sustainability Issue

Paonia Dam Colorado 2014

*Sedimentation—filling up a
reservoir in less than a lifetime.*



This newsletter is available at:
www.usbr.gov/research/docs/ks-2016-02.pdf
To subscribe to this newsletter,
see page 2.



Chief's Message

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Hello and welcome to the Spring 2016 edition of *The Knowledge Stream*! In this issue, we focus on reservoir sedimentation and sustainability.

As we move into the future, the growing number of water users in the West will continue to use aging reservoirs to manage surface water supplies. All rivers transport sediments ranging from fine clays and silts to coarse gravels and cobbles. All reservoirs trap much of this sediment load and, in some cases, all of it.

When our existing reservoirs were originally designed, the accumulation of sediment in reservoirs was anticipated, and reservoirs were often estimated to have a “sediment-design life” (e.g., 100 years or less). As reservoirs accumulate sediment and approach their sediment-design life, there is less space available to store water for a variety of beneficial uses, including water supply conservation, hydropower, environmental stewardship, and recreation. In addition, there is less space available to support flood risk reduction. Outlet works and hydropower intakes also become impacted, affecting infrastructure operation and maintenance. This prompts interest in strategies to better manage accumulating sediments in reservoirs.

Solutions to manage reservoir sedimentation other than simply storing sediment in reservoirs have been proposed and applied internationally. Reclamation is evaluating opportunities to potentially use some of these solutions, or develop new ones. In this issue, you will learn more about reservoir sedimentation challenges. You will also learn about collaborative research and development to address these challenges, extend the life of Reclamation reservoirs, and help Reclamation continue to meet its mission of reliably delivering water and generating hydropower in the Western United States.

*Levi Brekke
Chief of R&D*

**Sean Kimbrel and Tim Randle
in Reclamation's Technical Service Center
served as principal editors for this issue.**

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**Research and
Development Office
Science and Technology
Program Manager**



John Whitley joined the Research and Development Office in September 2015 as the Science and Technology Program Manager. Prior to joining Reclamation, John spent 2 years as a research manager at the Water Research Foundation in Denver, Colorado, supporting domestic and international water utilities with research for water supply diversification and other sustainable water management projects.

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Featured Faces

*R&D Office Science and Technology
Program Manager, John Whittler
—continued*

Before moving to Denver, John spent almost 10 years in Washington, D.C., as an environmental protection specialist for the U.S. Environmental Protection Agency (EPA). During his time at EPA, John supported drinking water and wastewater utilities with emergency preparedness and response, climate change, and other water management issues.

John has a Bachelors of Science in Public Affairs/Policy Studies from Indiana University and a Masters of Science in Environmental Science and Policy from Johns Hopkins University.



Tim Randle, Manager, Sedimentation and River Hydraulics Group.

Sedimentation and River Hydraulics Group 70th Anniversary

The Sedimentation and River Hydraulics Group in Reclamation's Technical Service Center was formed in 1946 to predict reservoir sedimentation, channel degradation below dams, local scour at canal and pipeline crossings of streams, and to develop ways to manage sediment in canals.

Past group managers include Whit Borland (1946–1972), Ernie Pemberton (1972–1982), Bob Strand (1982–1994), and Ted Yang (1994–2004).

For the past few decades, the group has actively worked in many areas of river restoration to keep Reclamation projects functioning.

Tim Randle, Hydraulic Engineer

Tim Randle, Ph.D., P.E., D.WRE, manages the Sedimentation and River Hydraulics Group in Reclamation's Technical Service Center in Denver, Colorado. He received his Bachelors of Science in Civil Engineering from the University of Utah. He also obtained a Masters of Science and a Doctorate in Civil Engineering from the University of Colorado. Tim is a registered Professional Engineer and a Diplomat for the National Academy of Water Resource Engineers (D.WRE). He has served Reclamation for 36 years, nearly all of it with the Sedimentation and River Hydraulics Group. In 1997, Tim was honored as Reclamation's "Engineer of the Year" and named one of the "Top 10 Federal Engineers" by the National Society of Professional Engineers.

Sediment accumulation in water storage reservoirs (clay, silt, sand, and gravel) is an ongoing threat to project operations and benefits. Proper management of sediment, however, can extend the useful life of these reservoirs over the long term. Tim's work on reservoir sedimentation began by participating in, and eventually taking leadership over, surveys of Black Canyon Reservoir, Idaho (1982); Lake Powell, Utah (1986); Paonia Reservoir, Colorado (1987); and Elephant Butte Reservoir, New Mexico (1987). Managing 27 million cubic yards of sediment for the Elwha River Restoration Project gave great insights to reservoir sustainability. Tim has had opportunities to evaluate reservoir sedimentation problems and solutions in Jordan, Japan, Taiwan, and Vietnam.

In addition to the above activities, Tim is leading efforts through the interagency Subcommittee on Sedimentation to increase awareness of reservoir sedimentation problems and find potential sediment management solutions to achieve reservoir sustainability. Subcommittee activities have included convening a reservoir sedimentation workshop in 2012 and the Federal Interagency Sedimentation Conference in 2015 (see the "Recent and Upcoming Events" segment in this issue). The subcommittee also formed the National Reservoir Sedimentation and Sustainability Team, which is composed of specialists from Federal agencies, consultants, and universities. These activities will lead to sediment management solutions that can be implemented at Reclamation reservoirs to achieve long term sustainability.

Tim and his wife, Kathy, have been married for 32 years. They have a son, Tom; a daughter, Jennifer; and two dogs, Bridger and Gunner. Tim enjoys bicycle riding, skiing, walking, running, hiking, and weightlifting.



... Highlighting People That Contribute to Reclamation Research and Development

Sean Kimbrel, Hydraulic Engineer

Sean Kimbrel is a hydraulic engineer in the Sedimentation and River Hydraulics Group in Reclamation's Technical Service Center. Sean earned his Bachelors and Masters of Science in Civil Engineering at Colorado State University and is a registered Professional Engineer in Colorado.

Since joining Reclamation in 2009, Sean has performed and led many hydraulic and sediment transport-related investigations in multidisciplinary teams for enhancing aquatic habitat through river rehabilitation, assessing impacts to infrastructure in and near rivers, and assessing reservoir sedimentation and sustainability. Sean's professional interests in reservoir sedimentation and sustainability stem from involvement in the Subcommittee on Sedimentation's Reservoir Sustainability Workshop (2012) and in the Paonia Reservoir Sediment Management Study (2012–present). This includes other past reservoir sediment management efforts, such as sediment data collection and numerical sediment transport modeling for the Elwha River Restoration Project (2013–2015). Sean has also been involved in the Reclamation Science and Technology Program study, "Formulating Guidelines for Reservoir Sustainability" (2013–2014), as well as sediment management planning for Eastern Colorado Area Office facilities (2015) in Reclamation's Great Plains Region.

Sean's current sediment-related efforts in Reclamation focus on several areas, which include: 1) supporting sediment management efforts at Paonia Dam in Colorado; 2) investigating the state of reservoir sedimentation in Reclamation's inventory of dams/reservoirs for Reclamation's Policy and Administration Office; 3) leading Reclamation's reservoir sedimentation database development efforts; 4) serving as the principal investigator for Reclamation's Science and Technology Program pilot research studies on reservoir sedimentation and sustainability; and 5) serving as the prize competition coordinator for sedimentation prize competitions within Reclamation's Water Prize Competition Center.

In his spare time, Sean juggles various hobbies and interests with his wife and two dogs, such as white water river trips, home brewing, skiing, running, hunting, fly fishing, gardening, and reading anything involving water and society.

Blair Greimann, Hydraulic Engineer

Blair Greimann has been a hydraulic engineer in the Sedimentation and River Hydraulics Group in Reclamation's Technical Service Center since 1998. He currently serves as the group's technical specialist. His primary work is related to the analysis and design of large scale dam removal and river restoration projects.

Blair has performed a critical role in several projects, including the San Joaquin River Restoration Program, the Klamath Dam Removal Studies, and Matilija Dam Removal. He is also a co developer of the Sedimentation and River Hydraulics–One Dimension (SRH-1D) hydraulic and sediment transport model. Blair has applied SRH-1D to the projects listed above, as well as to reservoir sluicing projects. He is currently engaged in developing reservoir sedimentation training and guidelines for the government of Laos.



Sean Kimbrel.

www.usbr.gov/research/projects/researcher.cfm?id=2353



Blair Greimann.

www.usbr.gov/research/projects/researcher.cfm?id=128

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Featured Faces

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Blair received his Bachelors and Masters of Science in Civil Engineering from the University of Colorado at Boulder and his Ph.D. in Civil Engineering from the University of Iowa. His Ph.D. research focused on the description of sediment transport using two-phase flow equations. The journal paper resulting from Blair's Ph.D. research won the biannual best paper award from the Journal of Hydraulic Research. He was also honored as Reclamation's "Engineer of the Year" in 2007.

Blair lives in Denver, Colorado. He has three children and spends his time teaching them his leisure activities of basketball, biking, hiking, camping, piano, skiing, golfing, tennis, and not catching fish.

Kent L. Collins, Hydraulic Engineer

Kent L. Collins has been a hydraulic engineer in the Sedimentation and River Hydraulics Group in Reclamation's Technical Service Center since 1997. He primarily works on reservoir and river surveying, hydraulic and sediment numerical modeling, and various research studies related to reservoir sustainability and river restoration.

Kent is a graduate of Colorado State University in Fort Collins, Colorado, where he obtained a Bachelors of Science in Civil Engineering in 1995. Kent is a Professional Engineer in the State of Colorado, as well as a member of both the American Water Resources Institute and National Reservoir Sedimentation and Sustainability Team. In addition, Kent is a certified instructor for the U.S. Department of the Interior's Motorboat Operator Certification Course.

During his career at Reclamation, Kent has performed more than 35 reservoir surveys. In addition, he has played a vital role in numerous river restoration and reservoir sedimentation studies. Since 2012, Kent has served the lead role in developing a reservoir sustainability plan at Paonia Dam and Reservoir in Colorado. This sustainability plan includes coordination of and performing hydrographic and topographic surveying, sediment monitoring, sediment sampling, and numerical modeling tasks between multiple agencies, irrigation districts, and engineering consultants.

Currently, Kent is leading a Reclamation Science and Technology Program research project (Project ID 6080) to develop guidelines for formulating reservoir sustainability plans. As part of this research, he organized a July 2012 reservoir sustainability workshop involving national and international participants from multiple Federal, State, and county government agencies, as well as universities, irrigation districts, and private consultants. The purpose of the workshop was to develop and describe practical solutions for managing sediment for long-term sustainability. In addition to his research projects, Kent co authored a 2013 Eos (Earth & Space Science News) journal article on capacity loss due to sedimentation in United States reservoirs, a 2013 white paper summarizing the 2012 reservoir sustainability workshop, and a chapter on reservoir survey and data analysis in the Erosion and Sedimentation Manual, published by the Sedimentation and River Hydraulics Group in 2006.

Yong Lai, Hydraulic Engineer

Yong Lai is a hydraulic engineer in the Sedimentation and River Hydraulics Group in Reclamation's Technical Service Center. He currently serves as the group's technical specialist. Yong obtained his Ph.D. in Mechanical and Aerospace Engineering in

— continued



Kent L. Collins.

www.usbr.gov/research/projects/researcher.cfm?id=1278

... Highlighting People That Contribute to Reclamation Research and Development

— continued

1990 from Arizona State University. Since then, he has been involved in numerous research and engineering projects focused on areas such as aerospace, automotive, bioengineering, and hydraulic engineering.

Before joining Reclamation in 2003, Yong was a senior research staff and adjunct associate professor at IIHR–Hydrosience & Engineering, a unit of the University of Iowa’s College of Engineering, where he was in charge of various research and engineering projects. Yong has supervised more than 10 graduate students in carrying out various research projects and has taught graduate level courses as well. In addition, Yong has published more than 30 peer reviewed papers in international journals and over 50 conference papers in diverse engineering areas.

Currently, Yong serves as a project leader and numerical modeling expert for Reclamation in flow hydraulics and hydrology, sediment transport, geomorphic processes, reservoir sedimentation, watershed runoff/erosion, temperature, and water quality. He has worked on rivers throughout the United States, as well as internationally. He is also an expert in two and three-dimensional computer model research, development, and applications. Yong is the lead author of both the widely used Sedimentation and River Hydraulics – Two-Dimensional (SRH-2D) model and the Unsteady and Unstructured Reynolds Averaged Navier-Stokes (U²RANS) model. He has also provided short courses on how to use the SRH-2D model for hydraulic and sediment transport modeling at various locations.

Joel Murray, Physical Scientist

Joel Murray is a physical scientist with the Geographic Applications and Analysis Group in Reclamation’s Technical Service Center. He has over 15 years’ experience in Geographic Information Systems (GIS), spatial database design, and spatial data management.

Joel obtained a Bachelors of Science in Earth Sciences from Pennsylvania State University, a Masters of Science in Environmental Science from the University of Idaho, and a Masters of Natural Resources Stewardship in Watershed Science from Colorado State University. In addition, Joel has a postbaccalaureate certificate in GIS and is a certified GIS Professional. Before joining Reclamation, Joel worked for the U.S. Geological Survey in New Jersey and the National Oceanic and Atmospheric Administration in Washington, D.C. He also spent a summer at McMurdo Station in Antarctica, which included a weeklong trip to the South Pole. In 2014, Joel was hired as a physical scientist for Reclamation, where his work has focused mainly on Geographic Information Science.

Two of Joel’s reservoir sedimentation and sustainability studies have been funded by Reclamation’s Science and Technology Program. The first study, “Use of a Continuous Simulation, Process Based Model to Predict Sediment Inflow in Unsurveyed Reservoirs,” investigated using SWAT2005 to model sediment inflow to three small reservoirs with uncomplicated upstream hydrography. The second study, “River Sedimentation Information Database Stewardship,” is currently underway and aims to improve the management of Reclamation river sedimentation information with integration into a river sedimentation database jointly developed with the U.S. Army Corps of Engineers.

Joel lives in Denver, Colorado, with his wife, Maegen and daughter, Eloise. In his spare time, Joel enjoys camping, hiking, skiing, and spending time with his family.



Yong Lai.

www.usbr.gov/research/projects/researcher.cfm?id=118



Joel Murray at the South Pole, Antarctica, during his site visit to test the drinking water quality of the new Elevated Station.

www.usbr.gov/research/projects/researcher.cfm?id=2672



Background: Understanding the Impacts of Reservoir Sedimentation

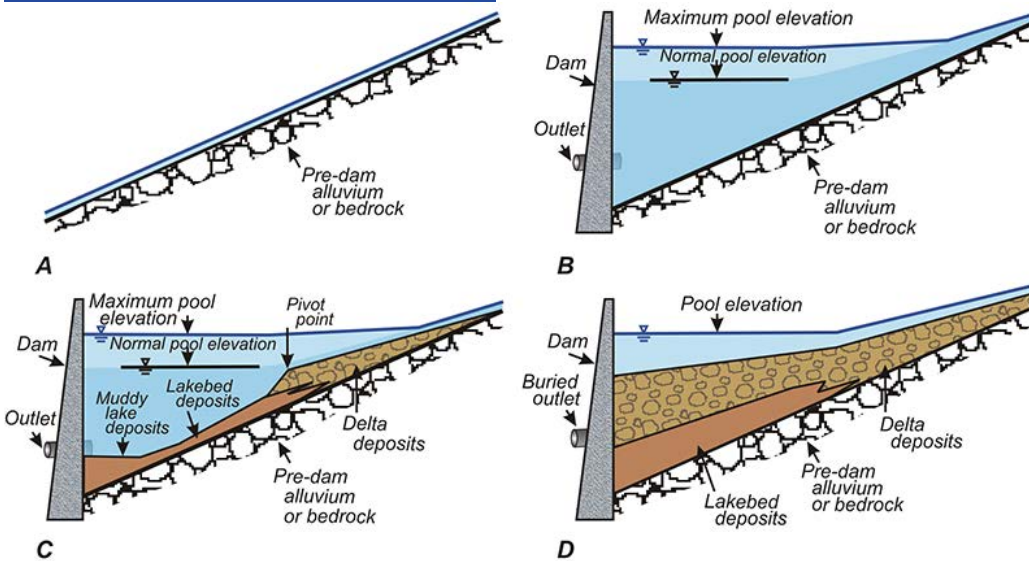
In arid portions of the Western United States, dams are critical to storing water in reservoirs to provide reliable water supply and benefits. Dams produce multiple benefits including irrigation water, hydropower generation, municipal and industrial water, recreation, and flood control. Ensuring dams continue to function and produce benefits well into the future requires new ways to address reservoir sedimentation.

Reservoir Sedimentation 101: The Process

Rivers naturally transport sediment at various rates, depending on hydrologic, geologic, biologic, and human-influenced factors. Thus, when a dam is constructed and the reservoir is filled with water, sediment that would normally have continued downstream accumulates over time in the tranquil waters of the reservoir. This process of sediment accumulation is known as reservoir sedimentation.

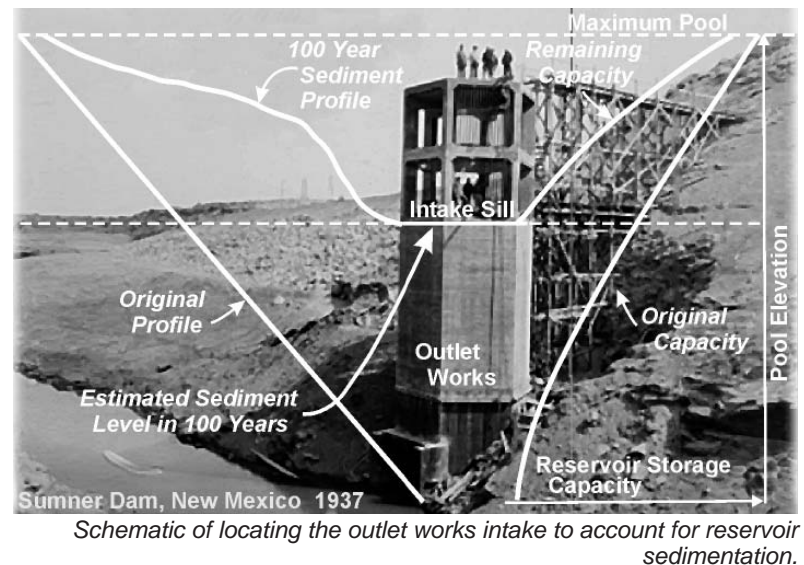
Reservoir sedimentation in large federally-owned reservoirs in the United States can be viewed in general as a long-term and large-scale process. This process was taken into consideration by the original dam designers; however, the original designers planned for the accumulation of sediment in a reservoir for a limited amount of time (sediment-design life) with no plan of management after this time period (typically 100 years and sometimes 50 years).

Under this approach, the reservoir sedimentation volume (over the sediment-design life) was estimated by considering the quantity and distribution of incoming sediment in the reservoir as well as the reservoir size, shape, and future reservoir operations. Based on the estimated sediment inflow and distribution in the reservoir, the elevation of appurtenant features at the dam (e.g., outlet works and intakes) were designed to be above the projected sediment level at the dam throughout the sediment-design life. The pool below the lowest intake elevation is known as the “dead pool,” though reservoir sedimentation occurs at all levels in the reservoir.



Process of reservoir sedimentation:
A) original riverbed, B) new dam construction, C) sedimentation that is near the “sediment-design life,” and D) dam outlet works burial.

For the past century, the sediment-design life approach has worked as planned, but a significant number of dams are close to, or have reached, the age of their sediment-design life. As of 2014, half of Reclamation’s reservoirs were over 60 years old, nearly 20 percent were at least 80 years old, and 7 percent were already older than 100 years. By the year 2024, 31 (13 percent) of Reclamation reservoirs will be at least 100 years old and that number will increase to 46 (19 percent) by the year 2034. New sedimentation management methods are needed to extend the life of these dams to the end of this century and beyond.



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Reservoir Sedimentation 101: The Impacts

Fast forward to current times, in many cases, the actual rate of reservoir sedimentation has been different than the original estimate because of limitations in available data and analysis methods, improvements in sediment measurement technologies, new upstream dams, and changes in upstream land use practices, such as urbanization or improved agricultural and forestry practices. These factors make assessing the timing of future sedimentation impacts based on the age of the dam problematic.

Measuring the reservoir sedimentation volume provides much better information to help assess past and future sedimentation impacts. Because sediment accumulation is hard to visually observe below the depths of a reservoir, the best way to track the amount and distribution of sediment in reservoirs is through a bathymetric (below water) survey of the reservoir bottom, typically by a boat mounted with a Global Positioning System (GPS) and depth sounding equipment. Even with this available technology, as of 2015, only 35 percent (i.e., 83 of 238) of Reclamation's large storage reservoirs are known to have had at least one such sediment survey since first filling of the reservoir. More than half of these reservoir sediment surveys are more than 20 years old. Of the surveyed reservoirs, 5.1 million acre-feet of storage were lost to reservoir sedimentation.

When projecting sediment accumulation rates for surveyed reservoirs up to year 2015, the estimated storage loss is 7.3 million acre-feet of storage, which is 5 percent of Reclamation's cumulative storage capacity. When using the average sediment accumulation rate for surveyed Reclamation reservoirs and expanding to all Reclamation reservoirs, the estimated storage loss is approximately 20 million acre-feet (14 percent), which is the equivalent of 200 reservoirs with a median storage capacity of 100,000 acre-feet, or the average volume of water 44.6 million households would consume in one year. Additional survey information would greatly improve assessments of past and future impacts across Reclamation's inventory of dams and reservoirs.

Locations of Reclamation Dams and Reservoirs in the Western United States

Because so many reservoirs have not been surveyed since first filling, prioritizing which reservoirs need surveyed sooner, and finding ways to cut survey costs through improved technologies, is key to moving forward into the future.

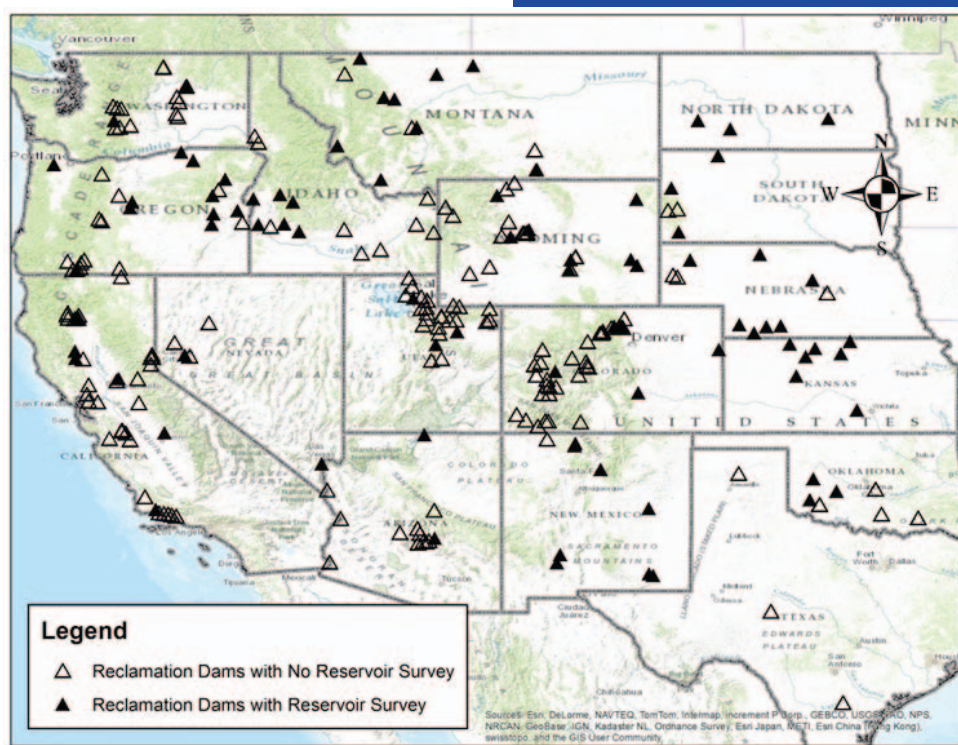
Sedimentation surveys are needed to assess impacts. Reservoir survey costs have substantially decreased over the past few decades, while the quantity of data has dramatically increased.

For Reclamation-wide users, an inventory of Reclamation reservoirs, their last survey date, and storage volume lost to sedimentation can be found at:

<http://intra.usbr.gov/tsc/techreferences/reservoir.html>

This inventory will also be available in the near future on Reclamation's Technical Service Center Internet site at:

www.usbr.gov/tsc/



Map of surveyed Reclamation reservoirs.

Background: Understanding the Impacts of Reservoir Sedimentation

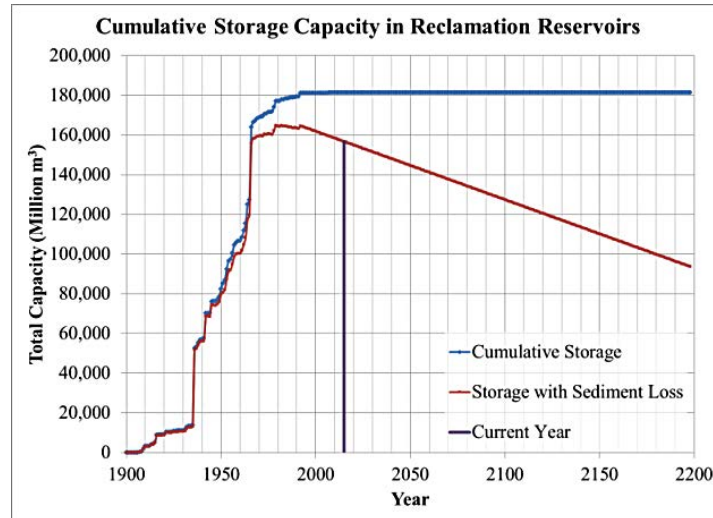
Partnership and Outreach

Reclamation is working with partners nationally and internationally to help ensure sustainable reservoirs:

- The national outreach efforts by the Subcommittee on Sedimentation's National Reservoir Sedimentation and Sustainability Team (see article on page 26).
- International outreach efforts to provide technical assistance as new dams are being constructed in the Mekong River Basin (see article on page 28).

Reservoir Sedimentation 101: Why Addressing Reservoir Sedimentation is Relevant to Water Management

As reservoirs fill with sediment, less room is available for water storage. Future sediment inflows will continue to decrease reservoir storage capacity, thereby further decreasing the operational capabilities and Reclamation's ability to provide water and hydropower.



Reclamation cumulative storage capacity shows a decline in storage loss from reservoir sedimentation during the last few decades and projects a continued decline over the next 200 years.

Moreover, the impact of increased hydrologic variability with climate change could increase the quantity of inflowing sediment and timing of flows from upstream watersheds, and increase reservoir pool fluctuation, thus changing the temporal and spatial distribution of reservoir sediments.

General reservoir sedimentation impacts include:

- Storage loss, resulting in reduced water supply reliability
- Burial of recreational facilities such as marinas and boat ramps
- The cutoff of sediment supply to downstream sediment-dependent aquatic species
- Upstream channel aggradation (increasing channel bed elevations with sediment deposition), which increases upstream flood stage
- Downstream channel degradation (channel bed lowering with sediment erosion) and reduced habitat availability
- Abrasion, plugging, and burial of infrastructure, such as outlet works and hydropower intakes (see article on page 16)

Of most concern is the potentially devastating impacts of reservoir sediments and submerged debris reaching the level of outlet works and hydropower intakes that are not designed to pass the arriving sediment and submerged debris. The eventual plugging and abrading of these features by sediment and debris will result in a partial-to-complete disruption of delivering water and hydropower well before a reservoir becomes full of sediment (see article on page 14 for an example of sedimentation posing operational concerns at Paonia Dam and Reservoir, Colorado).

If reservoir sedimentation is not managed, eventually all storage space in a reservoir will be completely full of sediment, which can become a dam safety issue.



Outlet works impacted by sediment at Belle Fourche Reservoir, South Dakota.



Reservoir Sedimentation 101: Assessing the Future Impacts of Reservoir Sedimentation

Multiple research efforts are underway to improve how reservoir sedimentation information is stored and disseminated for future assessments at Reclamation facilities:

- Collaborative database development efforts with other Federal agencies, such as the U.S. Army Corps of Engineers (supported by Reclamation’s Science and Technology Program; see article on page 18).
- Time-based prediction methods of when sediment will arrive at appurtenant features are being investigated (supported by Reclamation’s Science and Technology Program; see article on page 16).
- Standardizing and improving the measurement of sediment transported by rivers with many agencies (supported by Reclamation’s Science and Technology Program; see article on page 30 and Research Update on page 34).
- Recent research efforts on computational methods to estimate the amount of incoming sediment from watersheds into reservoirs has been performed (supported by Reclamation’s Science and Technology Program; see Research Update on page 32).
- Developing numerical three-dimensional models to simulate sediment transport and deposition in reservoirs and potential downstream releases.

Pursuing Potential Solutions and Research Opportunities

Throughout the world, much has been learned about dealing with reservoir sedimentation, particularly in countries such as South Africa, China, Japan, and Taiwan where sediment management solutions are implemented. A good example is Three Gorges Dam in China, where low-level sluice gates in the dam were designed and constructed to pass sediment.

In the United States, because a growing number of reservoirs are nearing the end of their sediment-design life, new problems and opportunities are emerging in how to deal with reservoir sedimentation in a sustainable manner.

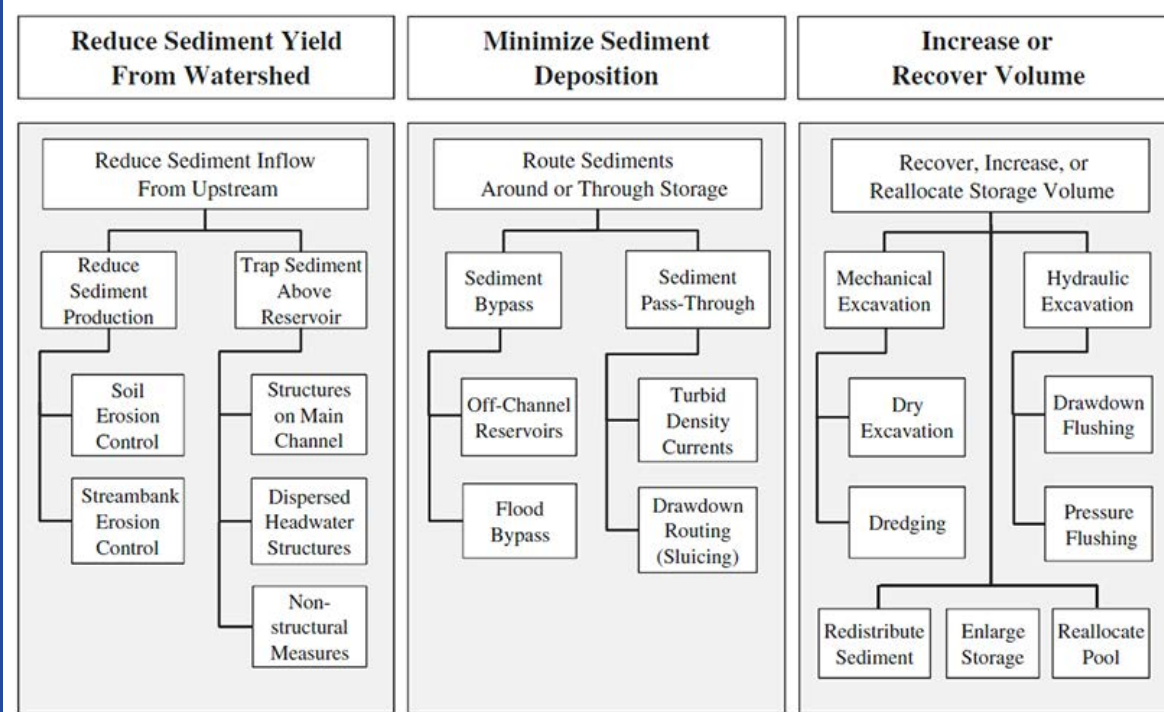
Reservoir sedimentation management solutions can be divided into three general categories:

1. Reduce the amount of sediment entering reservoir (e.g., check dams and watershed management).
2. Pass sediment downstream of reservoir before sediment particles settle in the reservoir (e.g., sluicing, turbidity current venting, and sediment bypassing)
3. Maintain, increase, or recover reservoir storage through sediment removal (e.g., flushing, dredging, and excavation).

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Background: Understanding the Impacts of Reservoir Sedimentation



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Several research efforts are currently underway by Reclamation staff to further evaluate these various solutions in Reclamation’s Science and Technology Program, and abroad:

- Reducing the upstream inflow of sediment where managing inflowing alluvial material from washes is evaluated on the Lower Colorado River (see Research Update, *Predicting, Managing, and Controlling the Movement of*

Diagram of sediment management solutions for reservoir sustainability (Kondolf et al., 2014).



Sediment bypass tunnel at Miwa Dam, Japan. Photograph by Tim Randle.



Dredging at Strontia Springs Reservoir, Colorado. Photograph by Tim Randle.

River Rocks and Sand, which can be found at: www.usbr.gov/research/docs/updates/2015-04-movement.pdf.

- Pilot studies on reservoir sustainability options, which aim to sustainably maintain storage capacity, are underway in two different Reclamation regions. These efforts began in fiscal year 2016 and are multiyear investigations (see article on page 20).
- Applying the new capability of modeling the downstream passage of turbid density currents to maintain reservoir storage (see article on page 24).
- Investigating ways to manage incoming saturated wood debris at intakes.
- Researching the economics and benefits/costs of reservoir sedimentation management and deciding which options are the most economically viable. The economics of reservoir sedimentation and relevant research efforts are addressed in this issue (see article on page 22).
- Water prize competitions in reservoir sedimentation (see the “Technology Prize Competitions” segment in this issue).
- Innovation and cost reduction in measuring sediment accumulation, for example with automated methods (e.g., unmanned aerial systems), is necessary to increase the capability of measuring unsurveyed reservoirs with limited resources.

Reservoir Sedimentation 101: Key Messages

1. Over time, sediment accumulates in reservoirs located on rivers and streams. This is known as reservoir sedimentation and is a long-term and large-scale process.
2. Reclamation dams and reservoirs were originally designed to allow for the accumulation of sediment over the sediment-design life, which was typically 100 years.
3. The majority of Reclamation dams are over 60 years old and will continue to be relied upon for water supply and hydropower well into the future.
4. If not managed, sediment and woody debris accumulation will continue to decrease storage capacity, decrease water supply reliability, and eventually plug all dam outlets not designed to pass sediment and debris.
5. Reservoir sedimentation occurs both above and below the reservoir water level and, normally, measured with survey equipment and depth sounders.
6. The rate and distribution of reservoir sedimentation is known in only 35 percent of all Reclamation reservoirs, which makes assessing the magnitude and timing of future impacts to operations across Reclamation's inventory of dams less certain.
7. Increased hydrologic variability, caused by a changing climate, will affect reservoir sedimentation rates and continue to reduce the reliability of the reservoir water supply.
8. Sediment management solutions are available to maintain storage capacity and extend the life of reservoirs, which can have downstream benefits, but come with an economic cost. These solutions will cost more than present operation and maintenance practices, but in many cases the costs will be less than the cost of lost reservoir benefits, dam decommissioning, and mitigation of sediment impacts to the aquatic environment, infrastructure, and property.
9. Much is known about managing reservoir sediment internationally; however, research and innovation are still needed to increase effectiveness and reduce costs.

More Information

Kondolf, G. M. et al. 2014. "Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents." *Earth's Future*, 2, doi:10.1002/2013EF000184.



Case Study

Paonia Dam and Reservoir in western Colorado is an example of potential sedimentation impacts to Reclamation's dams and reservoirs.

How Sedimentation Impacts Reclamation's Operations

The potential impacts of reservoir sedimentation to the operation and maintenance of a facility can be seen at one of Reclamation's facilities, Paonia Dam and Reservoir in western Colorado within Reclamation's Upper Colorado Region. Constructed in 1962, Paonia Dam is a zoned earthfill embankment dam 199 feet tall on Muddy Creek, a tributary to the North Fork Gunnison River. Because of the high sediment loads from Muddy Creek, Paonia Dam was designed for a 50-year sediment-design life. Thus, designers set the intake tower sill elevation 70 feet above the original valley bottom, according to the estimated sediment yield and projected distribution of reservoir sediment over 50 years. Now that this dam has passed its 50-year anniversary, sediment and woody debris are jeopardizing the operation and release of late-season irrigation flows downstream.



Downstream face of Paonia Dam, Colorado.

A June 2013 bathymetric survey of the entire reservoir revealed that the average rate of reservoir sedimentation has been 101 acre-feet per year—enough to cover a football field with sediment about 10 stories high. Nearly one quarter of the reservoir's original capacity of 20,950 acre-feet has been lost to reservoir sedimentation.

In 2010, the outlet works at Paonia Dam became partially blocked with woody debris and sediment. The amount of woody debris and sediment accumulation indicated an impending issue of the upstream sediment delta arriving at the outlet works.

After the 2010 blockage, operations were changed to draw the reservoir down in the early spring and use high spring runoff flows to sluice (seasonally flush) sediment through the outlet works before closing the gates to refill the pool for the irrigation season. Meanwhile,



Sediment deposition at Paonia Reservoir's outlet works (Colorado) over 53 years.

studies to monitor and develop a long-term reservoir sustainability plan were set forth by Reclamation and the U.S. Geological Survey. Until fall 2014, this flushing strategy was able to pass a measurable amount of sediment through the long, narrow reservoir (which is about 3 miles long and 0.2 mile wide) to the downstream river channel.

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However, reservoir drawdown in late October 2014 revealed the entire reservoir's dead pool and 6 feet of the active pool had completely filled with sediment, and the outlet works intake trashracks became partially plugged with a mixture of submerged woody debris and sediment. In November 2014, Fire Mountain Canal and Reservoir Company and North Fork Water Conservancy District crews worked 10-hour shifts for 2 weeks to manually clear sediment and debris around the intake tower trashracks by hand and with a long-reach excavator. Each morning, when crews returned to the tower, they found debris and fine cohesive sediments had blocked the intake tower trashracks again to an elevation 6 feet higher than the bottom of the intake. The manual clearing process continued until sediment levels near the outlet works intake remained at or near sill level overnight and ice formed in the low-flow channel near the tower.

To address these pressing issues, Reclamation developed short-term reservoir operation strategies for water delivery during the 2015 irrigation season. In addition, Reclamation continued work on a long-term reservoir sustainability plan to more efficiently manage existing and future reservoir sediments. The 2015 reservoir operations maintained a higher reservoir pool during spring runoff to keep sediment deposition in the upstream portion of the reservoir, temporarily preventing sediment and debris from travelling through the reservoir and plugging the outlet works. A July 2015 bathymetric survey confirmed that this recommended short-term, high-pool operation was successful at preventing critical amounts of sediment and debris from being transported downstream to the outlet works. The 2015 survey and gate opening tests verified that an open operating pool had been maintained surrounding the outlet works intake tower.

Although this short-term strategy does not maintain reservoir capacity nor passes sediment downstream, it does continue to deliver water while long-term sediment management alternatives are being formulated. Current long-term plans are in progress to maintain reservoir storage capacity and sustainably manage the arrival of sediment and debris, which is especially important for future dam operations.

More Information

Developing a Sediment Management Plan for Paonia Reservoir:

<http://acwi.gov/sos/pubs/3rdJFIC/Contents/9C-Collins.pdf>



Long-reach excavator removing sediment and debris from around the intake tower at Paonia Reservoir, Colorado, in November 2014 (see the 2014 photograph on previous page of the manual clearing process by hand).



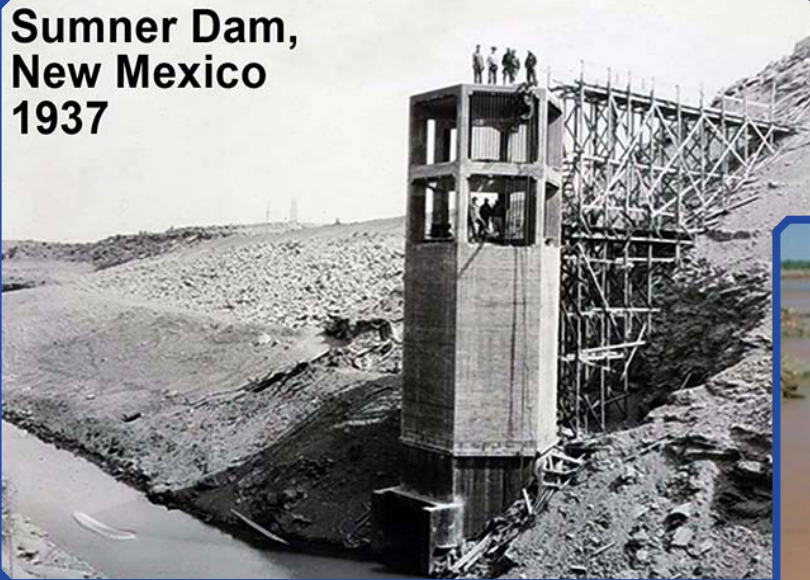
View looking upstream from Paonia Dam, Colorado, showing the reservoir sediment and partial burial of the outlet works in November 2014. Photograph courtesy of Phillip Ipson, Reclamation's Western Colorado Area Office.



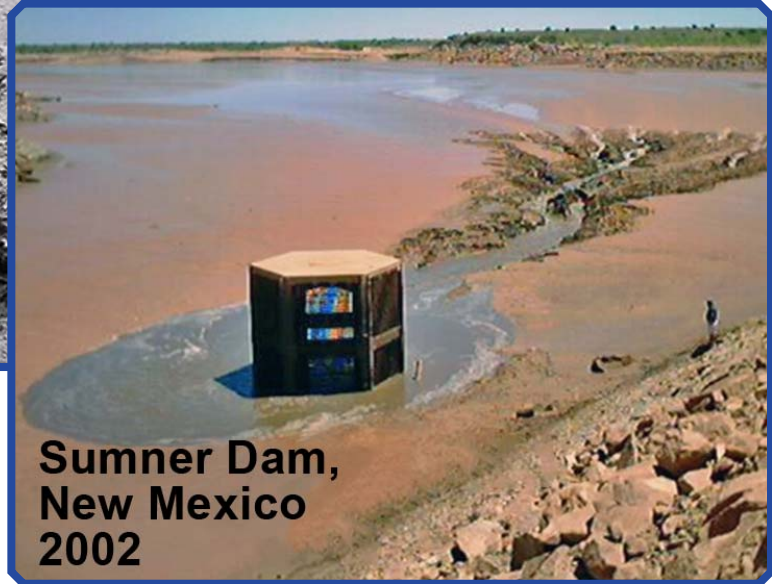
Current Science and Technology Program Research Projects

When Does Sedimentation Impact Features? How Long Until Sediment Arrives at Outlet Works?

**Sumner Dam,
New Mexico
1937**



Imagine going to turn on your faucet, or open your dam's headgate or outlet works, and no water came out because tons of sediment and woody debris have plugged the outlet. Now, how will we get water? Why was this not foreseen?



**Sumner Dam,
New Mexico
2002**

Photographs showing before and after sediment buildup around Sumner Dam, New Mexico.

To allow for reservoir sedimentation and to avoid sediment-related impacts to water intakes such as plugging, dam designers locate the intake at a higher elevation above the original riverbed. The elevation of the intake is based on an estimate of how high sediment would accumulate against the dam outlet during the sediment-design life. The portion of the reservoir below the lowest intake elevation of the outlet works is known as the “dead pool” or “inactive pool.”

Eventually, this portion of the reservoir will completely fill with sediment and debris. At this critical point in time, more sediment will begin to pass through the dam and some will continue to build up in the area surrounding the outlet works. Eventually, if the intake structure is not designed to pass sediment and debris downstream, enough buildup of sediment around the intake area can plug and bury the outlet works, resulting in no water when the tap is turned on, impacting the downstream aquatic environment.

Providing an estimate of the number of years until sediment levels reach the intake elevation and potentially plug the outlet works is critical information for vulnerability assessments and project planning. However, in many cases the actual rate of reservoir sedimentation has been different than the original estimate because of different hydrology, wildfires, upstream reservoirs, and land-use practices.

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U.S. Department of the Interior
Bureau of Reclamation

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During fiscal year 2016, this Reclamation Science and Technology research project aims to improve and update empirical reservoir sedimentation distribution methods originally used by dam designers to estimate intake elevations over the sediment-design life. Researchers will review methods and compare results from these methods with available data to refine the relationships between sediment and water inflows, reservoir pool elevation changes, and where sediment accumulates in reservoirs over time. For example, if there are frequent reservoir fluctuations (if the pool fills and empties more often), sediment tends to travel further downstream and accumulate in the lower portion of the reservoir. If the pool stays full throughout the year, sediment tends to deposit in the upstream portion of the reservoir.

Knowing the elevation of existing intakes and an improved understanding of the rate of sedimentation in a reservoir, this research project will apply a preferred sediment distribution procedure in “reverse” to calculate the number of years left in the “sediment-design life until sedimentation reaches the outlet works or hydropower intake.

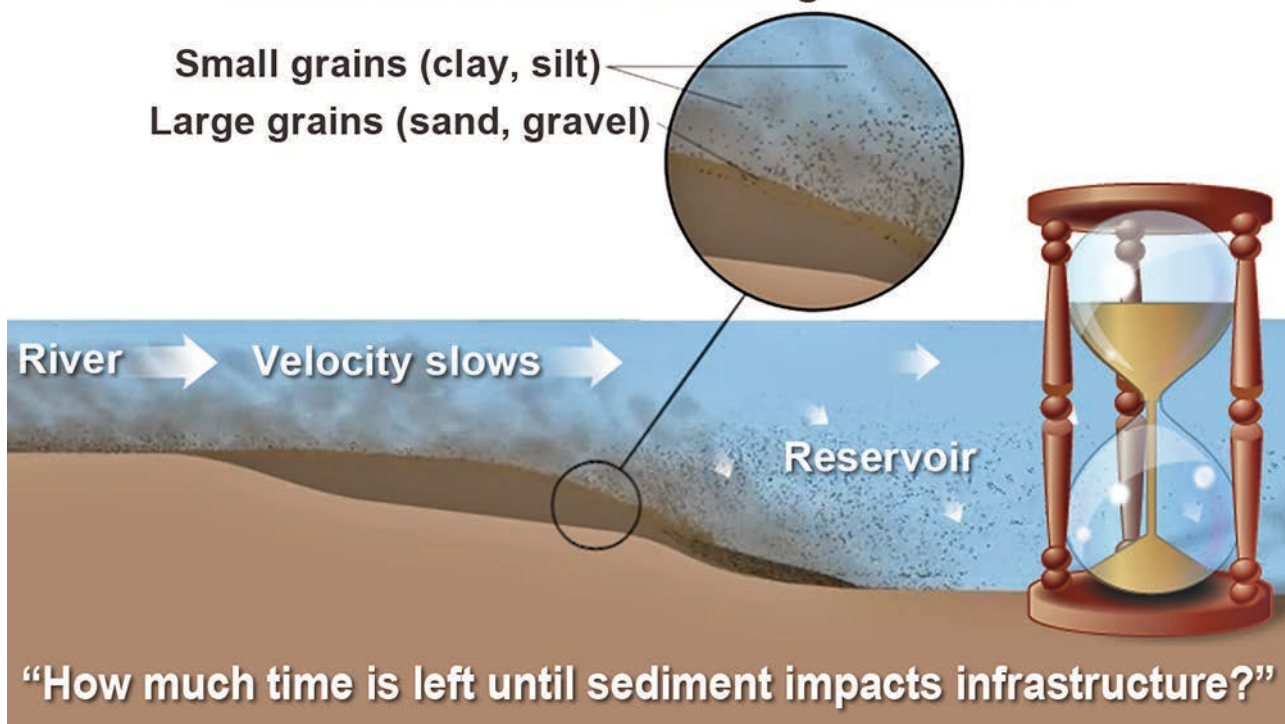
The research project is split into four phases over fiscal years 2016 and 2017:

1. Literature review
2. Select and/or develop an improved method
3. Translate the method into a computer program or model
4. Incorporate the method in a database inventory of reservoirs (e.g., Reservoir Sediment Information database) for vulnerability assessments

More Information

Refer to Reclamation’s Science and Technology Program Research Project, “Time-Based Estimation of Reservoir Sedimentation Impacts,” Project ID 9072.

Sediments in River Entering a Reservoir



Current Science and Technology Program Research Projects

This 2016 joint research project will help modernize, integrate, and improve the accessibility of Reclamation reservoir sedimentation data.

Calling All Sedimentation Data

This article also serves as a data call for any previous and unknown Reclamation reservoir survey data to add to the database. If anyone knows about Reclamation reservoir survey data at the regional, area, and project office levels, please send an email to Sean Kimbrel (contact information below) identifying the facility and year of survey.

Collaborators

- Reclamation's Policy and Administration Office
- U.S. Army Corps of Engineers

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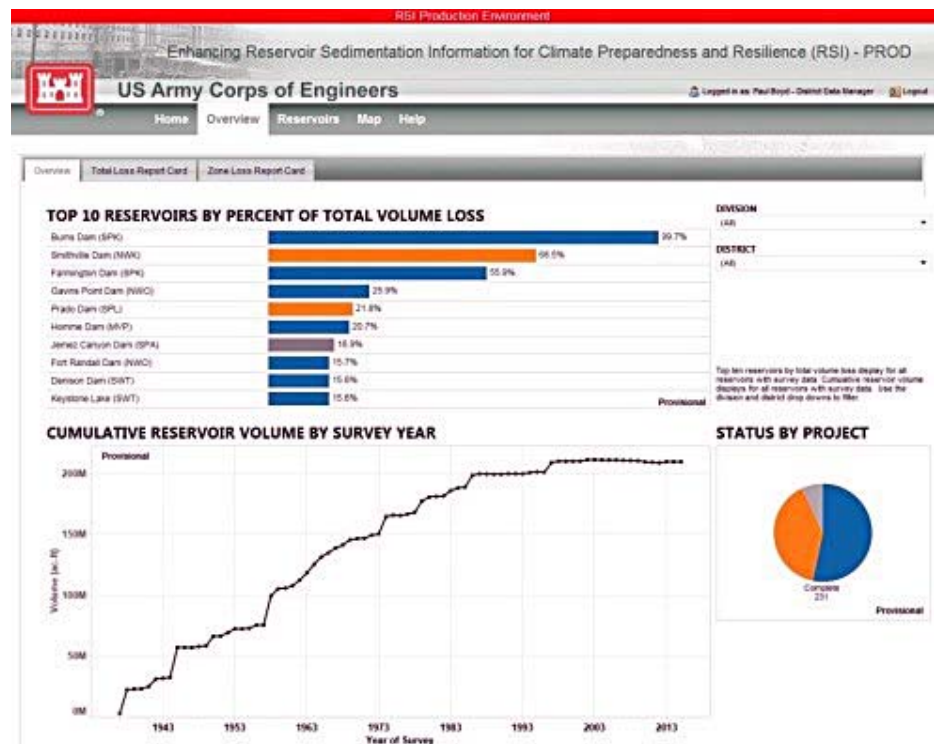
Developing and Assessing Reservoir Sedimentation Information

Reclamation is currently assessing the relative impacts of reservoir sedimentation across the inventory of Reclamation reservoirs. The most recent and comprehensive database of reservoir survey data for Reclamation reservoirs can be accessed through the publicly available U.S. Geological Survey Reservoir Sedimentation Database (RESSED). However, RESSED is limited in that it does not have the capability for dam owners and operators to add new reservoir surveys since the database was built in 2010.

In light of the growing obsolescence and need to correct data entry errors for Reclamation surveys, this 2016 Reclamation Science and Technology Program research project partnered with Reclamation's Policy and Administration Office to ask: Can Reclamation improve managing reservoir sedimentation information through data stewardship? This research project strives to find ways to develop and integrate Reclamation's reservoir sedimentation data into other reservoir sedimentation databases for multiagency and public uses.

The U.S. Army Corps of Engineers (USACE) operates and maintains an inventory of dams and reservoirs across the United States, and continues to develop its own Reservoir Sediment Information (RSI) database. The RSI database is used for multilevel assessments (project, district, and agency-wide) of past and projected storage loss, and to evaluate facility vulnerability as a result of climate change. This database is intended to serve as a more powerful, adaptable, updatable, and accessible platform to provide reservoir sedimentation information to scientists, engineers, natural resource managers, and policy makers.

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RSI database "overview" showing a reservoir storage loss summary. Image courtesy of Paul Boyd, USACE (subject to revision, property of USACE).

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Developing and integrating Reclamation reservoir sediment information into a database currently being developed by other dam owners (e.g., USACE’s RSI database) is key in planning and prioritizing for sediment management in reservoirs. Using this information for prioritizing and dealing with reservoir sedimentation could extend the life of reservoirs and facilities, thus increasing the benefits to stakeholders who depend on these dams for reliable water and power supply. Extending the life of reservoirs and facilities benefits all stakeholders that receive benefits from these facilities.

More Information

Refer to Reclamation’s Science and Technology Program Research Project, “Reservoir Sedimentation Information Database Stewardship,” Project ID 8988.

For Reclamation-wide users, an inventory of Reclamation reservoirs, their last survey date, and storage volume lost to sedimentation can be found at:

<http://intra.usbr.gov/tsc/techreferences/reservoir.html>

This inventory will also be available in the near future on Reclamation’s Technical Service Center Internet site at:

www.usbr.gov/tsc/

RSI database showing the change in reservoir elevation-capacity over time. Image courtesy of Paul Boyd, USACE (subject to revision, property of USACE).



Reclamation and USACE are expanding the usefulness and functionality of the RSI database and intend to allow public access to the completed database. They hope to encourage other agencies to partner in this effort to help build a comprehensive national reservoir sedimentation database.



Current Science and Technology Program Research Projects

Both of these pilot studies are important in developing Reclamation's capability in managing reservoir sedimentation to extend the operational life of reservoirs in the West.

More Information

Refer to Reclamation's Science and Technology Program Research Project, "Pilot Studies of Reservoir Sustainability Options—Flushing and Sluicing," Project ID 8235.

Research Project, "Developing Guidelines for Formulating Reservoir Sustainability Plans:"

www.usbr.gov/research/projects/detail.cfm?id=6080

Research Update, Dealing With the Inevitable: Sediment in Reservoirs:

www.usbr.gov/research/docs/updates/2015-03-sediment.pdf

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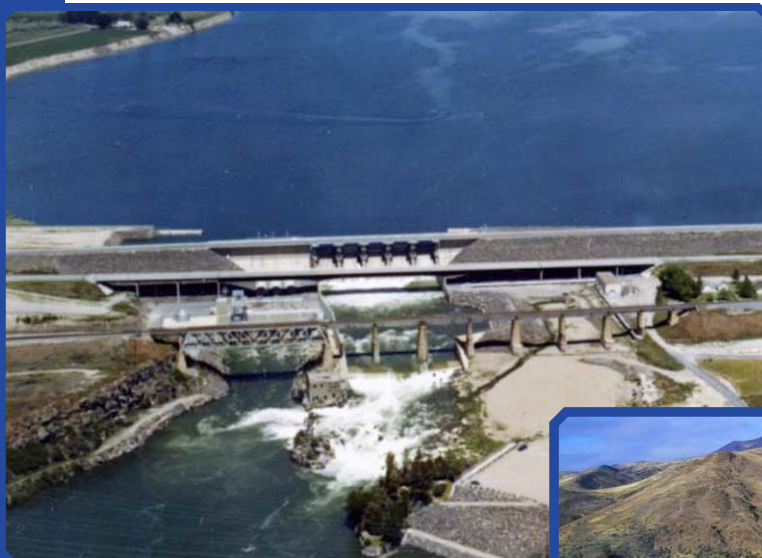
Pilot Studies of Reservoir Sustainability Options

In fiscal year 2016, two collaborative, multiyear Reclamation Science and Technology Program research projects under "Pilot Studies of Reservoir Sustainability Options" are in progress:

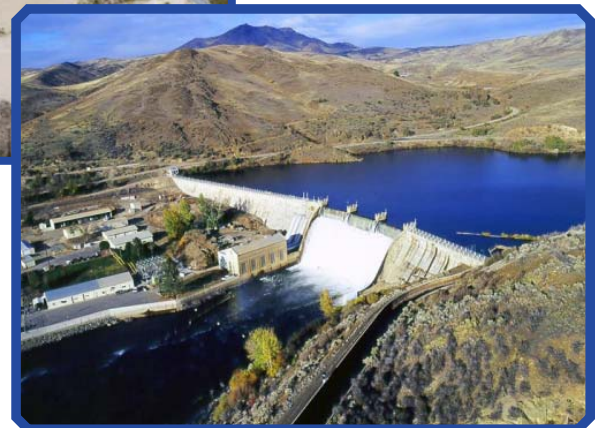
Flushing and Sluicing

This Reclamation Science and Technology Program research project partnered with Reclamation's Technical Service Center, Pacific Northwest Region, and Snake River Area Office staff to evaluate potential reservoir sediment management options in two pilot study locations—Reclamation's Black Canyon and American Falls Reservoirs in Idaho. In the past, regional and area office staff have observed the release of sediments downstream from these reservoirs after the reservoirs have been drawn down in the fall. Downstream river reaches are impacted as a result of low flows and sediment depositing downstream.

This pilot study builds on the initial fiscal year 2013/2014 Reclamation Science and Technology Program research project, "Developing Guidelines for Formulating Reservoir Sustainability Plans," to begin evaluating options to manage reservoir sediment in these reservoirs. Particularly, the ability to pass sediment downstream through the reservoir and farther downstream in river reaches during spring high flows (termed "sluicing" a reservoir). Mimicking the natural sediment cycle and passing sediment downstream during high flows benefits species downstream that depend on these flows and sediment, while maintaining storage in the reservoir and limiting the impacts to facilities such as outlet works or hydropower intakes at the dam. This pilot study will use the lessons learned from these two pilot study locations to improve the guidelines for reservoir sustainability.



American Falls Dam, Idaho.



*Black Canyon
Diversion Dam,
Idaho.*

Large Reservoirs

This Reclamation Science and Technology Program research project partnered with Reclamation’s Technical Service Center, Great Plains Region, and Montana Area Office staff to further evaluate potential sediment management options in Bighorn Lake, which is impounded by Yellowtail Dam in Montana.

This pilot study further develops and evaluates reservoir sediment management options where the reservoir must remain at “normal” operating levels. The accumulation of sediment in the upper portion of the reservoir is impacting recreational access (Horseshoe Bend Marina) of Bighorn Lake. Applicable and cost effective solutions to manage sediment while reservoirs are at normal operating levels are key to maintaining reservoir storage for reliable water supplies during droughts and for the long term. Reservoir sustainability options such as venting turbid density currents, altering the geometry of the upper portion of a reservoir to improve sediment passage downstream, dredging, and other methods that manage reservoir sedimentation are possible solutions. These solutions could help manage sediment in many reservoirs, where operations are constrained and the reservoir cannot be drawn down to pass or “sluice” sediment downstream during high inflows in the spring.

More Information

Refer to Reclamation’s Science and Technology Program Research Project, “Pilot Studies of Reservoir Sustainability Options—Large Reservoirs,” Project ID 9344.

Bighorn Lake Sediment Management Study, Final Report:

www.usbr.gov/gp/mtao/yellowtail/issues_group/2010_meetings/bighorn_sed_rep_final_mar10.pdf



Horseshoe Bend, Bighorn Lake, Montana/Wyoming.



Yellowtail Dam, Montana.



Economics—Considerations and Research

Future Research Considerations

Future research is warranted on several topics related to analyzing sediment management investments in benefit cost analysis:

- Further consideration of the costs and benefits related to sediment management techniques (e.g., dredging and/or sluicing) and dam decommissioning
- Investigating construction schedules related to sediment management strategies and how this impacts economic benefits
- Further investigation and potential case studies employing long-term discount methods (as discussed in Reclamation’s Science and Technology Program report, “Discounting for Long-Lived Water Resource Investments”) and their applicability
- Questions related to extended periods of analysis beyond 100 years should be considered

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Economic Considerations of Reservoir Sedimentation

Reclamation’s dam project designs did not include plans and costs associated with sediment management to maintain the remaining reservoir storage beyond the analysis period, as determined by the plan formulators. Reclamation dams and reservoirs were designed and costs were developed based on estimated quantity and distribution of reservoir sediment for an assumed analysis period, which coincides with the “sediment-design life.” In the past, the period of analysis used in Reclamation’s economic analyses to determine if projects are economically justified have been limited to 100 years or less, per agency guidance.

Half of Reclamation’s dams are over 60 years old and many are reaching the end of their economic life assumed in the original planning studies (Reclamation, 2015). Future planning studies related to decisions regarding aging infrastructure will need to address the engineering, economic, and financial feasibility of potential actions, which may be necessary to maintain existing project benefits. Sediment management strategies will be an important consideration in these planning studies both in terms of engineering designs and economics.

Reclamation prescribes a standardized planning process to evaluate projects based on engineering, environmental, economic, and social considerations (see U.S. Department of the Interior Agency Specific Procedures [ASPs] 707 Departmental Manual 1 Handbook and Reclamation Manual CMP 09-02 for further explanations). Analyzing the economic impacts to the Nation of a proposed action is a critical element in Reclamation’s decisionmaking process. An action is deemed to be economically justified if the economic benefits of an action exceed the economic costs. Reclamation uses benefit cost analysis as a preferred approach to determine if an action is economically justified.

In a benefit cost analysis, the costs and benefits associated with a particular action are determined by estimating the incremental value of that action. The estimation method employed varies based on many factors, but the general framework of “with vs. without” remains the same. The “with vs. without” framework allows for the isolation of changes that are solely due to an action by analyzing future conditions in the planning area without the action in place, and then compares them with the future conditions with the proposed action in place.

In the case of reservoir sedimentation, the future conditions and management strategies under the with- and without-action alternatives are defined during the multidisciplinary plan formulation phase of project development. The with- and without-action alternatives should consider, and the benefit cost analysis should attempt to quantify:

- Impacts of sedimentation to reservoir storage and water supply (both the loss and any gain of benefits)
- Impacts to operation and maintenance costs due to sediment accumulation (actual and avoided costs)
- Environmental costs and benefits

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- Project decommissioning costs incurred if the project cannot be sustained (actual and avoided costs).

For example, under no-action conditions, as reservoirs reach their sediment-design life, reservoir storage and water supply will decline resulting in lost project benefits (irrigation, recreation, power, fish and wildlife, and flood control). As sediment reaches outlet works and/or intake structures, under without-action conditions, increasing operation and maintenance costs may be necessary to maintain annual benefits. Eventually, the quantity of sediment may reach levels that require dam decommissioning and sediment mitigation costs.

An action or “with sediment management” alternative example may include the costs necessary to manage sediment (e.g., dredging, low-level sluice gates, etc.). In the short term, under the with-action alternative example, potential lost benefits related to water supply or reservoir storage during the dredging or construction period should be quantified. It may be necessary to include dam decommissioning costs, but these may be delayed or unnecessary under this alternative if the project life can be extended to a much longer time period, or if the project becomes sustainable. Finally, the with-action alternative may maintain annual project benefits associated with irrigation, recreation, power, fish and wildlife, and flood control, which should be quantified for the benefit cost analysis.

The plan formulation phase must also estimate the timing of an action’s costs and benefits (e.g., construction schedule and sedimentation rate). The timing of costs and benefits is a crucial part of a benefit cost analysis as, based on economic theory, future and past economic impacts are to be placed in present value terms for comparability. The approach for present valuing future costs and benefits is termed “discounting” and is accomplished by mathematically applying a “discount rate” to future values. For example, a future benefit of \$100, at a time of 100 years from now, would only be worth \$5.20 today, assuming a constant discount rate of 3 percent. Congressional legislation dictates that all Reclamation planning studies must be brought to present value terms using the “Plan Formulation and Evaluation Rate” (Planning Rate) as annually established by the U.S. Department of the Treasury (Federal Register, December 2015).

Although Reclamation planning studies must currently be evaluated at the Planning Rate, ASPs do provide the flexibility to include sensitivity analyses in planning studies, which use alternative discount rates and present valuation techniques. Depending on the timing of costs and benefits, the effects of an alternative discount rate or technique can have a significant impact on the results in a benefit cost analysis, especially in long-lived investments such as sediment management projects. Reclamation’s Science and Technology Program funded a report, “*Discounting for Long-Lived Water Resource Investments* (Reclamation, 2014),” which explores some potential alternative discounting methods for application in Reclamation planning studies. The report identifies some approaches that may potentially be better suited for analyzing long-lived investments than the current Planning Rate method, due to intergenerational equity concerns and uncertainty about future conditions. However, the report also finds that some of the identified approaches appear to be inconsistent with neoclassical economic theory and that there continues to be much debate amongst the economic profession as to the appropriate method for present valuing costs and benefits.

More Information

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U.S. Department of the Interior
Agency Specific Procedures,
707 Departmental Manual
1 Handbook:

www.doi.gov/sites/doi.gov/files/uploads/707%20DM%20HB.pdf

Reclamation Manual,
CMP 09-02:

www.usbr.gov/recman/cmp/cmp09-02.pdf

Federal Register:

www.federalregister.gov/articles/2015/01/29/2015-01616/discount-rates-for-cost-effectiveness-analysis-of-federal-programs

Discounting for Long-Lived
Water Resource Investments:

www.usbr.gov/research/projects/detail.cfm?id=3574

www.usbr.gov/research/projects/download_product.cfm?id=898



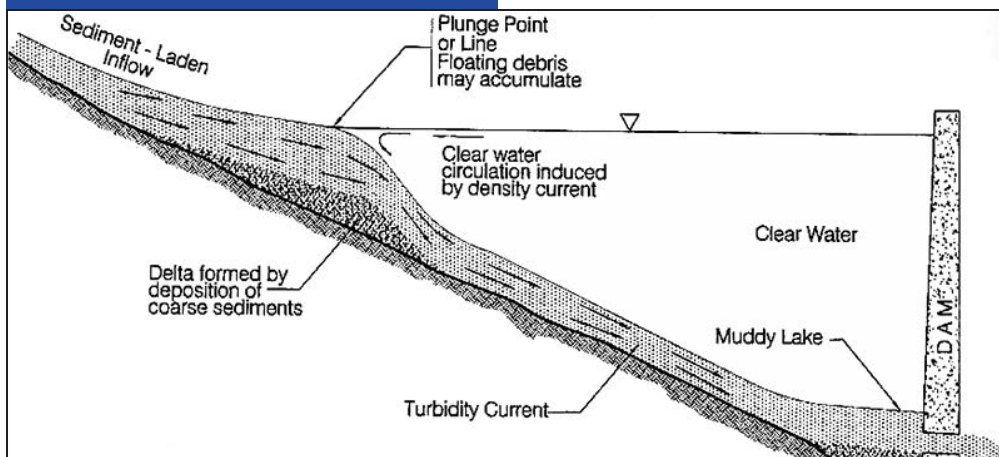
Reclamation Collaboration With Federal and International Partners

Reclamation staff are providing technical assistance on numerical sediment modeling to the Taiwan Water Resource Agency, especially as it relates to the management of reservoir sedimentation.

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Reservoir profile of a turbid density current. Source: Morris and Fan, 1998.



Using Turbid Density Currents to Pass Reservoir Sediment Downstream

When typhoons collide into the small island of Taiwan and pour up to 3 feet of rainfall in one storm, landslides can occur on highly erodible siltstone and mudstone hills—delivering large quantities of sediment into the few storage reservoirs on the island.

Three million people in Taiwan rely heavily on Shihmen Reservoir for water supply and hydropower, but it has lost over 30 percent of its 250,000 acre-feet of storage capacity since the dam started to operate in 1964. To maintain a limited water supply and extend the life of Shihmen Reservoir, agencies in Taiwan such as the Water Resources Agency are planning, designing, and implementing a combination of reservoir sediment management efforts, including dredging, flushing, and venting (bypassing) turbid density currents.

Turbid density currents (or turbidity currents) are sediment-laden flows that enter and travel along the bottom of a relatively clear reservoir pool, and have been documented in the past in Lakes Powell (Utah/Arizona) and Mead (Nevada/Arizona). In some cases, the plume of turbid sediment can reach the upstream face of the dam and solutions can be found to pass this sediment downstream before the plume settles on the bottom of the reservoir.

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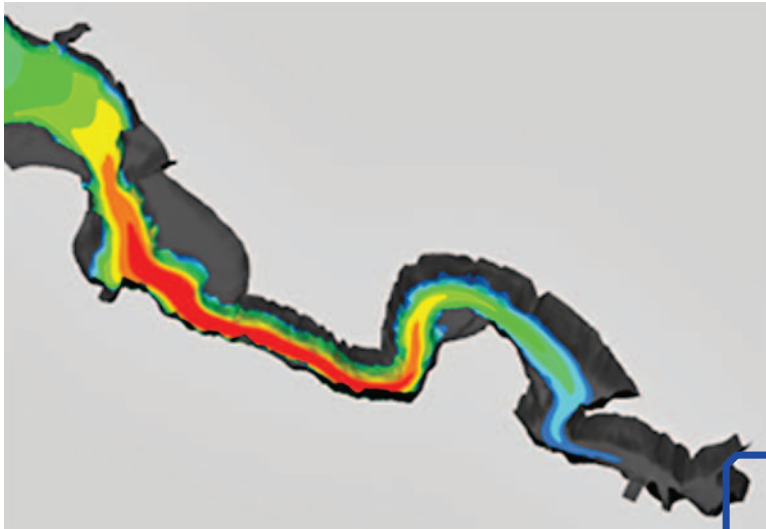


Island of Taiwan (top) and map of the Shihmen Reservoir (bottom). Shihmen Reservoir is within the ovals. Source: WRPI, 2011.

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To help Taiwan agencies plan and design venting gates and bypass tunnels in the Shihmen Reservoir to pass turbid density currents downstream and to extend reservoir life, Reclamation staff developed a two-dimensional layer-averaged numerical turbidity current model. This model can simulate a turbid density current plume in the bottom of Shihmen Reservoir and predict venting and bypassing effectiveness. With physical modeling data from the Water Resources Planning Institute (WRPI), the Sedimentation and River Hydraulics Group in Reclamation's Technical Service Center verified and calibrated turbidity current model, SRH-TC. The work was documented in the report, *A Two-Dimensional Layer-Averaged Turbidity Current Model* (Lai, 2013), and has recently been published in a renowned scientific journal (Lai et al., 2015).

SRH-TC, with the proper input information, can simulate the concentration and distribution of a turbid density current plume and the eventual amount of sediment that is deposited in the reservoir or is passed downstream from the reservoir. At Shihmen Reservoir, SRH-TC predicted the passing of 30 to 40 percent of the incoming sediment through a sediment bypass tunnel for a given typhoon. Computational models such as SRH-TC can be applied to reservoirs where turbid density currents have been observed to occur and, with a proper dataset collected, can help identify ways to extend the life of reservoirs with this sediment management technique.



An SRH-TC model-computed turbidity current moving through Shihmen Reservoir towards the dam, Taiwan.

Shihmen Reservoir,
Taiwan.



More Information

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WRPI. 2011. *Shihmen Reservoir upstream of the main anti-silting river diversion project planning and preliminary hydraulic model test research*. Hydraulic Model Test. Water Resources Agency inspection of the water resources planning Wei, December 2011 (translated from Chinese).

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Reclamation Collaboration With Federal and International Partners

Reservoir Sedimentation and Sustainability Resolution
In 2014, the Subcommittee on Sedimentation unanimously passed this resolution, which the Federal Advisory Committee on Water Information approved:

“Continued sedimentation threatens the project benefits for many of the Nation’s reservoirs. The subcommittee encourages all Federal agencies to develop long-term reservoir sediment management plans for the reservoirs they own or manage by 2030. These management plans should include either the implementation of sustainable sediment management practices or the eventual retirement of the reservoir. Practices are those that enable continued reservoir function by reducing reservoir sedimentation and/or removing sediments through mechanisms that are functionally, environmentally, and economically feasible. The costs for implementing either the practices or retirement plans are likely to be substantial, and sustainable methods to pay for these activities should also be identified.

Federal agencies are encouraged to start developing sustainable reservoir sediment management plans now for one or two reservoirs per year on a pilot basis. From this experience, interagency technical guidelines will be developed for preparing management plans.”

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Subcommittee on Sedimentation Sends an “SOS”

The Subcommittee on Sedimentation includes nearly all Federal agencies concerned with water and sediment, along with some universities and non-governmental organizations. The subcommittee was formed in 1939 and reports to the Federal Advisory Committee on Water Information under the U.S. Department of the Interior’s Assistant Secretary for Water and Science. The objectives of the subcommittee are to:

- Determine major sediment-related problems and issues facing the United States in the 21st century.
- Coordinate developing countermeasures to reduce sediment problems for water resources.
- Provide scientifically defensible standardized information and data for policymakers.
- Coordinate and pool the resources of the participating agencies to effectively share information, consolidate sediment databases, and address important sediment problems.
- Promote analyzing sediment data from a watershed or river basin perspective.

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Advisory Committee on Water Information

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Subcommittee on Sedimentation



Sediment-data collection in the Little Colorado River a kilometer upstream from the Colorado River, Grand Canyon, Arizona, September 2002

<< **Announcement** >>

The Subcommittee on Sedimentation

The Water Information Coordination Program, Subcommittee on Sedimentation website/homepage.



U.S. Department of the Interior
Bureau of Reclamation

— continued

The Subcommittee on Sedimentation is actively engaged in activities to address reservoir sedimentation and promote options for long-term sustainability, including:

National Reservoir Sedimentation Database. For the last several decades, the subcommittee has promoted compiling sedimentation data for federally-owned reservoirs. The Reservoir Sedimentation Database (RESSED), the subcommittee's first database, is being replaced with the Reservoir Sediment Information (RSI) database (see article on page 18).

Federal Interagency Sedimentation Conference. Since 1947, the subcommittee periodically sponsors the Federal Interagency Sedimentation Conferences. Beginning in 2006, these sedimentation conferences were joined with the Federal Interagency Hydrologic Modeling Conference as SEDHYD. Engineers and scientists can meet to discuss recent accomplishments in the physical, chemical, and biological aspects of sedimentation, and in developing and using hydrologic models addressing surface water quality and quantity issues. These well-attended conferences allow an interdisciplinary mix of scientists and managers from government agencies, academia, and the business community to present their recent accomplishments and progress in research and have produced over 2,100 technical papers (see the "Recent and Upcoming Events" segment in this issue).

Reservoir Sustainability Workshop. To develop and describe practical options for managing sediment for long-term reservoir sustainability in the United States, the subcommittee sponsored the Reservoir Sustainability Workshop with national—and some international—specialists from Federal agencies, universities, and consultants in 2012. One recommendation was to form the National Reservoir Sedimentation and Sustainability Team (NRSST).

Training From NRSST. Specialists from Federal agencies, universities, and consultants on NRSST:

- Provided short-course training on reservoir sedimentation and sustainability
- Provided web-based resources to inform agencies and the public about the problems and solutions associated with reservoir sedimentation
- Recommended interagency protocols for web-based storage and retrieval of reservoir survey datasets
- Encouraged storage of reservoir capacity and sedimentation data in the national reservoir database, and formulated a white paper on reservoir sedimentation and sustainability



Reservoir Sustainability Workshop, Lakewood, Colorado, July 10 through 12, 2012.

More Information

Subcommittee on Sedimentation website/homepage: <http://acwi.gov/sos/index.html>

Member Organizations

U.S. Department of Agriculture:

- Agricultural Research Service
- National Resources Conservation Service
- U.S. Forest Service

U.S. Department of Commerce:

- National Oceanic and Atmospheric Administration

U.S. Department of Defense:

- U.S. Army Corps of Engineers

U.S. Department of Interior:

- Bureau of Land Management
- Bureau of Reclamation
- National Park Service
- Office of Surface Mining
- U.S. Geological Survey

U.S. Department of Transportation:

- Federal Highway Administration

Other Federal Agencies:

- U.S. Environmental Protection Agency
- Federal Energy Regulatory Commission
- Tennessee Valley Authority

Professional Organizations and Research Centers:

- American Society of Civil Engineers
- Colorado Water Resources Research Institute
- Consortium of Universities for the Advancement of Hydrologic Science, Inc.
- Missouri Water Resources Research Center
- National Center for Earth-Surface Dynamics
- Universities Council on Water Resources



U.S. Department of the Interior
Bureau of Reclamation

Reclamation Collaboration With Federal and International Partners

Reclamation engineers provided technical assistance in Laos and Vietnam on sedimentation issues related to dam construction on the Mekong River as part of the U.S. Department of the Interior International Technical Assistance Program (DOI-ITAP).

DOI-ITAP is providing Lower Mekong region partner countries with rapid, demand-driven technical and scientific assistance on environmental and social safeguards for infrastructure development. This assistance is funded through the U.S. Agency for International Development's Smart Infrastructure for the Mekong Program.

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Smart Infrastructure for the Mekong Program, Sediment Management and Flushing Technical Guidance in the Mekong River

The Mekong River in Southeast Asia, largely undeveloped prior to 1990, is undergoing rapid dam construction. Seven dams are under construction on the mainstem in China and 133 dams are proposed for the Lower Mekong River and tributaries in Thailand, Laos, and Cambodia.

Technical Assistance to Laos

Reclamation and the U.S. Army Corps of Engineers (USACE) are providing technical assistance to the Lao PDR Ministry of Energy and Mines (MEM) to help develop technical capabilities to design, construct, and operate reservoir sediment management solutions. This will help MEM achieve environmental, social, and economic reservoir sustainability. Proper sediment management will help ensure reservoir and dam functions over the long term, and also reduce environmental and public safety issues along the river channel upstream and downstream from the reservoirs.

Reclamation's technical assistance includes:

Developing Guidance Documents. Technical guidelines for sediment management at hydropower projects are being developed. The guidelines will be based largely on the information gathered in the literature/document search and review. The operational aspects of the guidelines will include performance-based monitoring of reservoir sedimentation, and the potential degradation of the downstream river channel. An adaptive management approach will help ensure that project objectives are achieved.

Reclamation's technical assistance also included:

Conducting Training Workshops. The Reclamation and USACE technical assistance team conducted two training workshops:

- The Basic Sediment Transport and Sediment Transport Analysis Workshop, which covered sampling techniques, basic sediment yield, sediment transport, and sediment deposition processes.
- The Sediment Transport Analysis in Rivers and Reservoirs Workshop, which was an advanced training class that covered sediment modeling, reservoir analysis, and reservoir flushing/management techniques.



General location map of the Mekong River through Southeast Asia.

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This advanced training was accomplished by building on existing guidance that MEM had, as well as other sources; reviewing case studies; site visits; and a series of knowledge transfer (training) activities. Final material was presented through guidelines and executive briefing workshops to MEM staff, as well as other Lao agencies determined by MEM.



Laos trainees from the Basic Sediment Transport and Sediment Transport Analysis Workshop with USACE staff (Paul Boyd, seated second from left, and Daniel Pridal, seated second from right).



Laos trainees taking pebble count measurement to assess sediment grain size distribution.

Technical Assistance to Vietnam

The U.S. Department of the Interior, International Technical Assistance Program, provided scientific peer review of a major regional study that assessed the environmental and social impacts of proposed hydropower dams on the Mekong River and tributaries. The study, conducted by Vietnam’s Ministry of Natural Resources and Environment, included a baseline assessment report, impact assessment report, and an avoidance and mitigation report. Staff from the Sedimentation and River Hydraulics Group in Reclamation’s Technical Service Center was part of this interdisciplinary team, which was funded by the U.S. Agency for International Development’s Smart Infrastructure for the Mekong Program.

Technical Assistance Team for Laos

- Jason Riley, U.S. Department of the Interior, SIM Program Manager
- Jim Ligh, USACE, Project Manager
- John Remus, USACE, Co-Technical Lead
- Tim Randle, Reclamation, Co-Technical Lead
- Kendra Russell, Reclamation, International Affairs
- Blair Greimann, Reclamation, Technical Staff
- Kent Collins, Reclamation, Technical Staff
- Paul Boyd, USACE, Technical Staff
- Daniel Pridal, USACE, Technical Staff
- Travis Dahl, USACE, Technical Staff
- Stanford Gibson, USACE, Technical Staff

More Information

www.usaid.gov/asia-regional/fact-sheets/smart-infrastructure-mekong



Reclamation Collaboration With Federal and International Partners

The Federal Interagency Sedimentation Project is actively working to advance the state of science and coordinate research efforts for surrogate sediment measurement methods and devices, and provide guidance on sediment measurement methods and devices.

More Information

<http://water.usgs.gov/fisp/>

See Research Update on page 34.

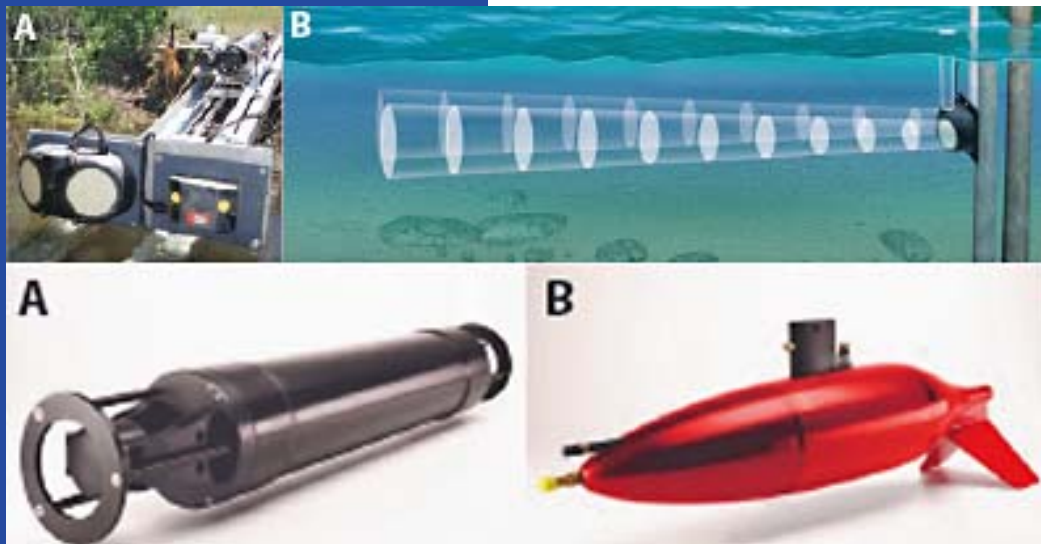
Williams, C.A., R.J. Richards, K.L. Collins. 2015. *Suspended-Sediment Transport and Storage: A Demonstration of Acoustic Methods in the Evaluation of Reservoir Management for a Small Water-Supply Reservoir in Western Colorado*. Proceedings of the Joint Federal Interagency Conference, Reno, Nevada, April 19-23.

The Federal Interagency Sedimentation Project—Advancing the Technology of Sediment Measurement in Rivers and Reservoirs

Improving technologies and reducing costs to continuously measure river (fluvial) sediment helps to assess sediment-related impacts, which, in turn, improves water management decisionmaking. Sediment measurement methods that provide a continuous sediment record with limited manual sediment measurements (termed “surrogate sediment measurement methods”) improve sediment records at a site and reduce long-term costs. Various Federal agencies and universities are developing these methods, including measuring both suspended sediment and bed load. Surrogate sediment measurement methods measure sediment in rivers many times per hour at reduced long-term costs. These devices most often use acoustic or optic technology for deployment in a river to measure suspended sediment concentrations (shown in the figures). Surrogate sediment measurement devices are currently deployed at several locations across the country.

For example, the U.S. Geological Survey (USGS) has deployed two acoustic Dopplers upstream and downstream from Paonia Reservoir, Colorado, to monitor the seasonal quantity of incoming and outgoing suspended sediment to establish the timing and rate of reservoir sedimentation (Williams et al., 2015). These near real-time sediment measurements improve the capability of operating Paonia Reservoir for sustainable sediment management (see article on page 14).

The Federal Interagency Sedimentation Project (FISP) was created in 1939 to unify and standardize the equipment and methodology of sediment measurement for consistent data collection by all practitioners. FISP provides Federal approval and guidance for sediment measurement devices, instruments, techniques, methods, and data processing in an effort to standardize fluvial sediment measurement.



Example of an acoustic Doppler device used to measure backscatter and attenuation to obtain suspended sediment concentration. [A] Acoustic Doppler meters used for estimating suspended sediment concentrations in Clearwater River, Spalding, Idaho. Source: USGS (<http://pubs.usgs.gov/fs/2014/3038/>). [B] Cartoon of a side-looking acoustic Doppler device projecting dual acoustic beams across a channel. Image courtesy of SonTek (www.sontek.com/).

Example of two optic devices to measure suspended sediment concentration and particle size. [A] LISST-100. [B] LISST-SL. Images courtesy of Sequoia Scientific, Inc. (www.sequoiasci.com/).

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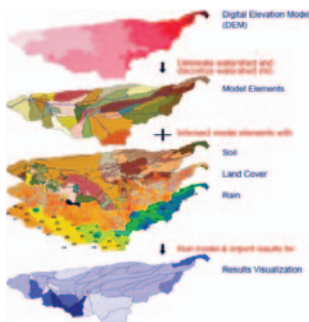
FISP will continue their research and coordination efforts to refine and standardize measurements from surrogate sediment measurement devices and is working toward Federal approval of acoustic Doppler devices for measuring suspended sediment concentration. FISP leads two efforts: the Sediment Acoustics Leadership Team and the development of the Surrogate Analysis and Index Developer tool, both co-sponsored by FISP and USGS.

Research Updates

The following Research Updates (Bulletins) showcase completed research within Reclamation's Science and Technology Program. Contact the authors/principal investigators for more information about these final research projects.

Bulletin Title, Quote, and Website

Page



Tracking Sediment Inflow Into Reclamation's Reservoirs

"Sediment capture is the most significant factor in determining the expected lifetimes of reservoirs. Measuring sediment inflow is vital in sustaining storage capacity, preventing infrastructure damage such as burying outlet works and/or recreational facilities, and avoiding downstream erosion and habitat loss. Because most reservoirs have not been surveyed, a model to estimate sediment would be an invaluable aid for Reclamation."

Joel Murray, Physical Scientist
Reclamation's Technical Service Center

www.usbr.gov/research/docs/updates/2016-05-tracking-sediment.pdf

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Federal Interagency Sedimentation Project

"FISP is an effective partnership with Federal, State, and other agencies to find the best ways to obtain comparable, meaningful sediment information using common instruments, standards, and procedures."

Robert C. Hilldale, Hydraulic Engineer
Reclamation's Technical Service Center

www.usbr.gov/research/docs/updates/2016-06-FISP.pdf

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Registering Bed Load Impacts on the Riverbed for Surrogate Bed Load Measurement

"Monitoring sediment during and after dam removal is a significant step forward in understanding the transport of bed material in a gravel-bed river. The impact plates on the Elwha River, using geophones and accelerometers, will not only provide valuable information for the Elwha River, but will advance technologies to continuously measure bed load in other rivers."

Robert C. Hilldale, Hydraulic Engineer
Reclamation's Technical Service Center

www.usbr.gov/research/docs/updates/2016-07-registering-bed-load.pdf

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Listening to Bed Load

"Knowing and understanding the flow conditions under which bed load is transported in a fluvial system is critical for efforts to improve degraded conditions for the improving ecology and aquatic habitat, as well as protecting riverine and riparian infrastructure. A portable system to continually measure bed load movement over a long period of time will provide valuable information for practitioners to greatly improve their understanding of bed load transport."

Robert C. Hilldale, Hydraulic Engineer
Reclamation's Technical Service Center

www.usbr.gov/research/docs/updates/2016-08-listening-bed-load.pdf

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Research Update

Spring 2016
Bulletin 2016-05

Bottom Line

This research project examined hydrologic models to determine whether they could predict annual sediment inflow.

Better, Faster, Cheaper

Measuring sediment inflow is critical in addressing potential operation sustainability issues, including:

- Loss of storage capacity
- Burial of outlet works and/or recreational facilities
- Downstream erosion
- Habitat loss

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Tracking Sediment Inflow Into Reclamation's Reservoirs

Using a continuous simulation, process-based model to predict sediment inflow

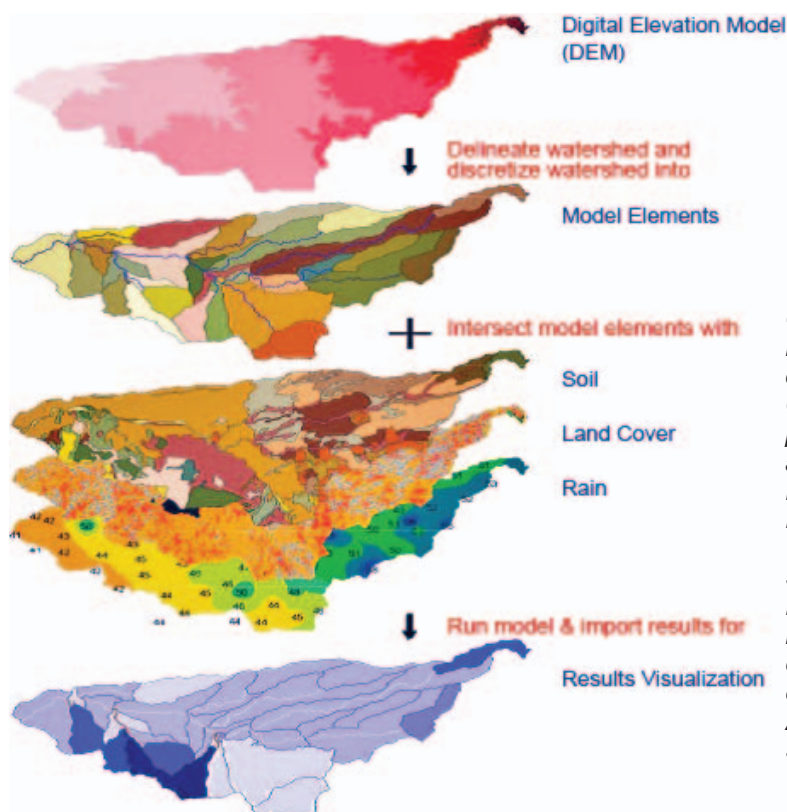
Problem

Reclamation manages over 400 storage facilities, but only 30 percent have had bathymetric surveys conducted since initial filling to determine the amount of sediments entering the reservoirs and what has accumulated over time. As the sediments accumulate in the reservoir, the storage facility gradually loses its ability to store water. Sediment storage rates vary widely, and determining these levels for each storage facility is critical for predicting the efficiency of infrastructure and operations.

Regular surveys provide estimates of annual sediment inflow; however, surveys are labor intensive and expensive undertakings. Hydrologic models might be able to estimate sediment inflows based on watershed size, sediment mobility, and wildfire susceptibility. This would provide a reasonable estimate of sedimentation rates for unsurveyed reservoirs to help develop reservoir sedimentation strategies to keep Reclamation's hydropower and water delivery infrastructure functioning.

Solution

This Reclamation Science and Technology Program research project reviewed two models to determine if they could be used to estimate sediment inflows based on watershed size, sediment mobility, and wildfire susceptibility. Process models calculate sedimentation rates by simulating elevation, land cover, soils, climate, and hydrological processes within a watershed.



The AGWA tool is a GIS-based hydrologic modeling tool that uses commonly available GIS data layers to fully parameterize, execute, and spatially visualize results for the RHEM, KINEROS2, KINEROS-OPUS, SWAT2000, and SWAT2005 watershed runoff and erosion models. Figure courtesy of the U.S. Department of Agriculture, Agricultural Research Service, Southwest Watershed Research, Tucson, Arizona.

Application and Results

The Water Erosion Prediction Project Model was only suitable for smaller watersheds, under 300 hectares, while watersheds in the Western United States are usually much larger.

The Soil and Water Assessment Tool (SWAT), using the Automated Geospatial Watershed Assessment (AGWA) tool as an interface, could be an appropriate model for predicting annual sediment inflow in unsurveyed reservoirs. The AGWA tool is a Geographic Information Systems (GIS) interface jointly developed by the U.S. Environmental Protection Agency, the U.S. Department of Agriculture's Agricultural Research Service, and the University of Arizona to automate the parameterization and execution of the hydrologic models, SWAT and KINEROS2 (a kinematic runoff and erosion model). Based on the individual model requirements, watershed model elements are intersected with soils and land cover data layers to derive the requisite model input parameters.

Researchers reviewed documentation, gathered input data, and validated model output using the SWAT/AGWA model for three test dams: Bully Creek, Oregon; Paonia, Colorado; and Nambé Falls Dam, New Mexico. To calculate sediment accumulation and reservoir capacity loss, sediment data and topographic maps (i.e., observed values) were acquired at these dams. Researchers ran the SWAT2005 model and compared model results to observed values. The SWAT2005 model consistently overestimated the observed values by approximately 63 percent. Possible causes for magnification of the model output may include:

- **Data Resolution.** As data resolution increases, model results may improve.
- **Land Cover Change.** Consideration of wildfires or other land cover changes may influence model results.
- **Interpolated Climatic Data.** Some of the precipitation and temperature data were interpolated, which may inflate the estimated sedimentation rates.

Future Plans

Future modeling efforts are needed to effectively model sediment inflow into Reclamation's reservoirs. Actions could include:

- Calibrating the SWAT2005 model using the AGWA tool, which should improve the accuracy of the estimated values.
- Examining the influence of wildfires to SWAT. Many Reclamation reservoirs are in watersheds that experience frequent and extensive wildfires, thus this may be an extremely useful calibration tool.
- Developing a new GIS-based model to predict sediment yield as a function of nine individual drainage basin characteristics: surface geology, soils, climate, runoff, topography, ground cover, land use, upland erosion, and channel erosion.

More information

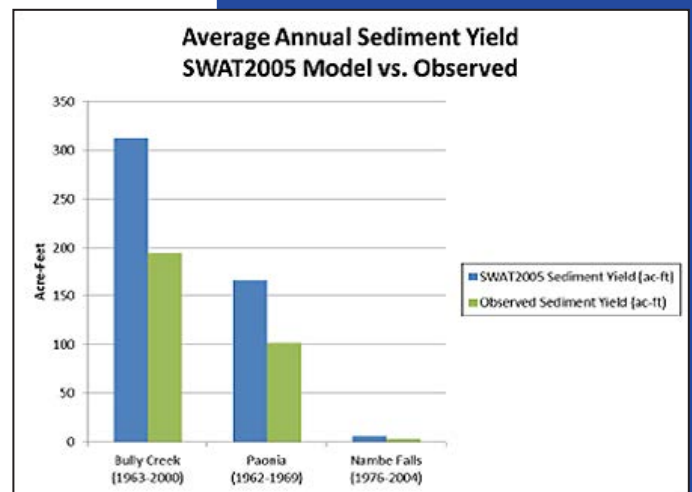
www.usbr.gov/research/projects/detail.cfm?id=8653

Automated Geospatial Watershed Assessment tool:

www.tucson.ars.ag.gov/agwa

“Sediment capture is the most significant factor in determining the expected lifetimes of reservoirs. Measuring sediment inflow is vital in sustaining storage capacity, preventing infrastructure damage such as burying outlet works and/or recreational facilities, and avoiding downstream erosion and habitat loss. Because most reservoirs have not been surveyed, a model to estimate sediment would be an invaluable aid for Reclamation.”

Joel Murray
Physical Scientist
Reclamation's Technical Service Center



Comparison of modeled and observed average annual sediment yield at three Reclamation reservoirs.

Research Update

Spring 2016
Bulletin 2016-06

Bottom Line

The Federal Interagency Sedimentation Project researches effective and consistent ways to measure sediment transport and ensures uniformity in collection techniques and methods.

Better, Faster, Cheaper

Federal, state, and local agencies need unbiased, standard testing technologies to measure or infer select fluvial sediment characteristics for comparable and reliable sediment transport data.

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Four hand-held versions of pressure difference bed load samplers used in laboratory flume experiments: (C) BL-84, (D) Helley-Smith, (E) Elwha, and (F) TR-2.

Federal Interagency Sedimentation Project

Coordinating effective research into sediment measurement solutions

Problem

Measuring how much sediment a river transports is difficult and hazardous, but the information is priceless to planners determining the amount of sediments transported into reservoirs and shaping rivers. Most of the sediment is transported during floods, and thus it is hard to mobilize and deploy equipment safely. Having people measure sediment is costly and necessarily intermittent.

Moreover, the Nation needs standardized techniques and equipment for fluvial sediment data collection to ensure that data collection is uniform in its collection and processing. Fluvial sediment data can only be meaningful if all parties are held to the same standard. Additionally, equipment used for such data collection must be standardized.

Solution

This Reclamation Science and Technology Program research project partners with the Federal Interagency Sedimentation Project (FISP). Reclamation has been a partner with FISP since its inception in 1939. FISP has conducted research, development, fabrication, and evaluation of instrumentation and methods for sediment data collection, analysis, testing, storage, distribution, and interpretation of information related to sediment and the sampling of surface waters and sediments for analysis of their chemical, biological, and physical properties. FISP develops physical sediment samplers, sampler deployment protocols, and analytical methods that are the standards by which most Federal agencies collect sediment and water quality samples from rivers. FISP equipment and methods are also accepted as the standards used by public and private practitioners collecting sediment data in the United States, and by a number of countries and organizations around the world.

FISP has expanded its traditional role to include research, development, and evaluation of indirect (surrogate) methods and instruments produced by others for potential acceptance. The goal of FISP has been and is to develop and promote the use of standardized sampling and monitoring technologies and methods that produce fluvial sediment and water quality data that are representative, consistent, and comparable. Without such data, technically supportable evaluations of changes in the quality and content of our Nation's waters would not be possible.



New technologies and methods for surrogate monitoring of fluvial sediment can provide much greater temporal- and spatial-data resolution with increased data quality at lower long-term costs. The cooperative efforts of all Federal agencies involved in sediment data collection, analysis,

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and distribution are needed to ensure the integrity of the Nation’s sediment data and effective responses to sediment-related issues.

Application and Results

During the semiannual FISP meeting held December 2 and 3, 2015, the committee evaluated and ranked 10 proposals for funding in 2016. The top four proposals were awarded and are described below:

- 1. Testing the Effect of Different Mesh Sizes of Three Bed Load Samplers.** This testing will take place in a laboratory flume to gain an understanding of the effect the opening size has on the hydraulic efficiency of the bed load sampler. To obtain a representative bed load measurement with a pressure difference sampler, flow conditions at the nozzle (entrance) of the sampler must closely match the ambient flow conditions. To date, the BL-84 is the only pressure difference sampler approved for use by FISP. This testing is for FISP approval of larger pressure difference bed load samplers, such as the Elwha and TR-2.
- 2. Quantifying and Comparing the Sampling Efficiency of Four Pressure Difference Bed Load Samplers: Helley-Smith, BL-84, Elwha, and TR-2.** The flume testing for this study has been completed and the proposal addresses the analysis of the testing. This is also required information for FISP approval of additional pressure difference bed load samplers.
- 3. Investigation of Sound Propagation and Flow-Induced Noise in Gravel-Bed Streams for Sediment-Generated Noise Measurement.** This research works directly with research being conducted jointly by Reclamation and the University of Mississippi’s National Center for Physical Acoustics to determine a method for measuring coarse bed load with hydrophones (funded by Reclamation’s Science and Technology Program, Project ID 2559).
- 4. Analysis of Side-Looking Hydroacoustic Backscatter for Suspended Sediment Concentration in the Rio Grande, Albuquerque, New Mexico.** This research will investigate a possible point of saturation for acoustic backscatter measurement of suspended sediment for very high concentrations. A potential solution for measuring suspended sediment in very high concentrations is the use of densimetric methods, making use of a dual orifice bubbler. As densimetric methods measure pressure differences to determine the concentration of suspended sediments, the ability to measure suspended sediments using this method improves as concentrations increase.



Full-size TR-2 used in the field.

“FISP is an effective partnership with Federal, State, and other agencies to find the best ways to obtain comparable, meaningful sediment information using common instruments, standards, and procedures.”

Robert C. Hilldale
Hydraulic Engineer
Reclamation’s Technical Service Center

Collaborators

FISP is an interagency committee that is funded by each partner agency, which are currently:

- Bureau of Reclamation
- Bureau of Land Management
- U.S. Geological Survey (USGS)
- U.S. Army Corps of Engineers
- U.S. Department of Agriculture’s Agricultural Research Service
- U.S. Environmental Protection Agency

The committee and related funding is managed by USGS. USGS provides a full-time position for the FISP Chief, who is currently Dr. Mark Landers.

More Information

www.usbr.gov/research/projects/detail.cfm?id=2559

<http://water.usgs.gov/fisp/>

Future Plans

The committee puts out a Request for Proposals once a year to solicit research toward surrogate sediment measurement and other sediment measurement-related topics. FISP occasionally specifies certain topics for which answers are needed.

This committee also addresses regular business issues related to standards, methods, and procedures for sediment measurement and sharing that information with the sediment community. FISP plans to continue its function and operation well into the future.

Research Update

Spring 2016
Bulletin 2016-07

Bottom Line

This research project will help determine the appropriate signal processing from impact plates instrumented with an accelerometer to provide an alternate means to measure bed load on the Elwha River using plates. The impact plate system is currently measuring bed load with geophones.

Better, Faster, Cheaper

Physical measurements of bed load are dangerous and expensive. This technology could provide continuous, safe measurements critical for designing and protecting infrastructure and habitat.

Reclamation Investigator

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Registering Bed Load Impacts on the Riverbed for Surrogate Bed Load Measurement

Quantifying coarse bed load transport rates at fixed cross sections of a riverbed

Problem

Measuring how gravel and rocks move along a riverbed is a critical component for understanding a river's geomorphology, which is needed to understand the channel morphology for better prediction of sediment transport. This is especially crucial downstream from a dam removal to determine how channels form—and where very little sediment measurement data exist.

Quantifying the movement of bed sediment in a river (the bed load) is difficult because bed load moves only during high flow events, perhaps once a year under normal conditions. Measuring bed load transport using classical means, with pressure difference bed load samplers, only provides snapshots (1 to 2 minutes) of data at discrete times and locations across the channel and is dangerous during floods. To truly understand bed load transport, a reliable way to continuously measure its movement is needed.

To perform continuous measurements, a series of bed load impact plates have been installed on the Elwha River for measuring bed load during and after dam removal. Each plate is instrumented with either a geophone (46 plates) or accelerometer (26 plates). Either sensor can be used to quantify bed load. These instrumented steel plates are mounted adjacent to one another and span the active channel.

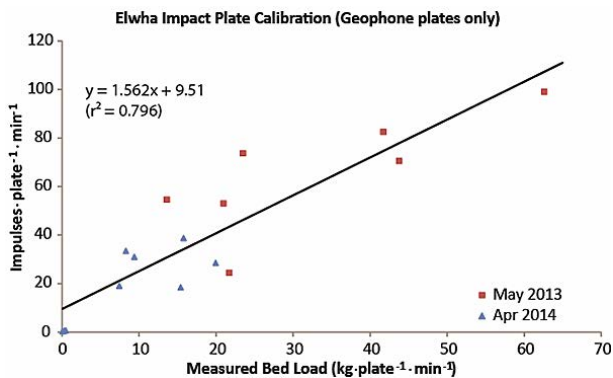
While these plates can measure the signals generated as bed load moves across them, the signals need to be interpreted. Characterizing bed load based on these signals requires understanding these signals—which signals indicate what amount and type of sediment movement?



Photograph looking down on the Elwha River impact plate system and surface water diversion structure (left). Closeup photograph of the impact plates mounted on the downstream side of a concrete weir (right). In both images the flow of water is from left to right.

Solution

To date, the impact plate system has had a preliminary calibration for the impact plates instrumented with geophones.



Most recent calibration of the geophone impact plates.

regarding the best method to process the accelerometer signals to quantify bed load transport and possibly determine particle size.



“Monitoring sediment during and after dam removal is a significant step forward in understanding the transport of bed material in a gravel-bed river. The impact plates on the Elwha River, using geophones and accelerometers, will not only provide valuable information for the Elwha River, but will advance technologies to continuously measure bed load in other rivers.”

Robert C. Hildale
Hydraulic Engineer
Reclamation’s Technical Service Center

Photograph looking upstream at the Agricultural Research Service’s recirculating flume (left). Closeup photograph of two full-scale impact plates instrumented with accelerometers (right).

Future Plans

Future efforts include additional physical bed load measurements (spring 2016) for *in situ* calibration of the accelerometer plates and additional calibration information for the geophone plates.

This bed load impact plate system will provide continuous measurement of bed load downstream from two former dams on the Elwha River and contain valuable information regarding bed load transport during and after dam removal. Recent research on this topic will be presented at River Flow 2016, eighth international conference on fluvial hydraulics, in St. Louis, Missouri.

More Information

www.usbr.gov/research/projects/detail.cfm?id=4542

www.usbr.gov/research/docs/updates/2014-24-bed-load.pdf

Hildale, R.C., W.O. Carpenter, B.T. Goodwiller, J.P. Chambers, and T.J. Randle. 2015. “Installation of Impact Plates to Continuously Measure Bed Load: Elwha River, Washington, USA.” *Journal of Hydraulic Engineering*, #141, DOI:10/1061/(ASCE)HY.1943-7900.0000975.

Magirl, C.S., R.C. Hildale, C.A. Curran, J.J. Duda, T.D. Straub, M. Damanski, and J.R. Foreman. 2015. “Large-Scale Dam Removal on the Elwha River, Washington, USA: Fluvial Sediment Load.” *Geomorphology*, #246, pp. 669-686.

Hildale, R.C. 2015. *Continuous Bed Load Measurement With Impact Plates on the Elwha River, Washington*. Proceedings, Joint Sedimentation and Hydrologic Modeling Conference, Reno, Nevada, April 19-23.

Collaborators

- U.S. Department of Agriculture’s Agricultural Research Service
- The University of Mississippi’s National Center for Physical Acoustics

Research Update

Spring 2016
Bulletin 2016-08

Bottom Line

This research project provided a simple, mobile method needed to reliably measure the movement of coarse bed material (bed load) in rivers.

Better, Faster, Cheaper

Bed load measurements are difficult, expensive, and often dangerous to obtain. For these reasons, bed load measurements are infrequently collected. A surrogate device will allow continuous measurements at a reduced cost.

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Listening to Bed Load

Using hydrophones to continuously monitor sediment moving along a riverbed

Problem

Reclamation needs to be able to protect its investment in reservoirs, diversions, and other water supply infrastructure as well as bridges, water treatment plants, and levees. Habitat restoration is also an important objective. Tracking the movement of gravel along a riverbed is critical to achieve these goals. Numerical predictions of sediment transport benefit greatly from direct field observations for model calibration and verification.

Reclamation engineers and scientists studying rivers need an accurate picture of bed load transport to understand a river's sediment transport processes, which in turn provides the insights needed to understand the channel morphology for better prediction of sediment loads. However, physically measuring bed load in rivers is costly, difficult, and often dangerous—particularly as most bed load moves during floods or high flows. As a result, these crucial data are very limited temporally and spatially.

Solution

A hydrophone system for measuring bed load has been developed as a portable and easily deployable way to measure bed load for short or extended periods of time. As gravel particles are transported along the riverbed, they generate sound when they collide with each other, which is termed “self-generated noise.” This occurs in every gravel-bed riverbed, but the acoustic environment varies with a river's cross section shape, flow depth, and flow velocity. Hydrophones can record this self-generated noise, which registers as acoustic energy and is recorded with a field-ready data recorder.



Installing Bunte bed load traps immediately downstream of two hydrophones on Halfmoon Creek, Colorado. The hydrophones are installed near the bed using posts and hydrodynamic fairings.

This Reclamation Science and Technology Program research project is working with the U.S. Department of Agriculture's Agricultural Research Service to define the acoustic environment in a river. This information will help inform the placement of hydrophones in the river so that acoustic measurements encompass the entire width of the stream without overlapping the measurement volume between devices.

Application and Results

Past hydrophone deployments have taken place in the Trinity River (California) and Elwha River (Washington). Reclamation has deployed the hydrophones in close proximity to locations where physical bed load measurements were being made. While the correlation between acoustic energy and measured bed load was positive, there were problems understanding the acoustic sound field in a river.

To address this issue, this research project is deploying two hydrophones in two locations in Halfmoon Creek (Colorado), a much smaller channel than previous deployments. To correlate the hydrophone results with other bed load measurements, this project measured bed load using the Bunte bed load traps (a federally approved method for bed load measurement in small streams) at the same place and time.

Researchers from the Agricultural Research Service gathered data to analyze the acoustic sound field. They took acoustic measurements to evaluate flow noise compared to self-generated noise from gravel collisions. Acoustic measurements were also recorded at various distances from an induced underwater signal using a source of known amplitude and frequency.

Future Plans

Future efforts will expand the scale of the measurements and data collected to date. Opportunities to collect acoustic measurements concurrent with physical bed load measurements are rare. As such, the pace of research is often slow to arrive at conclusive determinations. Future work will continue with concurrent acoustic and physical bed load measurements in the Elwha River during spring runoff in 2016. Agricultural Research Service researchers will also be present to explore the acoustic environment and sound propagation in a riverine environment.

The end goal of this research is a portable device that can be used to quantify bed load transport in mass/time values. This will necessarily be accompanied with guidelines for site-specific use and calibration. Recent progress will be presented at River Flow 2016, eighth international conference on fluvial hydraulics, in St. Louis, Missouri.

More Information

www.usbr.gov/research/projects/detail.cfm?id=9342

Wren, D.G., B.T. Goodwiller, J.R. Rigby, W.O. Carpenter, R.A. Kuhnle, and J.P. Chambers. 2015. *Sediment-Generated Noise: Laboratory Determination of Measurement Volume*. Proceedings of the 10th Federal Interagency Sedimentation Conference, Reno, Nevada, April 19-23.

Goodwiller, B.T., D.G. Wren, J.R. Rigby, W.O. Carpenter, J.P. Chambers, R.A. Kuhnle, and R.C. Hilldale. 2015. *Design and Implementation of a Field Deployable Passive Acoustic Bedload-Monitoring Surrogate*. Proceedings of the 10th Federal Interagency Sedimentation Conference, Reno, Nevada, April 19-23.

“Knowing and understanding the flow conditions under which bed load is transported in a fluvial system is critical for efforts to improve degraded conditions for improving ecology and aquatic habitat, as well as protecting riverine and riparian infrastructure. A portable system to continually measure bed load movement over a long period of time will provide valuable information for practitioners to greatly improve their understanding of bed load transport.”

Robert C. Hilldale
Hydraulic Engineer
Reclamation’s Technical Service
Center

Collaborators

- University of Mississippi’s National Center for Physical Acoustics
- U.S. Department of Agriculture’s Agricultural Research Service, Oxford, Mississippi
- Colorado State University
- Graham Matthews and Associates, Weaverville, California

Recent and Upcoming Events

The list of events below is for informational purposes only and does not necessarily constitute an endorsement by Reclamation. These events may be of interest to the science, research, and related communities and are not necessarily hosted by Reclamation. A list of recent and upcoming events can also be found at: www.usbr.gov/research/events.

Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling 2015 (SEDHYD 2015)—10th Federal Interagency Sedimentation Conference and 5th Federal Interagency Hydrologic Modeling Conference

April 19 through 23, 2015 | Reno, Nevada

The SEDHYD 2015 Conference is now part of the rich history of the Sedimentation and Hydrologic Modeling Conferences stretching back to 1947. There were 240 technical presentations on a range of cross-cutting topics. Opening remarks were provided by Tom Iseman, U.S. Department of the Interior's Deputy Assistant Secretary for Water and Science.

Contact and additional conference information: Tim Randle | 303-445-2557 | trandle@usbr.gov
Post conference information: www.sedhyd.org/2015



National Reservoir Sedimentation and Sustainability Team Workshop

October 20 through 22, 2015 | Lakewood, Colorado

National and international specialists in the field of reservoir sedimentation and sustainability convened a workshop to continue the team objectives of:

- Providing publicly available web-based resources on reservoir sedimentation and sustainability
- Providing training on reservoir sedimentation and sustainability
- Developing interagency protocols for web-based storage and retrieval of reservoir survey datasets
- Encouraging storage of sediment survey data in a national reservoir database
- Formulating a White Paper on reservoir sedimentation and sustainability

Contact and additional workshop information: Tim Randle | 303-445-2557 | trandle@usbr.gov
Additional information on the team: <http://acwi.gov/sos/nrsst>

White House Water Summit—Livestreamed Event

March 22, 2016 | Washington, D.C.

In conjunction with the United Nations World Water Day, the Administration hosted a White House Water Summit to raise awareness of water issues and potential solutions in the United States and to catalyze ideas and actions to help build a sustainable and secure water future through innovative science and technology. Some Reclamation activities were punctuated at the event.

Post event information: www.whitehouse.gov/webform/share-your-input-activities-and-actions-build-sustainable-water-future

National Priorities: Water Scarcity and Drought—Kickoff Meeting

March 30, 2016 | Denver, Colorado

This U.S. Environmental Protection Agency-hosted kickoff meeting showcased grantees from the Request for Applications, National Priorities: Systems-Based Strategies to Improve The Nation's Ability to Plan And Respond to Water Scarcity and Drought Due to Climate Change.

The objective of the water scarcity and drought grants is to develop innovative strategies to protect water quality and public health during periods of drought. This meeting featured presentations from each of the grantees on their proposed research projects and included a panel discussion focusing on water quality impacts from drought and wildfire.

Post meeting information:

www.epa.gov/research-grants/national-priorities-water-scarcity-and-drought-kick-meeting



19th International Conference in Aquatic Invasive Species (ICAIS)

April 10 through 14, 2016 | Winnipeg, Manitoba, Canada

2016



ICAIS

ICAIS is a comprehensive international forum on aquatic invasive species addressing new and emerging issues. Presentations include new technological developments for prevention, monitoring and control, policy and legislation, and mechanisms of public outreach and education.

Several staff members from the Engineering and Laboratory Services Division in Reclamation's Technical Service Center will present their research on invasive dreissenid mussels. Reclamation will present information about dreissenid mussel monitoring efforts, advances in genetic testing, and control of dreissenid mussel settlement at hydropower facilities with ultraviolet treatment and coatings.

Additional conference information: <http://icais.org/>



The Groundwater Visibility Initiative: Integrating Groundwater and Surface Water Management Workshop (No. 347)

April 28, 2016 | Denver, Colorado

This workshop, being held jointly by the National Groundwater Association and American Water Resources Association, will examine the challenges—and successes—of managing the integration of groundwater and surface water. All aspects of water availability and quality will be considered and will include panel presentations on three specific topics representing diverse views.

Additional workshop information: www.ngwa.org/Events-Education/shortcourses/Pages/347apr16.aspx

Reclamation Facility-Scale Photovoltaic Training

May 4 through 6, 2016 | Denver, Colorado

Federal agencies are required to achieve key goals related to renewable and “clean” energy. Installation of renewable energy systems not only makes progress on these goals, but also reduces energy use and associated greenhouse gas emissions, decreases utility costs, promotes efficiency, and demonstrates new technologies. This course, provided by the National Renewable Energy Laboratory (NREL), will focus on procurement of facility-scale photovoltaic systems with presentations by NREL and Reclamation's Research and Development and Policy and Administration Offices, and visits to solar installations on the Denver Federal Center.

Contact and additional training information: Erin Foraker | 303-445-3635 | eforaker@usbr.gov



20th Annual WateReuse Research Conference

May 22 through 24, 2016 | Denver, Colorado

The latest research focused on helping communities develop resilient water supplies will be presented. The conference provides a unique opportunity for water professionals and researchers to interact, network, and discuss current research and future trends. This solutions-focused event will provide water professionals and industry with tools to address water scarcity and sustainability challenges.

Additional conference information: <https://watereuse.org/news-events/conferences/annual-research-conference>

River Flow 2016—Eighth International Conference on Fluvial Hydraulics

July 12 through 15, 2016 | St. Louis, Missouri

This conference, in the area of river engineering and fluvial hydraulics, will provide a forum to report the latest scientific findings and promote information exchange and cooperation among scientists, engineers, and researchers who share a common interest in riverflows and transport processes.

This conference will focus on the latest advances in experimental, theoretical, and computational tools in the field of fluvial hydraulics to expand understanding and capacity in predicting flow and the associated fluid-driven ecological processes, anthropogenic influences, sediment transport, and morphodynamic processes.

Additional conference information: www.iuhr.uiowa.edu/riverflow2016

See Research Updates on pages 36 and 38.



U.S. Department of the Interior
Bureau of Reclamation

Technology Prize Competitions

More Information

Reclamation's Water Prize Competition Center:

www.usbr.gov/research/challenges

The Knowledge Stream Newsletter—
“Water Technology Prize Competitions Issue:”

www.usbr.gov/research/docs/ks/ks-2016-01.pdf

Water Prize Competition Center Contacts

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Reclamation's Water Prize Competition Center

Share your expertise and ideas! You can help solve some of the most critical water and water-related resource problems facing our Nation!

Federal agencies now have an exciting tool to invite the public and private sectors to come and work with Reclamation to solve problems that are important to Reclamation's mission. The prize competition authorities section included in the America COMPETES Reauthorization Act of 2010 (15 USC 3719) authorizes all Federal agencies the option to use prize competitions as an additional tool to find solutions to the problems they need to solve. Prize competitions are partnerships that reach out to solvers—individuals, businesses, universities, and other organizations—to solve problems.

When each prize competition is launched and open for competition, potential solvers will be able to access and compete in each prize competition through Challenge.gov (www.challenge.gov/list) and on the Water Pavilion at the InnoCentive.com Challenge Center (www.innocentive.com/ar/challenge/browsepavilionName=Water&pavilionId=1942&source=pavilion).

Water prize competitions are being developed in three theme areas:

1. Water Availability
2. Ecosystem Restoration
3. Infrastructure Sustainability

In March 2015, Reclamation's Water Prize Competition Center broadened the Ecosystem Restoration theme area to start considering prize competitions that can help Reclamation solve problems related to sediment management.

Reservoir Sedimentation Prize Competitions

Prize competitions in the area of reservoir sedimentation are being developed by Reclamation's Water Prize Competition Center under the Ecosystem Restoration theme area. Three prize competition topics are currently being considered, with the following descriptions and anticipated launch dates:

- 1. Indirect Estimates of Reservoir Sedimentation Volume**
Fiscal Year 2016/2017
Can a more efficient and accurate model be created to predict the rate of storage loss over time for unsurveyed reservoirs?
- 2. Reservoir Sediment Dredging Technology**
Fiscal Year 2017
Can a new type of dredge system be designed to efficiently excavate clay, silt, sand, and gravel from shallow and deep reservoirs while keeping costs for manufacturing, operating, and maintaining dredges less than existing technologies?
- 3. Minimizing Sediment Abrasion in Conduits**
Fiscal Year 2017/2018
Can the abrasion of water intakes and pipes in dams be minimized with the passing of coarse-grained reservoir sediments?



About *The Knowledge Stream* . . .

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We welcome and encourage content from our readers. Please send your Recent and Upcoming Events, Innovation Around Reclamation, or any other content ideas to: research@usbr.gov.

Regional Science and Technology Coordinators Contact Information

Whether you are a regional researcher, Reclamation partner or customer, or just have an idea for a project that can help your region, the Regional Science and Technology Coordinators can help you with your research ideas, proposals, and projects.



Region	Coordinator	Email	Telephone
Pacific Northwest (PN)	Jennifer M. Johnson	jmjohnson@usbr.gov	208-378-5225
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Upper Colorado (UC)	Mark McKinstry	mmckinstry@usbr.gov	801-524-3835
Great Plains (GP)	Collins Balcombe	cbalcombe@usbr.gov	512-899-4162

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Your suggestions for improvements are always welcome. Please email them to Ronda Dorsey at: rdorsey@usbr.gov.

Thanks,

Research and Development Office





Sumner Dam New Mexico 2002



U.S. Department of the Interior
Bureau of Reclamation

This newsletter is available at:
www.usbr.gov/research/docs/ks-2016-02.pdf
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