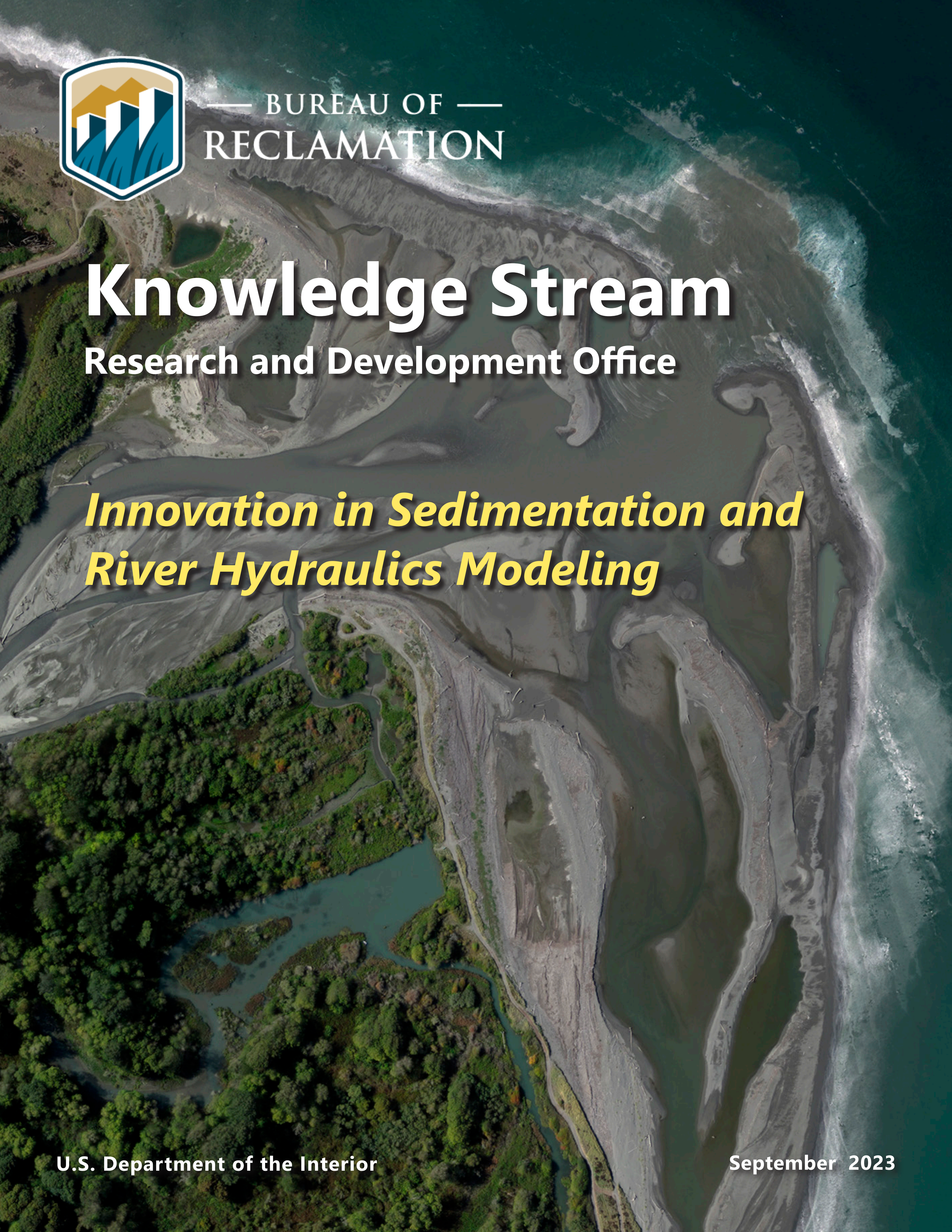

BUREAU OF RECLAMATION

Knowledge Stream

Research and Development Office

Innovation in Sedimentation and River Hydraulics Modeling

U.S. Department of the Interior

September 2023

Message from R&D

In this fall 2023 issue of the *Knowledge Stream*, we highlight the Sedimentation and River Hydraulics – Two-Dimensional (SRH-2D) model.

Since 2004, the Bureau of Reclamation (Reclamation) has developed and maintained SRH-2D as a numerical model for simulating river and reservoir processes. The model is used for investigation of a wide range of hydraulic, eco-hydraulic and sediment issues, and for assessing management alternatives and actions.

Developing and maintaining the model in-house has allowed it to be tailored to meet Reclamation's specific needs. Beyond Reclamation, SRH-2D is also used and supported by a range of U.S. and international agencies. The Research & Development Office has played a vital role in supporting the development and application of this internationally recognized model through our Science & Technology Research, Prize Competition, and Facilitated Adoption Programs.

Inside this issue, you can learn about:

- The history of SRH-2D
- The value of developing and maintaining the model
- SRH-2D research and project applications
- A prize competition to improve the model's execution speed
- The SRH-2D community beyond Reclamation
- The staff behind the model

About the *Knowledge Stream*

The *Knowledge Stream*, published by the Bureau of Reclamation's Research and Development Office, is a quarterly magazine bringing mission-critical news about the agency's innovations in the following:

- Science and Technology Program
- Desalination and Water Purification Research Program
- Prize Competitions Program
- Snow Water Supply Forecast Program
- Open Water Data Program
- Reclamation Geographic Information System Program
- Technology Transfer...and more

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Apples to Apples: Physical Model of Isleta Diversion Dam Paired with Numerical SRH Model Informs Real-Time Sediment Management

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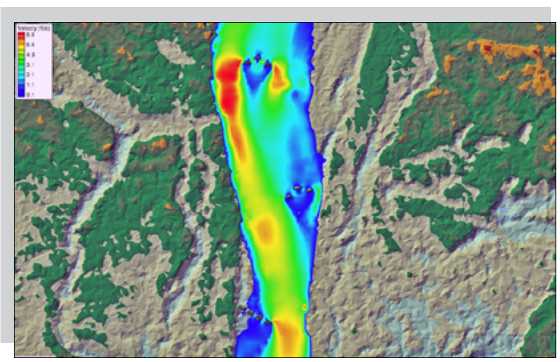

Large Wood Structure Representation in a Two-Dimensional Hydraulic Model

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Front Cover: The mouth of Elwha River, Olympic National Park, WA, in 2014, that has returned to its natural state with the formation of sedimentary features after dam removal. (Photo by National Park Service)

Back Cover: SRH-2D model images and photos for Elwha Diversion Dam, Savage Rapids Dam, & Willow Creek Watershed (Big Thompson) project.

Community Needs

Building SRH-2D for Science-Based Predictions in River Corridors

By Yong Lai, Ph.D., Ben Abban, Ph.D., & Jennifer Bountry, P.E., M.S.
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River corridor management has been recognized as critically important in protecting human livelihood and enhancing ecosystem health—and directly ties to the Bureau of Reclamation's (Reclamation) mission "to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public."

River management has traditionally focused on water storage, transportation, or methods to withstand the forces exerted by water. The importance of understanding complex dynamic river processes has increasingly been recognized, as rivers move not only water, but also sediment, water quality constituents, and large wood—all while serving important ecosystem functions for threatened or endangered species.

A natural river is normally in a dynamic state, continually evolving and changing, which can be further complicated by human influences along the river corridor and upstream watershed. Recent increases in wildfire and hydrologic "book end" events (multi-year droughts intercepted by large floods) has further altered how river corridors and associated infrastructure must incorporate resiliency to be sustainable. As a result, engineering design and operations based on local scale and/or static analyses are likely to be insufficient and can lead to failure. Various complex interacting physical processes may be at play, including flood propagation, channel evolution, fluvial and bank erosion, floodplain connectivity, groundwater influences, and riparian vegetation. The complexity increases significantly when instream infrastructure are present and must be maintained to meet water delivery requirements, typically while also addressing environmental compliance criteria.

Modern river management increasingly relies on science-based approaches for increased reliability and accuracy. One such approach is the use of physics-based numerical models—the primary reason why Reclamation's Sedimentation and River Hydraulics Two-Dimensional Model (SRH-2D) was developed. Only state-of-the-art, science-based models have the potential to take the complexities of dynamic river systems into account.

SRH-2D is a two-dimensional (2D), vertically-averaged hydraulic and sediment transport model. This marks a significant leap forward from the widely used one-dimensional (1D) models, which are cross-sectionally averaged. SRH-2D was first developed in 2004 when Reclamation was mandated to work on several high-profile projects, including the Elwha (Elwha River, Washington; figure 1) and Savage Rapids (Rogue River, Oregon; figure 2) dam removal projects. Both projects included complex construction staging, fish passage improvements, and new water diversions and pumping plants that needed to be addressed using knowledge of multi-dimensional hydraulic processes. However, no reliable 2D models were available at the time beyond a few commercial codes.

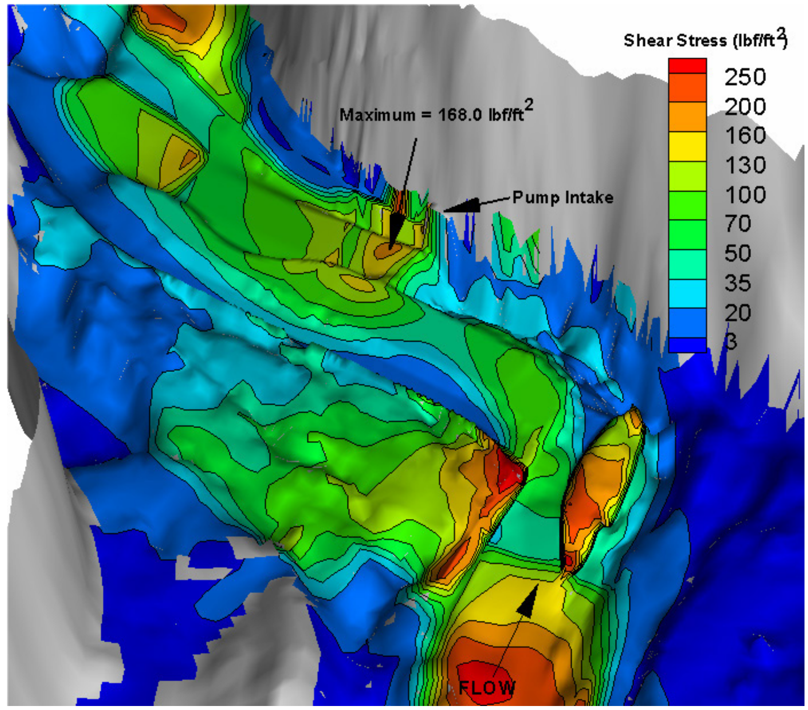

Figure 1.—SRH-2D predicted bed shear stress distribution at the water treatment site downstream of the Elwha Dam under the 100-year flow event.

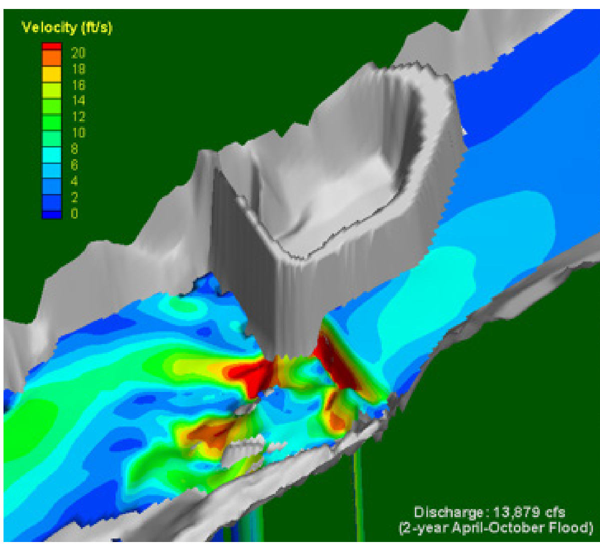

Figure 2.—Left: SRH-2D predicted flow velocity at the Savage Rapids Dam during the right cofferdam construction and a 2-year flow event (~14,000 cfs). Right: View of actual field conditions in May 2009 (5,100 cfs). A flood occurred a few days later at 11,200 cfs and the cofferdam failed exactly where the 2D model predicted high velocity. This resulted in the contractor using the model output to guide design improvements.

SRH-2D model development gained momentum in 2005 with the signing of an international technical collaborative program between Reclamation and the Taiwan Water Resources Agency. Under the agreement, several complex physical process modules were developed into SRH-2D, such as the riverbed erosion and sediment transport, bank and bedrock erosion, and reservoir turbidity current modules. This 18-year-old international program is still active today and is currently pursuing river basin management analyses.

The development of SRH-2D was also expanded to meet road and highway transportation needs. The Federal Highway Administration adopted SRH-2D as its agency model in 2013 and has since provided the technical and financial resources for the development, documentation, and training of SRH-2D for state and Federal highway applications.

Key Perspectives

The Need and History of Numerical Modeling

By Yong Lai, Ph.D., Ben Abban, Ph.D., & Jennifer Bountry, P.E., M.S.
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The Bureau of Reclamation's (Reclamation) Sedimentation and River Hydraulics (SRH) Group has been challenged with answering an extensive list of hydraulic/eco-hydraulic and sedimentation questions. In this 21st century, numerical models are increasingly being used to provide critical data to guide project planning, optimize facility operation, assist project design or improvement, select project alternatives, and assess/evaluate project uncertainties and risks.

One-dimensional (1D) cross-sectionally averaged hydraulic models have been developed and applied as far back as 60 years ago. Today, widely used models include HEC-RAS 1D by the U.S. Army Corp of Engineers (first released in 1995), and SRH-1D, a Reclamation model focused on sediment transport modeling (released in 2006). The popularity of 1D models lies in their low computational demand, efficiency, and ability to simulate large-scale river networks.

There is a widespread recognition that two-dimensional (2D) depth-averaged models are necessary for addressing other study questions when spatial scale is local in nature (i.e. shorter than the reach scale) or processes are 2D in nature and require finer-scale resolution. Although 2D models have been developed since the 1970s, they have not been as widely used as 1D models due to excessive computing time, poor stability, and lack of user-friendliness. Further, most early 2D models lacked sediment modeling capability. A good discussion comparing 1D and 2D models and why 2D models are being advocated for, was provided in a Federal Highway Administration *TechBrief* article (FHWA 2019). The popularity of 2D models is steadily growing as computational resources become widely available and the models themselves significantly improve.

At the SRH Group, an increasing number of high-profile projects were being carried out in the early 2000s that required the use of 2D models, including the Elwha Dam and Savage Rapid Dam removals. At the time, a lack of adequate 2D models and increased project needs, motivated the SRH group to embark on developing its own 2D flow and sediment model. This lead to the model now called the Sedimentation and River Hydraulics Two-Dimensional Model (SRH-2D). The model development built on 3D model development experience (e.g., Lai et al. 2003) and was supported by several funding sources (e.g., Reclamation, the Environmental Protection Agency (EPA), and a collaborative agreement with the Taiwan Water Resources Agency).

2D mesh developed for SRH-2D modeling of flows through bridges (FHWA 2019).

The first version of SRH-2D was released to the public in 2006. Since then, SRH-2D has gone through many revisions and improvements, expanding into a range of disciplines covering hydraulic, eco-hydraulic, hydrologic, environmental, and sediment areas. It has been applied to hundreds of Reclamation projects and used by thousands worldwide. Selected topics covered in this issue of the *Knowledge Stream*, reflect its diversity, utility, and impact.

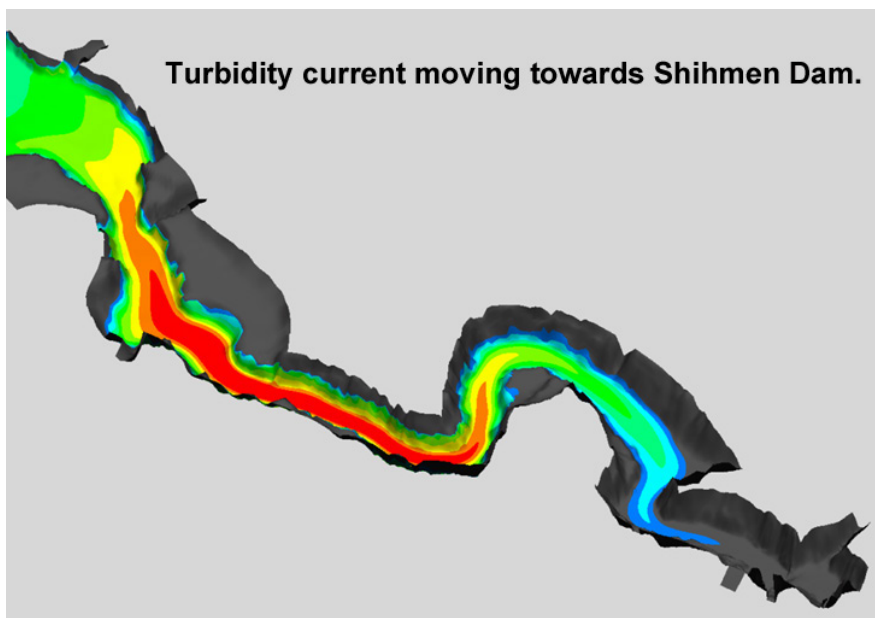
Today, SRH-2D receives continued support from Reclamation's Research & Development Office for model advancement. Its expansion and improvement are also being supported through collaborations with other agencies such as the Federal Highway Administration (since 2013) and the Taiwan Water Resources Agency (since 2004).

SRH-2D has been used for numerous applications including:

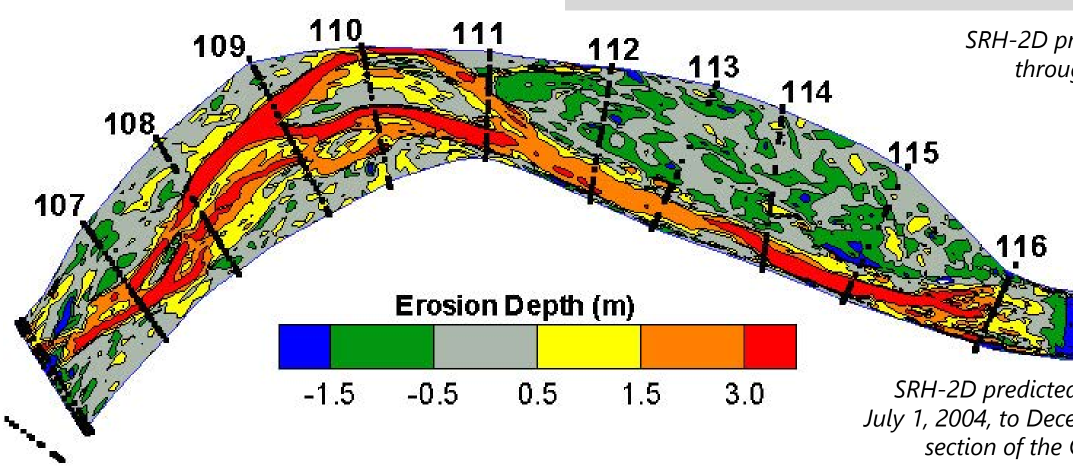
- River restoration design and evaluation
- Fish passage improvements
- Habitat suitability quantification
- Instream structure hydraulics and sediment erosion or deposition evaluation
- Stream vegetation assessment
- Stream erosion and deposition estimate
- Stream temperature assessment
- Dam decommissioning
- Reservoir sediment flushing and routing effectiveness
- Reservoir sedimentation processes and evaluation of management alternatives
- Paleo flood hydraulics predictions
- Spillway erosion
- Dam tailwater analysis

A key benefit of having our own hydraulic and sediment model is that current state-of-the-art technologies suitable to Reclamation projects may be readily adopted and used. Other benefits include:

- Quick model customization for specific project needs
- Maintaining in-house expertise through developing modeling guidelines and training courses
- Prompt technical support when modeling issues arise



SRH-2D predicted turbidity current movement through the Shihmen Reservoir in Taiwan during Typhoon Aere.



SRH-2D predicted bed erosion and bank retreat from July 1, 2004, to December 31, 2006, at the Chi-Chi Weir section of the Choshui (Zhoushui) River in Taiwan.

Reclamation SRH-2D Applications

Predicting Sediment Delivery to Reservoirs in Wildfire-Impacted Watersheds

By Benjamin Abban, Ph.D. & Yong Lai, Ph.D.
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Recent trends point towards an increase in the occurrence and size of wildfires across the western United States due to several factors including climate change (Meadow et al. 2020, Troy et al. 2022). In Colorado alone, three of the largest wildfires on record (Pine Gulch, Cameron Peak, and East Troublesome) have occurred in the last few years. Although, reservoir sedimentation issues are not new, elevated risks associated with sediment delivery are due to increased wildfires. However, increased risk does not necessarily translate to an increase in sedimentation. Ultimate sediment delivery is dictated by a set of interacting post-fire factors that include: atmospheric forcing, location and extent of burn within the watershed, connectivity of burn areas to the channel network, channel storage capacity and delivery potential, and recovery rates on the landscape. Consequently, only numeric models capable of simulating the interactions between these factors can be used to quantify associated risks and determine whether sedimentation will increase, and under what conditions.

Photo taken in Willow Creek watershed two years after East Troublesome fire. There are signs of watershed recovery as well as significant post-fire sediment delivery to low-lying areas (Photo by Bureau of Reclamation, N. Bradley).

There is an evident spatiotemporal (space-time) dimension to the interactions between the pertinent factors that necessitates the use of physics-based models capable of representing effects in space and time for risk quantification and sediment delivery prediction. Several good models are available for predicting soil erosion from wildfire impacted landscapes (Ebel et al. 2023). However, most of the models are limited to hillslopes or do not have the requisite level of in-stream representation needed to adequately predict sediment transport and delivery in the medium to large watersheds that typically contribute to reservoirs. Furthermore, even though wildfire effects last a few years, most models are event based and those that can simulate longer-term fluxes are too crude in process representation for effective watershed management. From Reclamation’s standpoint, there is an urgent need for a predictive tool for medium-to-large watersheds that can reliably predict sediment fluxes to our facilities.

The Sedimentation and River Hydraulics Two-Dimensional Model (SRH-2D) has recently been upgraded to a full hydrologic and hydraulic model (Lai et al. 2022) and, with its renowned well-established instream routines, is a prime candidate for fulfilling Reclamation’s needs. The model adopts a flexible adaptive mesh that can capture both fine and coarse-scale spatial resolutions and can perform both event-based and continuous simulations. Our research objective is to enhance SRH-2D to predict wildfire effects by incorporating state-of-the-art technology in wildfire process representation and demonstrate its application to real-world scenarios.

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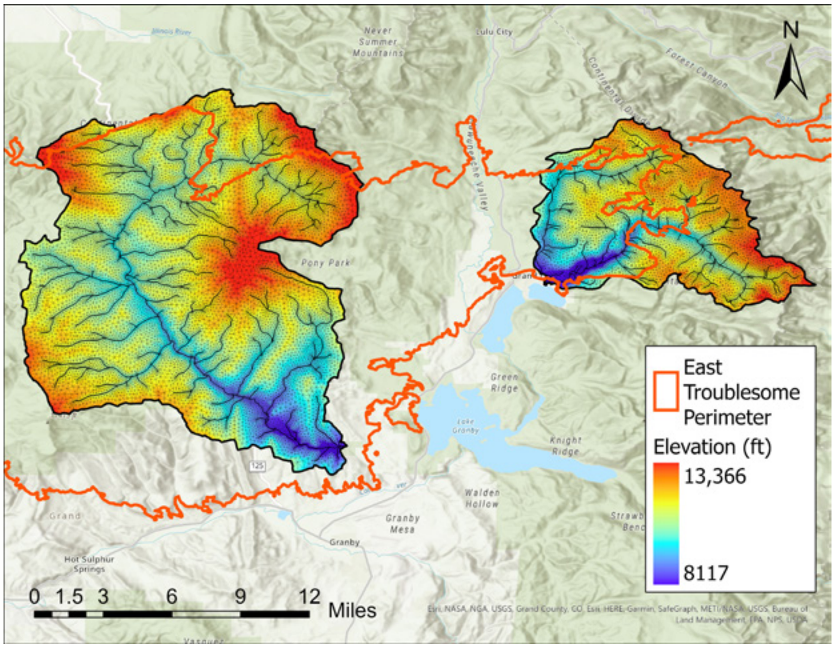

SRH-2D model domains/meshes for Willow Creek (left) and North Inlet (right) watersheds. This photo shows the perimeter of the East Troublesome fire where over 90% of the Willow Creek watershed burned.

– Wildfire-Impacted Watersheds continued

The study is an interagency and interdisciplinary effort with specific goals of representing spatiotemporal changes in soil hydrologic properties with burn intensity and magnitude, surface cover alterations, and changes in soil strength and aggregate stability. Several model updates have been made and efforts are underway to study the impacts of the East Troublesome fire on the Willow Creek, North Inlet, and Colorado watersheds, which contributes to the Big Thompson Project.

Improving the Accuracy of Water Quality Modeling

By Yong Lai, Ph.D.
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Acceptable water quality values, established by government regulators, impose constraints on the allowable discharges into streams and reservoirs and impacts Bureau of Reclamation (Reclamation) facility operation. Most existing water quality tools are based on low-order modeling which simplifies a stream to a simple line, limits the spatial distribution of inputs, and leads to poor model representation.

Reclamation has met this need through research that improves the capacity of higher-order water quality modeling. Improved modeling was achieved by extending the Sedimentation and River Hydraulics Two-Dimensional Model (SRH-2D)SRH-2D into water quality simulation. This resulted in greater accuracy using a 2D depth-averaged approach.

Reclamation has collaborated with engineers at the U.S. Army Corp of Engineers (USACE) to couple Reclamation's hydraulic model SRH-2D to the USACE's water quality module NSMI (Nutrient Simulation Module I). The 2D model uses data with both lateral and longitudinal geographic extents, rather than lumping heterogeneous spatial results into a point-to-point or uni-directional representation.

NSMI is a water quality module developed by USACE which was available to Reclamation for coupling as a dynamic linked library. NSMI simulates aquatic dissolved oxygen, carbonaceous biological oxygen demand, nitrogen and phosphorus cycles, and algae biomass with simplified processes and minimum state variables.

In the coupling of SRH-2D and NSMI, the water quality state variables were governed by their own transport equations within SRH-2D. The source terms of the water quality equations were treated with the operator-splitting method. The 5th-order Runge-Kutta scheme was applied and the following coupling strategies were adopted:

- Water quality was decoupled from the flow model so that an independent flow simulation might be performed;
- An implicit finite-volume discretization on an unstructured polygonal mesh so that the model might achieve robustness and flexibility; and
- The linkage to NSMI was designed so that both models might be developed independently in future.

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– Improving the Accuracy of Water Quality Modeling continued

Model performance was demonstrated by simulating the water quality issues on the 37-mile lower Minnesota River (see figure 1). One sample comparison of the model results with the data is shown in figure 2. In particular, the coupling strategy was verified and model results were compared with the available observation data with reasonable results.

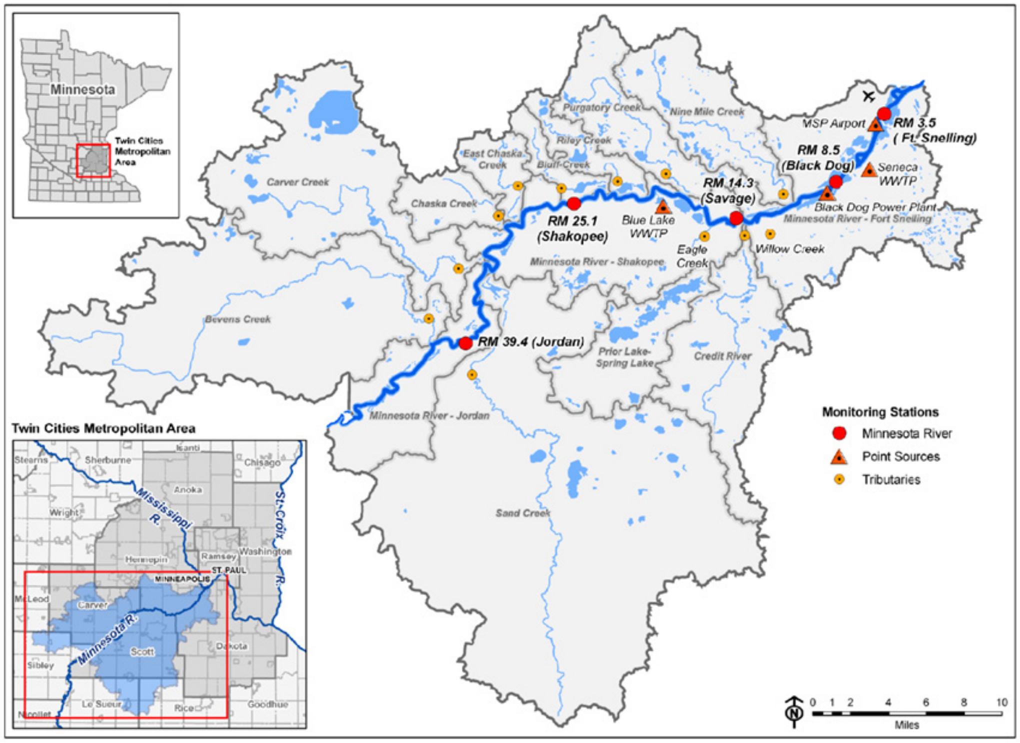

Figure 1.—Overview map of lower Minnesota River study area (figure adapted from the Metropolitan Council Environmental Services, St Paul, Minnesota).

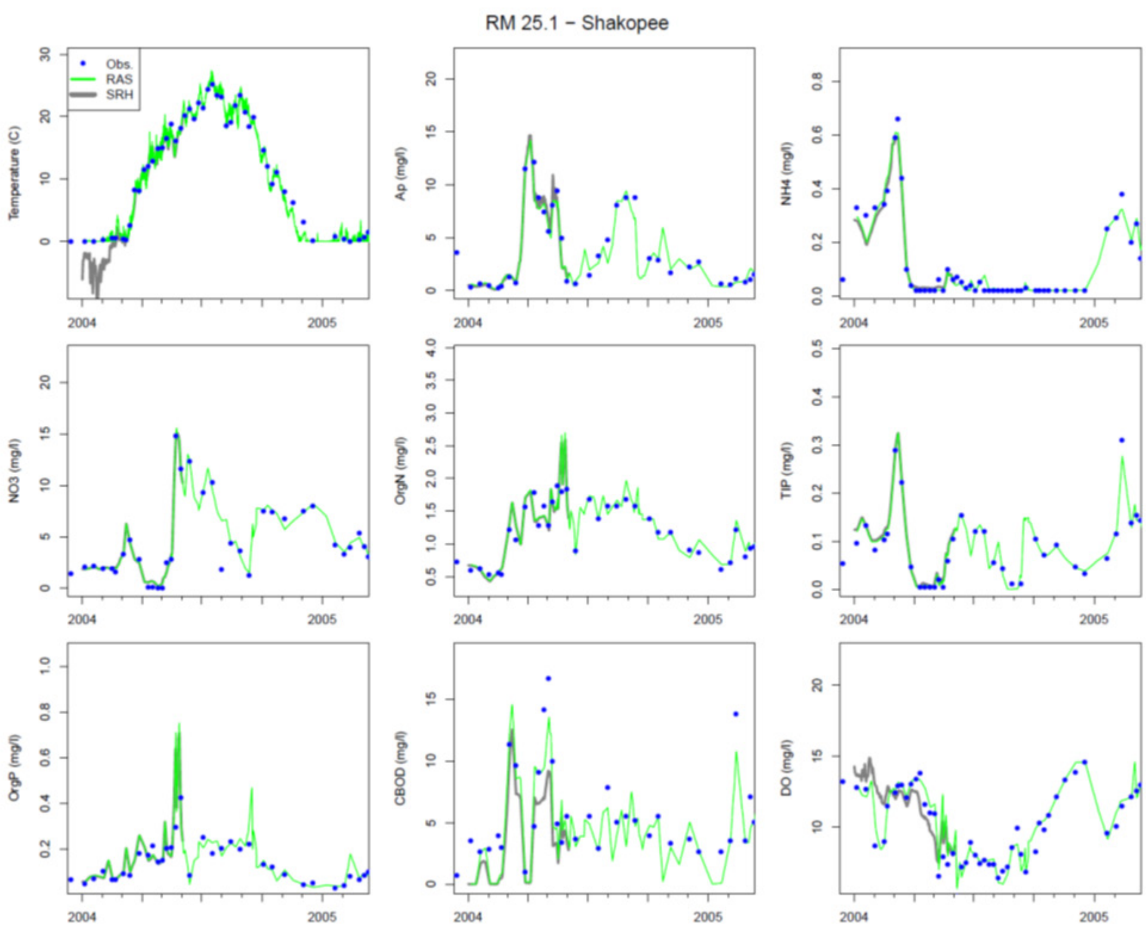

Figure 2.—Comparison of simulated and observed water quality variables at the Shakopee Station (Top: Temperature; Middle: NO3; Bottom: Organic Phosphorus).

SRH-2D Modeling of Stream Temperature Dynamics for Habitat Suitability Studies

By Erin Connor, Ph.D.
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Elevated stream temperatures negatively impact salmonoids and other ecologically important species. Many efforts within the Bureau of Reclamation (Reclamation) focus on improving native fish habitat through design of fish passage structures or floodplain reconnection. However, these types of projects require more than just design calculations. They also benefit from a thorough understanding of both velocity and temperature along the study reach. Therefore, temperature modeling capabilities were a natural addition to the suite of tools available in the Sedimentation and River Hydraulics Two-Dimensional Model (SRH-2D). The built-in SRH temperature module utilizes the 2D velocity solution to solve the depth-averaged energy conservation equation (Lai and Mooney 2009) and predict depth-averaged temperature along a stream. The power of this tool lies in its ability to explore hypothetical scenarios from climate change questions to design alternatives.

One of the earliest applications of the SRH-2D temperature module, which was accomplished through Science & Technology Program funding, demonstrated the model's readiness for comparing the effect of different climate scenarios on stream temperatures along a reach of the Methow River (Huang and Bountry 2014). For this study, the modeled reach sat along a relatively unaltered section of the Methow River in north-central Washington, near Winthrop. Model inputs included both tributaries and springs with measured water temperatures that differed from the Methow main channel. The study accounted for meteorological inputs (solar radiation, cloud cover, air temperature, dew point temperature, and wind speed) to model all physical processes (solar radiation, terrain and vegetation shade, atmospheric radiation, back radiation, heat exchange between water and riverbed, water surface evaporative and conductive losses). The model was validated using temporally resolved point measurements and spatially resolved temperature data from forward-looking infrared (FLIR) images. Authors concluded that SHR-2D temperature modeling could be a powerful tool for capturing a river's thermal dynamics and could inform decisions contingent upon changing climates.

A recent application of SRH-2D temperature modeling compared downstream temperature effects of two project scenarios for the Tieton Diversion Canal (Connor 2023). A total of six different alternatives are currently in consideration for replacement of the Tieton Diversion Canal, which was originally built in 1906. Several of the proposed alternatives relocate the diversion of irrigation water from near the Tieton Dam to over 12 river miles downstream to a spot that is below the confluence of the Tieton River and Naches River. This proposed relocation of the diversion canal will keep water in the Tieton River that was previously diverted for irrigation purposes.

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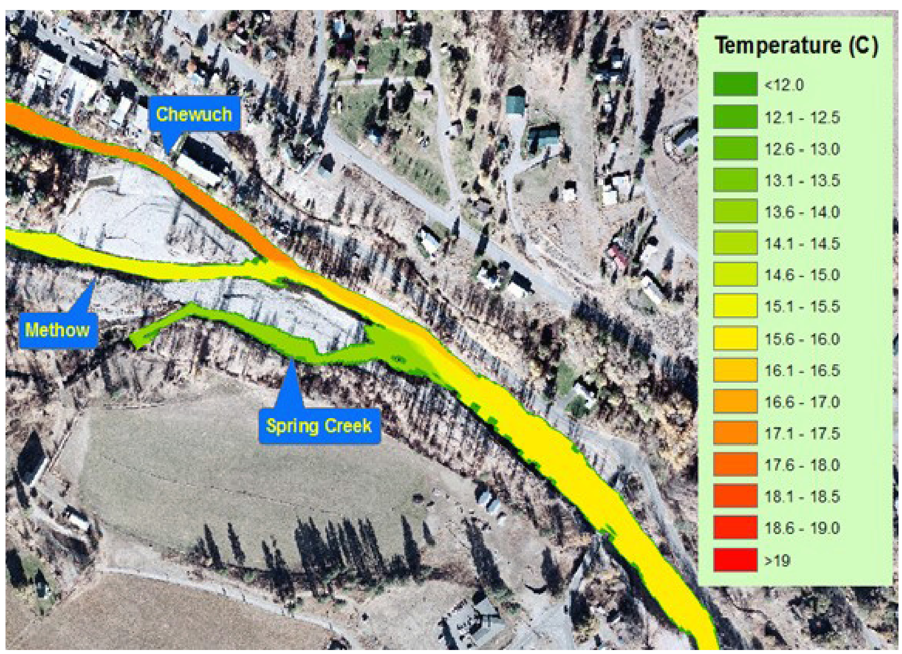

SRH-2D numerical simulation of water temperature at the confluences with the Chewuch River and Spring Creek, with tributaries modeled as point sources. Color scale is mapped to predicted depth-averaged temperature. Flow direction is from left to right. (Huang & Bountry 2014)

– SRH-2D Modeling of Stream Temperature Dynamics continued

An extensive study has already considered the ecological benefits of increased flows in the Tieton River (Hunziker et al. 2022). The assessment of the relocation of the diversion to downstream of the Tieton-Naches confluence also used a simple mass-balance approach to show that a larger fraction of colder, in-channel Tieton River water would mix with warmer Naches River water at the confluence. This would, in turn, provide the additional benefit of cooling the Naches River downstream from its confluence with the Tieton.

Through the Science & Technology Program, further work was funded to verify the benefits associated with diversion of irrigation water downstream of the Tieton-Naches confluence, and to potentially provide further insight into the spatial extent of the impacts. As a 2D model, SRH-2D was able to capture the lateral variability of temperatures across the channel at the confluence under different scenarios. Not only did the model results show a decrease in the overall water temperatures downstream of the confluence, but it also illustrated the enhanced benefit of a diversion located at the bank of the Naches River opposite the Tieton River inflow.

The ability to assess trends in water temperature on such a large spatial scale along with the ability to look at in-depth information about lateral variability in temperatures makes the SRH-2D temperature module an invaluable tool for design, for the Tieton Diversion Canal, and beyond.

Hydraulic Modeling for Salmonid Habitat Assessment and Design

By D. Nathan Bradley, Ph.D., & Colin Byrne, Ph.D.; with partners, Trinity River Restoration Program & the Methow Salmon Recovery Foundation
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River restoration efforts across California and the Pacific Northwest often focus on habitat creation for salmonids. The Sedimentation and River Hydraulics Two-Dimensional Model (SRH-2D) can provide flow estimates that inform habitat metrics to better understand existing habitat and potential restoration designs to improve habitat across salmonid life stages. SRD-2D modeling is currently informing salmonid restoration efforts in the Trinity River, Clear Creek, and the Methow River.

The Trinity River in Northern California is the largest tributary of the Klamath River. In partnership with the Trinity River Restoration Program, SRH-2D developed a two-dimensional model of about 40 river miles from Lewiston Dam to the confluence with the North Fork Trinity River near Helena, California. SRH-2D computed a juvenile Chinook salmon habitat metric developed by Som, et al. (2018), which estimates fish density based on modeled water depth, water velocity, and distance from vegetative cover.

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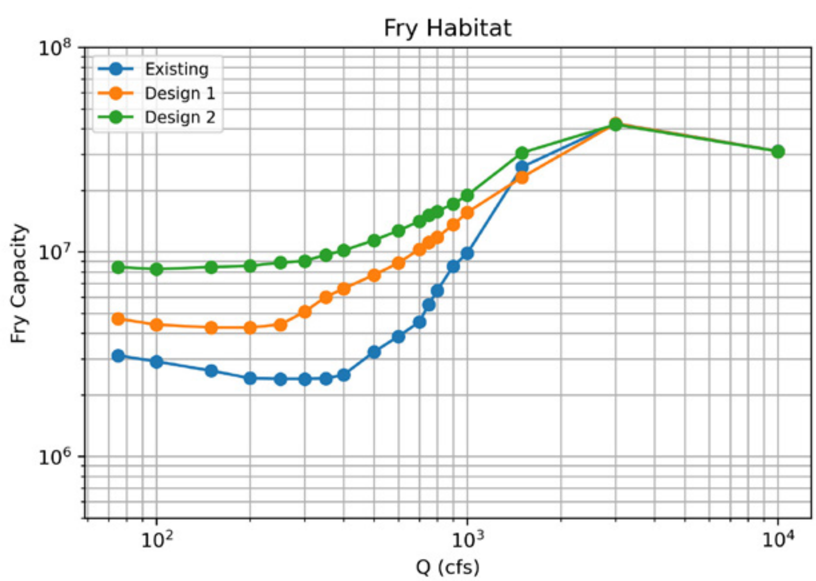
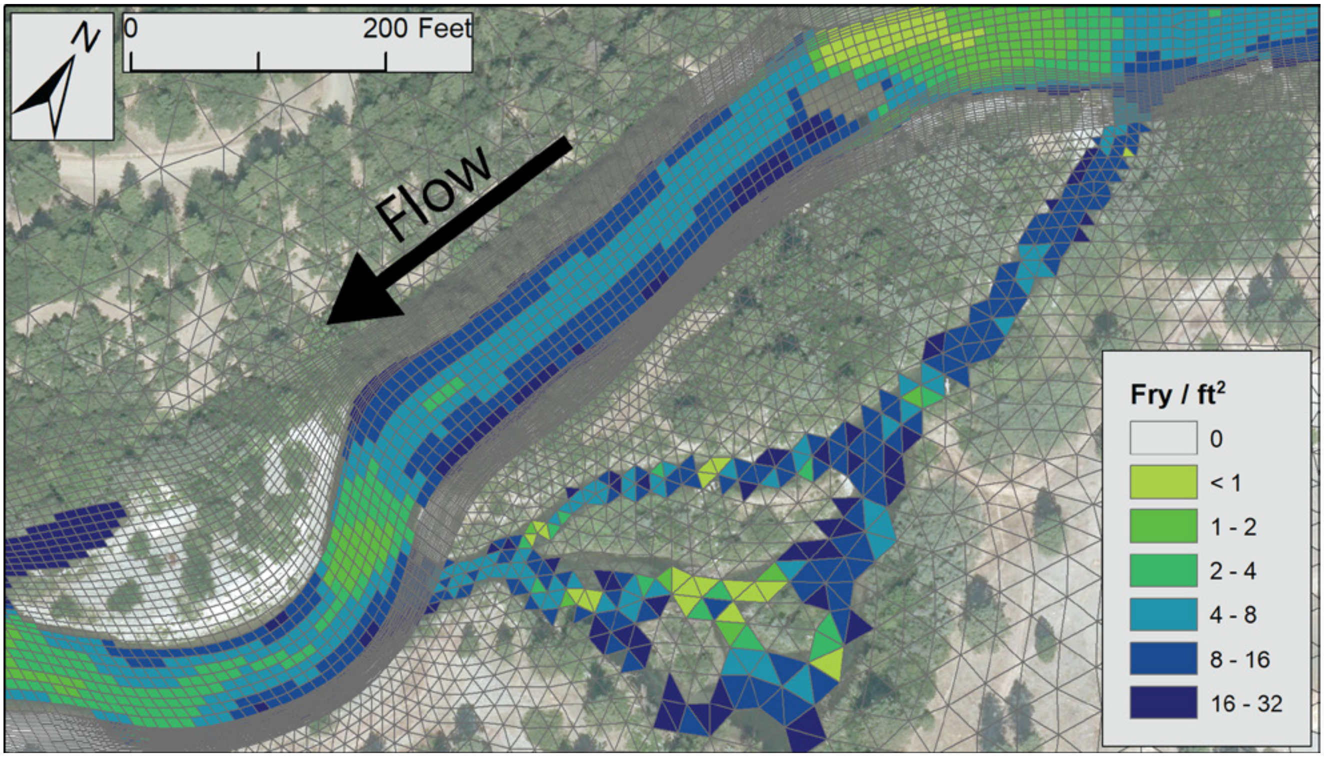


Flow to habitat curves for a restoration site on Clear Creek near Redding, California using the Trinity juvenile Chinook capacity metric.



Estimated Chinook fry density at the upstream end of the Trinity River Lowden Ranch site at a modeled flow of 300 cfs.

– Hydraulic Modeling continued

Juvenile salmonids prefer slow, shallow water near vegetative cover that provides the juvenile fish with protection from predation. The cell density multiplied by cell area is an estimate of number of fish that part of the river could support. Habitat metrics, such as juvenile Chinook salmon capacity, can be calculated over a range of flows to develop a flow-habitat curve. These curves can be used to design restoration features that provide refuge at flows that would otherwise sweep away juvenile fish and to evaluate how much habitat a restoration design could create relative to existing conditions.

Modeling of Clear Creek, a tributary of the Sacramento River near Redding, California, quantified existing habitat and evaluated several iterations of restoration designs intended to simulate restoration actions such as building transverse gravel bars to raise the channel bed elevation, cutting flow paths through riparian berms and floodplains, and lowering floodplain elevations in small, localized areas. The goal of the restoration designs was to increase the amount of area inundated at the lower flows that occur more frequently throughout the year in Clear Creek to create the kind of shallow, low velocity, food-rich habitat that juvenile salmonids prefer.

Restoration focusing on steelhead and spring Chinook habitat is ongoing at three locations along the Methow River in north-central Washington. Restoration goals at each site include re-engaging flow-split channels, increasing in-channel refuge, levee removal, connecting floodplains at lower flows, and activation of natural fluvial processes. Each design includes large wood structures that create habitat or impact flow hydraulics and sediment transport. While SRH-2D model results are being used to estimate habitat suitability across the sites, modeling is also being used to inform restoration impacts to adjacent landowners and improve designs to alleviate landowner concerns and ensure restoration benefits for salmonids can be implemented.

Apples to Apples: Physical Model of Isleta Diversion Dam Paired with Numerical SRH Model Informs Real-Time Sediment Management

By Carolyn Gombert, M.S., Drew Baird, P.E., Ph.D., BC.WRE, & Colin Byrne, Ph.D.; with partners, Albuquerque Area Office, Alden Research Laboratory, Middle Rio Grande Conservancy District, & Pueblo of Isleta
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In the American Southwest, many dams operated to divert water for irrigation have an unwanted passenger: river sediment. The Isleta Diversion Dam, located on the Rio Grande just south of Albuquerque, New Mexico, is no exception. Since the dam's completion in the 1930's, it has delivered water to tribal members of the Pueblo of Isleta. As the Isleta Diversion Dam nears its 100th birthday, sediment often clogs the two diversion canals that the structure feeds: the Belen Diversion Canal to the west, and the Peralta Diversion Canal to the east.

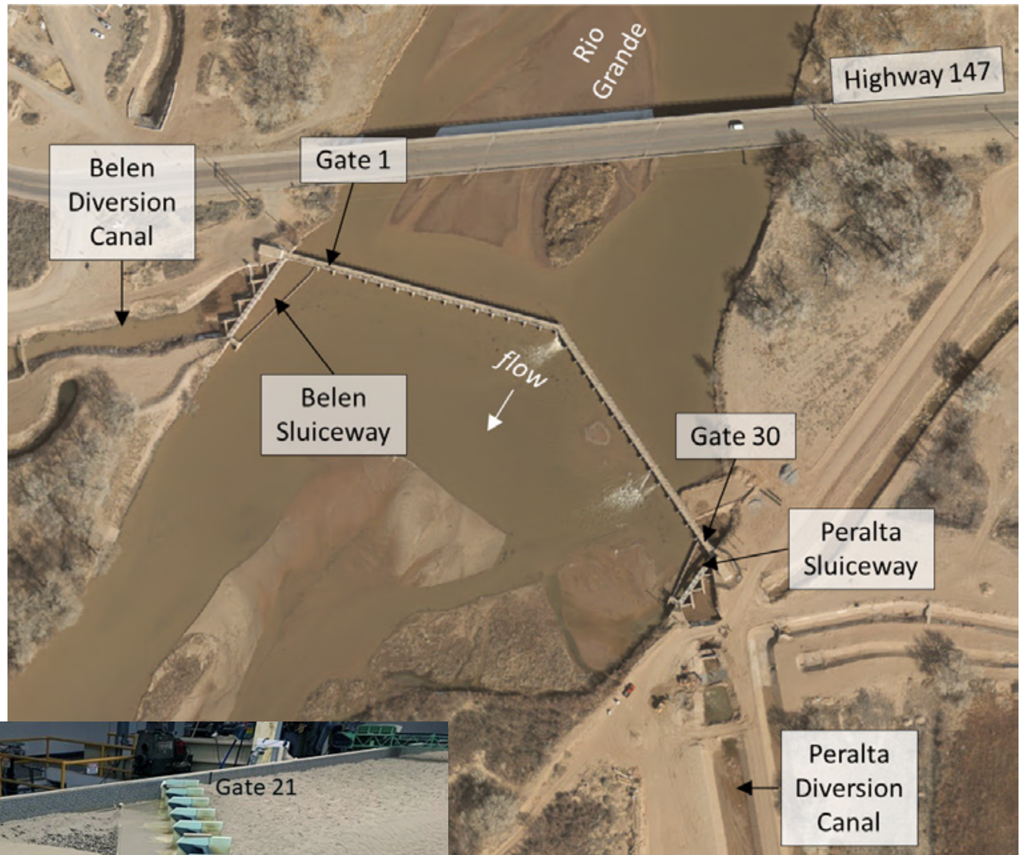
While current management involves the physical removal of sediment with dredging, predominantly on the east side, there is hope for a more sustainable solution. With the help of a scaled physical model built in the Bureau of Reclamation's Hydraulics Laboratory and SRH-2D, Reclamation is in a unique position to make management recommendations to decrease the amount of sediment diverted from the river to the irrigation canals.

Numerical modeling on the Isleta project has leveraged SRH-2D's ability to perform simulations of river hydraulics and the associated movement of riverbed sediments. The most recent version of the software also includes code that models the passage of sediment through flow control gates—an important numerical capability when considering a structure like the Isleta Diversion Dam, which has a total of 30 river gates.

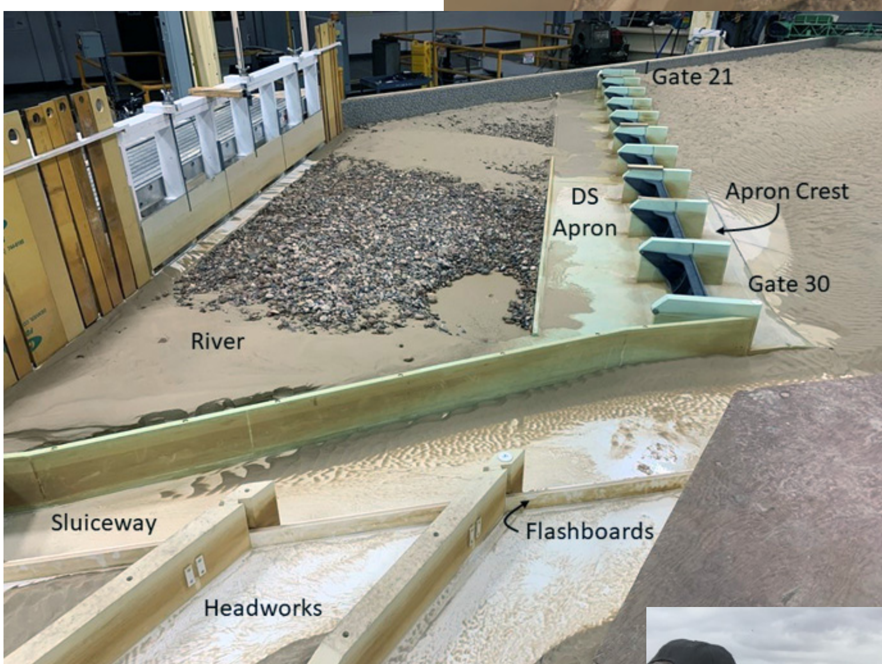
Reclamation has developed two separate numerical models of the dam in SRH-2D: (1) a lab-scale model representing the ten-gate segment of the dam constructed in the Hydraulics Laboratory, and (2) a full-scale model of the entire dam and its two diversion structures based on historical construction drawings and available field data.

Simulation of mobile-bed modeling with the lab-scale SRH-2D model provided an excellent opportunity for model calibration, using data collected during physical model runs in the Hydraulics Laboratory. Specifically, records of sediment deposition rates in key parts of the physical model could be compared to the rates modeled in SRH-2D. Turning model parameter knobs such as surface roughness made it possible to bring the numerical model output into close agreement with the lab's measured results. This yielded an understanding of the SRH-2D parameters and values that best characterized the Isleta Diversion Dam and Rio Grande reach within the numerical model's boundary. Ultimately, a series of mobile-bed runs with the full-scale model in SRH-2D will be able to show sediment deposition patterns under different gate operations.

Working with the dam tenders who operate the Isleta Diversion Dam gates year-round, Reclamation will be able to provide guidance on the locations and numbers of gates to be operated under different flow conditions. Moving forward, SRH-2D riverbed sediment simulations may be able to help inform sediment management for other diversion dams. The comprehensive approach of the work on the Isleta Diversion Dam has laid a strong foundation on which to continue to build.



The Isleta Diversion Dam spans the Rio Grande and includes 30 river gates, and two diversion structures, one on the west bank, and one on the east bank, to provide irrigation water to the Pueblo of Isleta. (Reclamation, March 2022)



Construction of the eastern portion of the Isleta Diversion Dam (1/8 scale) by Reclamation's physical modeling Hydraulics Laboratory represented key elements incorporated into the SRH-2D numerical model. (Reclamation, C. Byrne, December 2020)

The river gates of the Isleta Diversion Dam are still operated manually with a "mule" and team of dam tenders. (Reclamation, C. Gombert, May 2023)

Sediment Effects on River Restoration Habitat Features: Physical Processes and Guidelines for Effective and Sustainable Design, Planning, and Maintenance

By Drew Baird, P.E., Ph.D., BC.WRE, D. Nathan Bradley, Ph.D., & Nathan Holste, P.E., M.S.; with partners, Dave Gaeuman (Yurok Tribe), Michael Dixon, James Lee, Rod Whitler, John Hannon, Ann Demint, Robert Padilla, & Ari Posner
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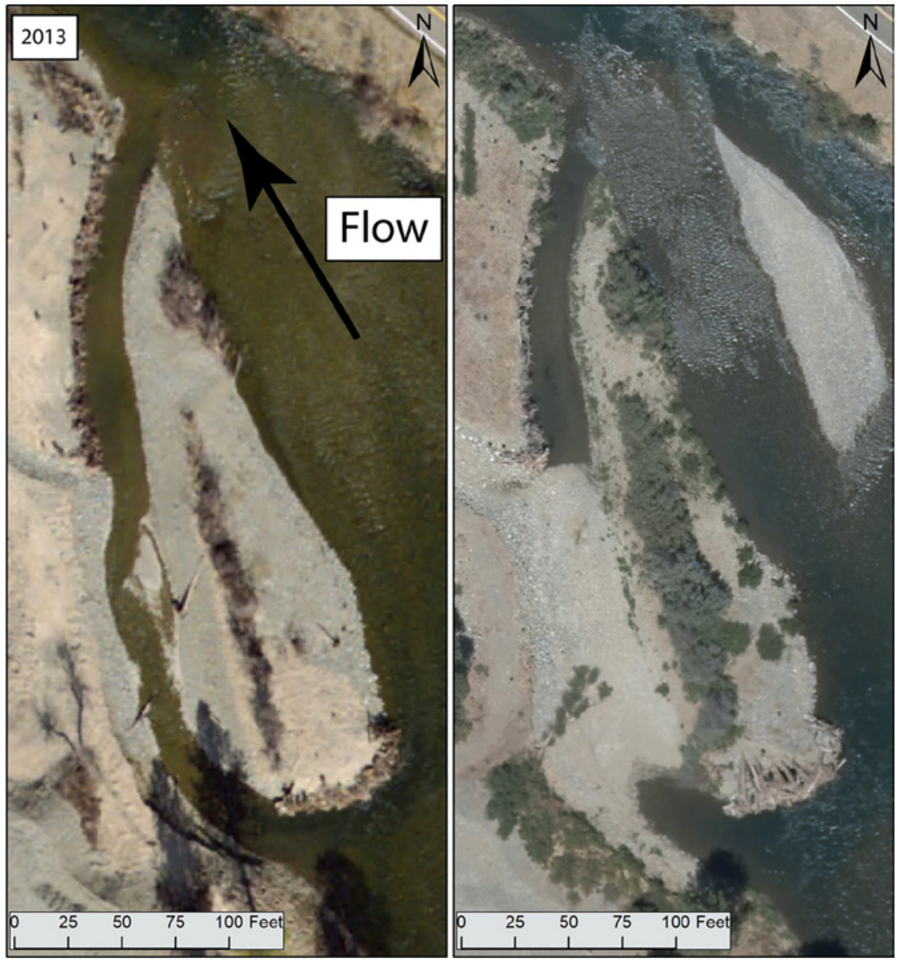
Within the Bureau of Reclamation's (Reclamation) species recovery programs, side channels, backwaters, channel widening, and bank line lowering measures are commonly constructed. These restoration features focus on threatened and endangered fishes that rely on slower and shallower flow within vegetated floodplains for certain critical life stages. Reduction in flood magnitude and frequency because of dam construction, removal of wood and riparian vegetation, channelization, and flood control measures such as levees has caused habitat reduction. This trend toward more uniform, less complex channels has decreased floodplain connectivity, leading to fewer opportunities for juvenile rearing beyond the main channel. Therefore, restoration features are being constructed across various river types to provide habitat for threatened and endangered aquatic species and their critical life stages.

Newly constructed habitat features that includes several connections to the main channel.

Constructed side channel after several years of inundation during spring runoff and monsoon thunderstorms.

Endangered species programs across Reclamation have implemented restoration projects on rivers ranging from the Trinity River in California to the Rio Grande in New Mexico. Restoration measures are determined from habitat suitability studies that identify the types of habitat deficiencies affecting particular river systems. Construction of side channels, backwaters, channel widening, and bank line lowering re-establishes these lost habitats, but over time habitat benefits change. Since these habitat types have slower velocities with shallower depths than the main river channel, river and tributary derived sediments tend to deposit over time reducing their habitat benefit.



A constructed side channel at the Upper Junction City site after construction in 2013 (left) and in 2017 (right). Substantial deposition occurred at the upstream (south) end of the side channel.

To maximize long term habitat benefits, program managers need guidelines to plan, design, construct, adaptively manage, and maintain habitat features to reduce effects of sediment deposition. This research goes beyond using historical observations to understand how these features evolve over time. Applying sediment transport modeling provides knowledge of the physical processes governing sediment effects to effectively plan and design habitat restoration. Guidance for restoration planners and designers on feature selection, topography, hydraulic geometries, and locations to maximize habitat restoration sustainability are being developed.

Our research is being carried out on two river systems that fall within Reclamation-funded endangered species recovery programs: The Trinity River, and the Middle Rio Grande. These rivers span a range of size, flow conditions, sediment regimes, and geology. We are using the well-established state of the art, two-dimensional (2D) flow and sediment transport model, the Sedimentation and River Hydraulics Two-Dimensional Model (SRH-2D). The 2D model enables flow and sediment to be routed into side channels, and lowered bank lines to determine characteristics that maximize sustainability.

Our research team assembled existing data and made additional field measurements on the Middle Rio Grande in 2022. The sand bed site, located on the Middle Rio Grande is near Escondida, New Mexico on the west side of the river and contains a high-flow side channel with several connections to the main channel. On the Trinity River, existing data was located to model a series of two side channels and floodplain lowering. SRH-2D numerical modeling has begun on the Trinity River site near Upper Junction City. The left bank and right bank side channels have experienced sediment transport and deposition during the 2015 and 2016 water years. Initial modeling indicates that the areas of deposition in the model are similar to the observed locations.

This research will provide planning and design guidance based on the understanding of sediment transport and deposition processes within side channels and floodplain lowering projects. Guidance will include changes that can be made to past approaches to reduce sediment deposition thereby increasing restoration project sustainability.

Numerical Modeling of Reservoir Drawdown Flushing

By Victor Huang, P.E., Ph.D.
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The Bureau of Reclamation's (Reclamation) Sedimentation and River Hydraulics Group has developed and applied numerical models to study drawdown flushing in reservoirs. Numerical models can be used to determine the optimal flushing operation, informing the timing, sequence, duration, and release rate of water.

As our infrastructure ages and water storage and supply become increasingly threatened, reservoir sedimentation is impacting Reclamation facilities. Drawdown flushing is one technique that can be used to remove sediment from small, gorge-shaped reservoirs. This technique has been effective in extending infrastructure lifespan, especially in reservoirs with water storage that allows for sufficient water release.

Two numerical Sedimentation and River Hydraulics Models (SRH)—SRH-1D (One-Dimensional) and SRH-2D (Two-Dimensional)—were used to study reservoir drawdown flushing at the Paonia Reservoir. This Reclamation facility is located on Muddy Creek, a tributary of the North Fork Gunnison River in western Colorado. The reservoir is approximately 3 miles long and 0.2 miles wide. Based on a bathymetric survey of the entire reservoir conducted in June 2013, the estimated average annual rate of sedimentation has been 101 acre-feet per year.

A photo of Paonia Reservoir after a reservoir drawdown: a channel that incised through a portion of the reservoir sediments is visible.

Nearly 25% of the reservoir's original capacity of 20,950 acre-feet has been lost to sediment deposition. This high rate of sedimentation, combined with the reservoir's geometry, made it a good fit for numerical sediment transport modeling simulations designed to optimize operations to flush sediment out of the reservoir. These simulations also support our understanding of the challenges involved with modifying operational features required to best perform drawdown flushing.

As part of this work, SRH-1D was updated to incorporate reservoir operations rules for the simulation of operations at Paonia Reservoir. In addition, the SRH-1D model was calibrated using reservoir survey and sediment measurements from 2013 to 2015 and was applied to short-term and long-term sediment modeling simulations. Figure 1 shows the reservoir inflow and outflow in year 1 of a 20-year simulation under a different reservoir operation strategy than presently used. Currently, with no flushing operations in place, the reservoir trap efficiency is estimated to be around 95%. Figure 2 shows the cumulative reservoir sediment deposition volumes. In 20 years, spring flushing with a pessimistic (low runoff volume) forecast (90% non-exceedance) can reduce the trap efficiency to 29%, with 2.77 million m^3 (2248 acre-ft) incoming sediment and 0.81 million m^3 (656 acre-ft) deposited in the reservoir (figures shown on next page).

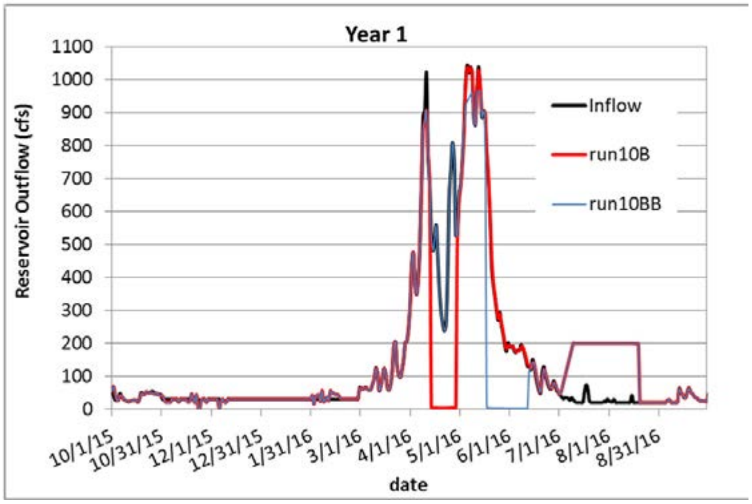


Figure 1.—SRH-1D long-term simulation of reservoir inflow and outflow in year 1 under different reservoir operation strategy.

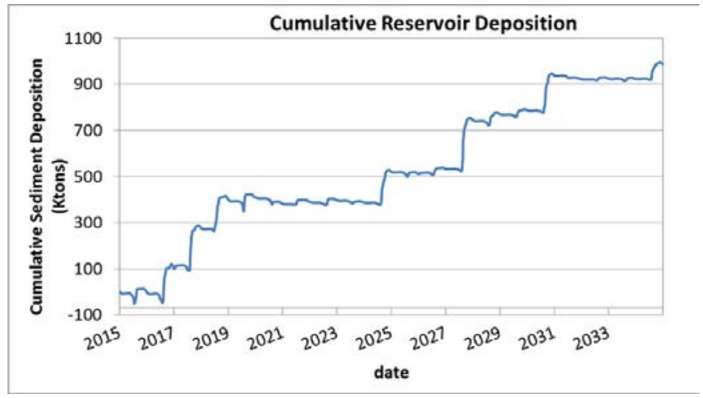
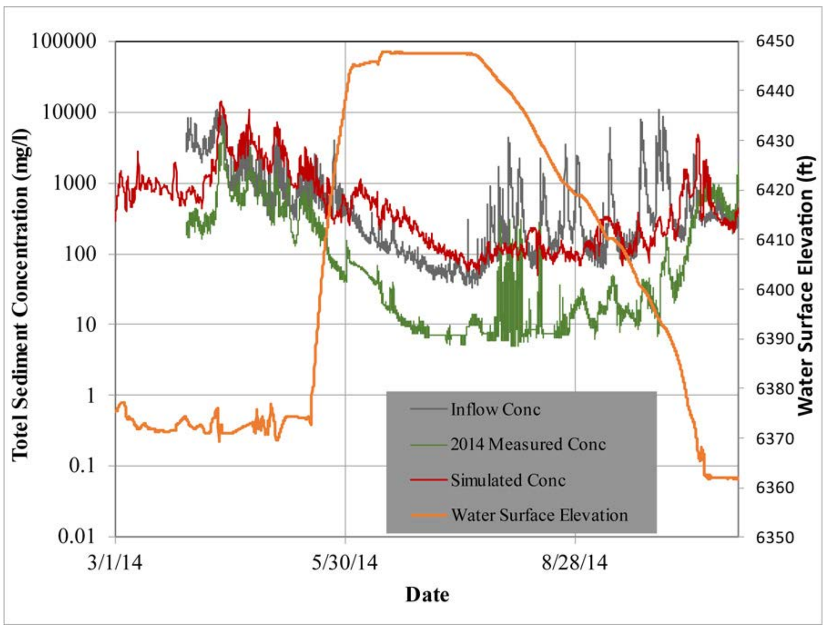


Figure 2.—Cumulative reservoir sediment deposition of long-term simulation.



SRH-2D was also calibrated using the sediment release concentration and load data from the 2014 reservoir drawdown flush. Figure 3 shows the calibrated sediment release concentration compared to the observed data.

Figure 3. SRH-2D simulated (red) and observed (green) suspended sediment concentration (mg/l) showing calibration of a drawdown flushing event at Paonia Reservoir.

Presently, SRH-2D is being used to study the efficiency of reservoir drawdown flushing in different types of reservoirs. Figure 4 shows different hypothetical reservoir shapes, created from the original Paonia Reservoir. As this research looks at drawdown flushing for different reservoir shapes, it could help dam operators better understand whether sediment flushing is suitable for a given Reclamation facility. If it is, this research should also provide guidance to help determine the timing and efficiency of sediment flushing.

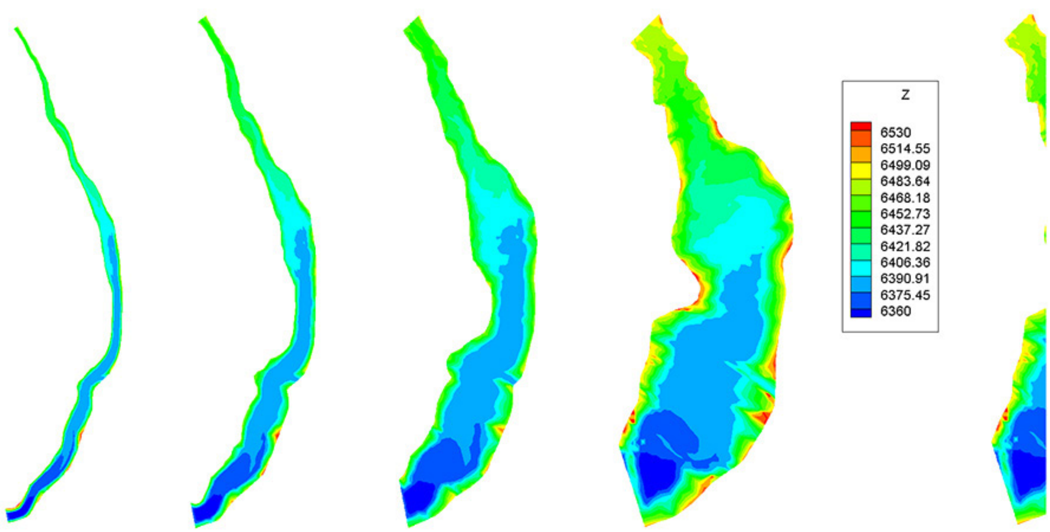


Figure 4.—Different reservoir geometries to be tested for drawdown flushing suitability and efficiency.

Predicting How Riparian Vegetation Affects Hydraulics and Sediment Transport

By Daniel Dombroski, P.E., Ph.D.; with partners, University of New Mexico, Massachusetts Institute of Technology, & U.S. Army Corps of Engineers
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The Bureau of Reclamation's (Reclamation) mission to manage, develop, and protect water and related resources in an environmentally and economically sound manner is more challenging than ever due to increasing and often competing demands. The Science & Technology Program has provided a key role in the advancement of tools to address these challenges in a comprehensive manner. Predicting the effects of riparian vegetation on hydraulics and sediment transport within managed riverine systems is a growing need due to the increasing priority of maintaining ecosystem function while sustaining water conveyance. Development of riparian modeling tools are motivated by a need to quantitatively address questions such as:

- **Conveyance:** How will re-vegetation actions within restoration projects affect flood risks?
- **Sediment:** How do varying riparian vegetation characteristics associated with restoration actions influence sediment transport dynamics within the system?
- **Habitat:** How will restoration actions impact quality, quantity, and distribution of habitat?
- **Management:** How do reservoir operations affect vegetation recruitment and survival in the downstream riparian corridor?

These questions are particularly relevant to regions of the Western U.S. where multi-benefit water projects (i.e., projects that enhance flood safety, irrigation, wildlife habitat, and public recreation) are legally mandated components of regional and state-wide planning and funding efforts. These multi-benefit projects can be critically dependent on modeling of riparian vegetation and the effects on hydraulic conveyance and sediment transport.

Why is riparian vegetation important?

Riparian vegetation includes all the leaf and branch coverage along a stream that bring welcome shade to keep stream temperatures cool in the summer and moderate in the winter.

To address these needs, a modeling suite has been developed for simulating vegetation lifecycle and the effects on hydraulics and sediment transport in the riparian environment. The models are based upon the Sedimentation and River Hydraulics Two-Dimensional Model (SRH-2D) (Lai 2010) which contains a two-dimensional flow and mobile bed sediment transport model. The capabilities of the modeling suite are comprised of two distinct components:

- A vegetation-hydraulic solver that uses measured vegetation parameters and calculated hydraulic variables to estimate a spatially-distributed, dynamic roughness coefficient that is coupled to the simulated hydrodynamics and sediment transport calculations through the bed shear stress.
- A cumulative stress lifecycle algorithm that predicts the establishment, growth, and removal of riparian vegetation based on measured parameters and calculated hydraulic variables.

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Measuring riparian vegetation characteristics along the banks of the San Joaquin River in California. The monitoring data was used to inform studies modeling the effects of restoration actions on hydraulics and sediment transport.

– Predicting How Riparian Vegetation Affects continued

The components of the riparian vegetation modeling suite have been developed and enhanced through a series of individually funded projects, the utility of which have been demonstrated at the project level: Platte River Recovery Implementation Program (Murphy et al. 2006), San Joaquin River Restoration Project (Dombroski 2017; Chaulagain, et al. 2022; Dombroski 2014). Trinity River Restoration Program (Dombroski 2016) Rio Grande Bosque Del Apache Realignment Project (Dombroski and Holste 2023). The model development has leveraged in-kind support through mutually-beneficial collaborations with other agencies and institutions, including the U.S. Army Corps of Engineers, Massachusetts Institute of Technology, and University of New Mexico.

Take a Deeper Dive —

Dombroski (2023) provides a background of development for the modeling framework, a review of literature on the topic, and the theory upon which the algorithms are developed. It provides conceptual guidance on how the modeling tools may be effectively applied and review common questions associated with challenges in managing water and riparian corridors in the West.

Large Wood Structure Representation in a Two-Dimensional Hydraulic Model

By Yong Lai, Ph.D., & Michael Sixta, P.E., M.S.; with partners, Reclamation's California-Great Basin Region, Reclamation's Columbia-Pacific Northwest Region, Federal Highway Administration, & Taiwan Water Resources Agency
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Large Wood Structures (LWS) have been widely used in stream and watershed restoration projects due to the many ecological benefits they offer. Today, LWS are being incorporated into project designs more frequently than ever before. The ability of LWS to effectively create dynamic, high-integrity aquatic and riparian habitats has led many regulatory agencies to recommend large-scale reintroduction and reinvigoration of large wood regimes. In addition, LWS have been adopted by numerous Reclamation projects for habitat restoration, channel stabilization, and fish passage purposes.

Numerical hydraulic model results are instrumental in choosing structure type, placement, design parameters, as well as determining its impact to stream morphology, safety and risk, and overall benefit. It has been shown that developed three-dimensional (3D) modeling tools can be used to predict flow patterns around complex LWS reliably and accurately (Lai et al. 2021). However, there are practical limitations with 3D modeling (knowledge/spatial scale/computing resources) that makes its use unpractical for most restoration projects, primarily the prohibitively long computing times and the complexity in developing accurate 3D models.

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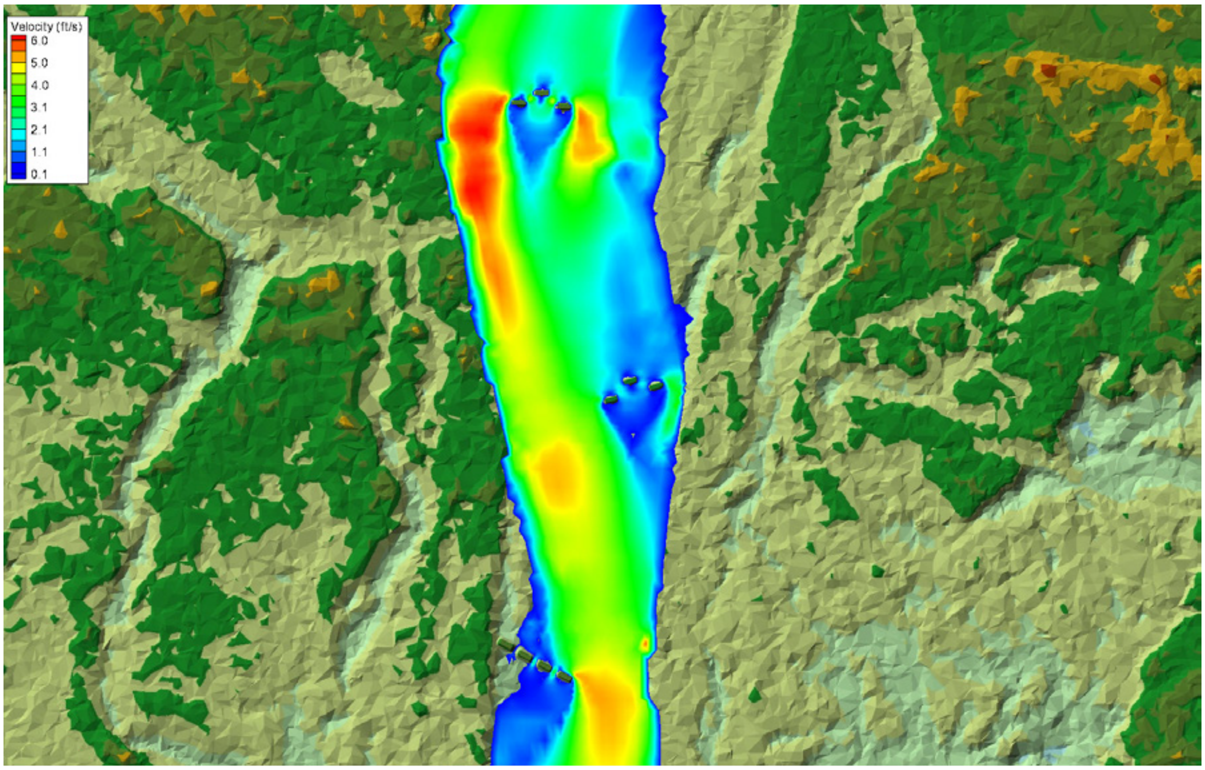
LWS installations on Dry Creek near Healdsburg, California.

– Large Wood Structure Representation continued

It is a consensus in the hydraulic community that two-dimensional (2D) models are the more practical models to use for restoration projects involving the use of LWS. The 3D model limitations are much less prominent in the 2D hydraulic modeling framework; and 2D models continue to be the tool of choice for restoration project design and analysis (Shields et al. 2017). However, accurately representing the LWS geometry, simulating structural evolution, and predicting LWS impacts through 2D modeling are challenging and remain unresolved at present.



Predicted 2D velocity magnitudes surrounding designed LWS.

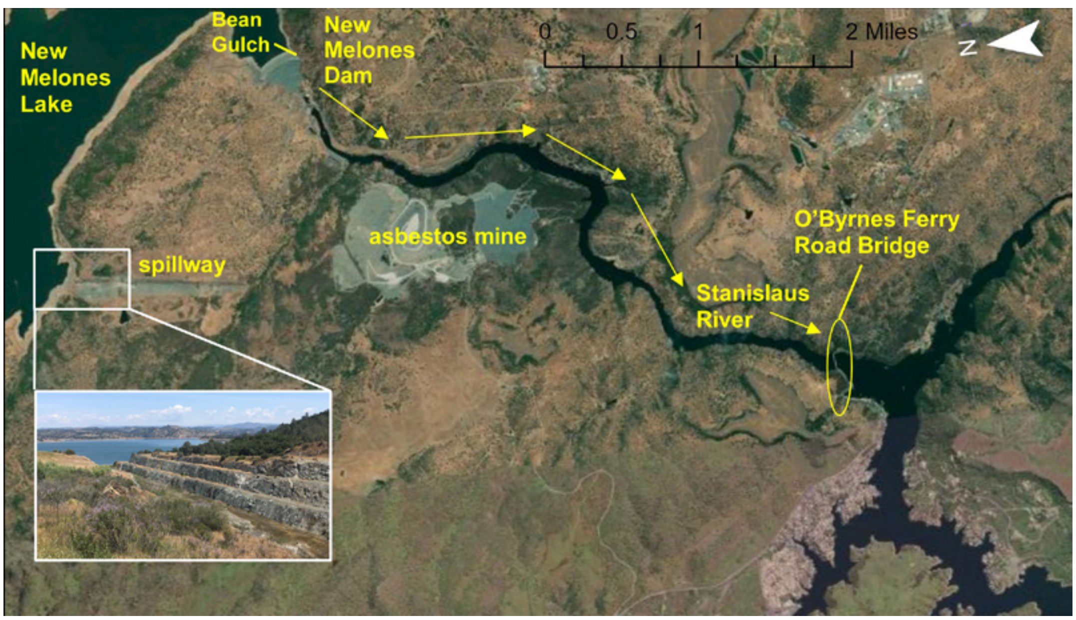
The current practice is to incorporate LWS in a 2D model using a simplified ad hoc approach – by artificially bumping up the flow roughness coefficient and/or representing LWS through an impervious blocked obstruction. Previous Bureau of Reclamation (Reclamation) research, sponsored by the Science & Technology Program, had tried to assess the impact and effectiveness of LWS using these simplified techniques through the Sedimentation and River Hydraulics Two-Dimensional Model (SRH-2D). It was concluded that the existing approaches were both inaccurate and inconsistent, resulting in unreliable design data.

Currently, a new research effort has started through Reclamation's Research & Development Office to develop innovative methods to represent LWS within SRH-2D. This work includes developing more general mathematical expressions and new modeling techniques and guidelines for LWS representation in a 2D model setting. The goal is to develop a new SRH-2D model that may be applied to streams with many LWS over a large spatial extent while maintaining an accurate and efficient modeling process. In addition, the project will also generate modeling guidelines that will be utilized to guide 2D model development, validation, verification, and validation for future users.

Modeling Spillway Erosion at New Melones Dam, California

By Aaron A. Hurst, Ph.D., & Melissa A. Foster, Ph.D.; with partners, Dam Safety Office (Reclamation)
ahurst@usbr.gov, mfoster@usbr.gov

The recent spillway erosion event at Oroville Dam in California garnered high news coverage, public interest, and highlighted the importance of understanding the complexities of spillway erosion incidents (Koskinas, et al. 2019). Spillway erosion is commonly associated with the potential for dam breach and massive flooding, which can be fatal for downstream communities. However, more often, spillway erosion events don't breach the dam, but do erode large volumes of sediment and/or bedrock that greatly impact the downstream system.



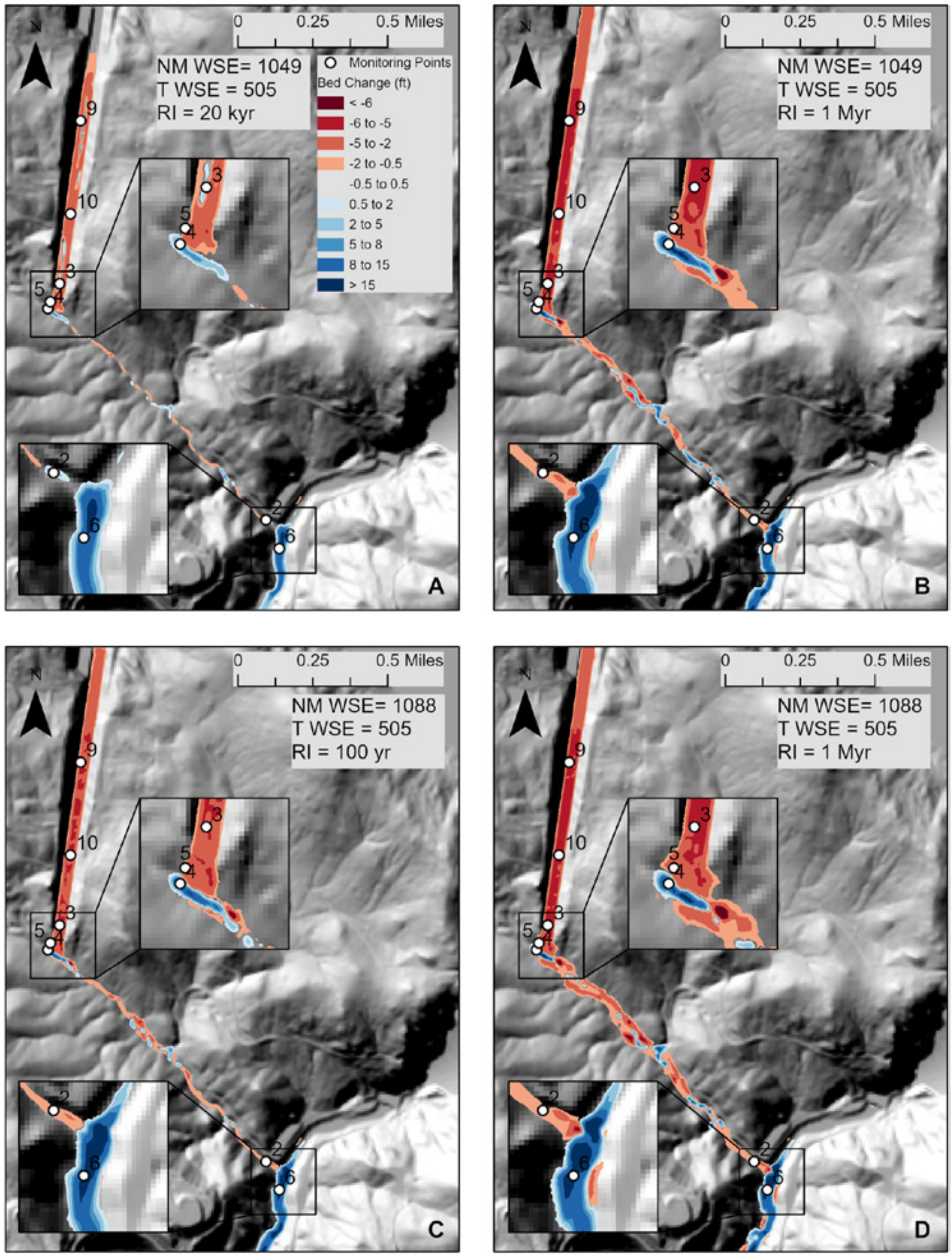
Detailed site map of the study area using satellite imagery from ESRI ArcGIS. The inset figure is a photo taken from the hillside adjacent to the spillway, looking upstream. (Reclamation, M. Foster)

The Bureau of Reclamation's (Reclamation) Dam Safety Office contracted the Sedimentation & River Hydraulics Group at Reclamation's Technical Service Center to explore the incident risk associated with unlined spillways at a pilot location at the New Melones Reservoir in California. This spillway is unlined and comprised of a mix of soft and hard bedrock material overlain by a thin layer of sediment and spillway-excavation debris. The spillway connects the New Melones Reservoir to Bean Gulch, a tributary of the Stanislaus River, which enters the river 4 miles upstream from Tulloch Reservoir. This project is not a dam failure investigation, but rather an attempt to understand potential sediment transport in the spillway, erosion of the underlying bedrock, and deposition of the eroded material downstream at extremely large flood events (up to the 1,000,000-year recurrence interval flow).

Existing spillway erosion models are not able to represent the combination of rock and sediment in the New Melones spillway. Thus, we applied a novel approach that combined three separate numerical models: (1) Reclamation's hydraulic model, the Sedimentation and River Hydraulics Two-Dimensional Modeling (SRH-2D), to model the sediment transport and deposition in the spillway and downstream river, (2) the Hurst one-dimensional (1D) Erosion model (H1DE) to model bedrock erosion, and (3) the Annandale 2D Erodibility Index model to map at-risk areas in the spillway.

The mobile bed modeling function of SRH-2D was leveraged to track local erosion and deposition throughout our model domain. This was a unique application of mobile bed modeling with SRH-2D, as the magnitude of modeled spillway flows far exceed the typical application of the mobile-bed model. This project highlights the capability of SRH-2D to perform under a vast range of flows while maintaining model stability.

The model results indicate that sediment erosion is mostly constrained to the spillway and Bean Gulch and that most sediment deposition is in the Stanislaus River near its confluence with Bean Gulch. Minimal sediment deposits approach Tulloch Reservoir at the downstream end of the model domain. The sediment cover on the spillway was completely removed for the majority of our modeled flow scenarios. Once sediment is removed, the underlying rock is susceptible to erosion, predominantly by rock plucking. The Annandale 2D Erodibility Index Method indicated that erosion was more likely in the intensely-fractured and softer rocks, concentrated at the downstream end of the spillway. Our 1D analysis using the H1DE model showed that even in zones at risk of erosion, the overall magnitude of incision was small and isolated to the downstream end of the spillway. Thus, we confirmed that a spillway erosional event at New Melones Dam does not pose a risk for dam failure or breach.



Erosion and deposition results from SRH-2D. Negative values (red) are erosion and positive values (blue) are deposition. For the model runs shown here, erosion is mostly occurring within the spillway and Bean Gulch and deposition occurs at the confluence with the Stanislaus (NM WSE: New Melones Reservoir elevation, T WSE: Tulloch Reservoir elevation, & RI: recurrence interval for the modeled flow).

This project provided a fortuitous opportunity to run extensive sensitivity analysis in SRH-2D to determine the best practices of modeling sediment transport associated with extreme events, including testing sediment transport modules using different sets of governing equations, determining the model sensitivity to varying sediment thickness and grain size distributions, and the effect of model mesh size and model timestep on model stability and the timeseries of model results.

Our results showed that the spatial patterns of erosion and deposition were generally consistent. However, hydraulically complex regions were sensitive to the timestep and transport model choice and required iterative model runs to home in on the proper timestep or mesh size to produce consistent results. This is an important consideration for future applications of SRH-2D to large flood scenarios and warrants further investigation.

Divide and Conquer Prize Competition

Faster Modeling of Large-Scale River Hydraulics

By Jennifer Bountry, P.E., M.S., Yong Lai, Ph.D., & Ben Abban, Ph.D.
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Reclamation partnered with the Federal Highways Administration Office of Innovation Implementation – Resource Center, NASA Tournament Lab, & Freelancer.com on this competition.

Prize competitions spur innovation by engaging a non-traditional, problem-solver community to help Reclamation tackle some of the most persistent science and technology challenges. We recently hosted the Divide and Conquer prize competition to find solutions that significantly improve the execution speed of large-scale river hydraulics (SRH) numerical models. Divide and Conquer in the computer science realm means breaking down a problem into two or more sub-problems until the solution becomes simpler—and faster—to solve.

The Sedimentation and River Hydraulics Two-Dimensional Model (SRH-2D) has a robust and reliable numerical model suite for simulating hydraulics, sediment erosion, transport, and deposition in rivers and reservoirs. However, the current algebraic linear equation solver used in the models can take more than 50% of the total execution time and can only run on a single CPU core on a PC, limiting the computing speed. As a result, applications are typically limited to cases with relatively short to medium time duration and limited spatial scales. As climate changes, endangered species requirements, and multi-faceted water uses expand complexity of operations at Reclamation's facilities, there is an increasing demand for addressing questions related to large river systems over decadal time periods that would benefit from higher computing power. Shortened run-times would also benefit other model uses such as complex sediment routing through diversion gates, erosion prediction around bridge piers, post-wildfire water and sediment routing at watershed scales, and other intensive modeling questions.

Reclamation contracted with NASA Tournament Lab and Freelancer to host Divide and Conquer. Starting in September 2021, solvers competed in two phases with final winners announced in June 2023. In Phase 1, $100,000 was awarded to four (out of six) independent competitors for creating linear equation sparse matrix solvers (LESMS) and demonstrating efficient speedup using multiple CPU cores or GPU hardware. During Phase 2, five competitors went on to incorporate their solvers into SRH-2D and successfully run practical cases in multi-core or GPU mode. A total of $255,000 was awarded in Phase 2 to four solutions that demonstrated the potential for significant speedup of SRH-2D.

Some integration and technology transfer is needed to get these innovative solutions into practice. A new facilitated adoption program within Reclamation's Research & Development (R&D) portfolio is helping to address this need by funding a new effort to formally integrate the Divide and Conquer solutions and to develop and provide training for Reclamation users over the next two years.

Divide and Conquer is an exciting example of how prize competitions can improve our capabilities to meet our mission at Reclamation. Senior Advisor for Research and Development, Levi Brekke, noted, "The results of this competition show promise that we can accelerate these models and provide results to decision-makers in a quicker, more cost-effective manner."

Thank you to all the competitors for your participation and efforts, and congratulations to the final Phase 2 winners:

First Place: $115,000

Christophe Choquet, Vanves, Ile de France, France – implemented a GPU-accelerated Parallel Smoothed Aggregation algorithm with the use of previous simulation time steps as the input of the finest multi-grid level. To speed up the overall process, most of the calculations between solver calls were implemented in OpenCL with a Fortran binding. By using a parallel solver, processing intermediate calculations on the GPU, and reducing CPU to GPU transfers, speedup in the 30x to 60x range was obtained.

Second Place: $85,000

Xiaofeng Liu, State College, Pennsylvania – developed a single unified code which can run in one of three modes: serial, MPI, and OpenMP. User experience of the parallel version of SRH-2D is the same as the original serial version, which enables a painless transition. The solution leverages high-performance linear equation system solvers in the Hypre library, which is designed for massively parallel computers.

Third place: $45,000

Mahdi Esmaily, Ithaca, New York – presented a solution using MPI technology and a graph partitioning algorithm developed from scratch to ensure that all components of SRH were parallelized. A dedicated library was developed for specialized calls to the MPI library to simplify the parallelization process while ensuring backward compatibility.

Fourth Place: $10,000

Zhi Jian Wang and Zhaowen Duan, Lawrence, Kansas – used domain decomposition and MPI to parallelize the model on multiple CPU cores. The linear solver used is a conjugate gradient squared solver with incomplete LU decomposition preconditioning.

SRH-2D User Community and Partners

> *"SRH-2D has been an essential tool for our river restoration work in the Central Valley. We use it regularly to develop salmonid spawning and juvenile rearing habitat designs in the Sacramento River and surrounding tributaries. SRH-2D helps us evaluate creative solutions to optimize habitat gains for our struggling fish populations."*
>
> — Jenna Paul, Civil Engineer with the Central Valley Project Improvement Act (CVPIA) program for the Bay-Delta Office

> *"I personally prefer the SRH-2D model and SMS interface combination. SRH-2D is a stable modeling platform and SMS provides a custom interface with many unique meshing tools. I have also found SRH-2D output solution files to be user friendly and allow for seamless integration into other GIS based programs, such as ArcGIS Pro, allowing for in-depth analysis of spatial data for design or research purposes."*
>
> — Robert Woockman, Hydraulic Engineer with the Columbia Pacific-Northwest Regional Office

Partnership with the Federal Highway Administration

By Scott Hogan, Federal Highway Administration
Scott.Hogan@dot.gov

What types of FHWA projects utilize the Sedimentation and River Hydraulics Two-Dimensional Model (SRH-2D)?

The Federal Highway Administration (FHWA) is primarily interested in evaluating the detailed hydraulics associated with any potential impacts of the nation's highway system with rivers. In some cases, it is design related (e.g., bridge and culvert crossing designs), and in other cases it may simply be to avoid flooding impacts when roadway improvements or maintenance activities encroach into a floodplain. The FHWA Resource Center provides technical assistance, technology deployment, and training to all State Departments of Transportation (DOTs) in hydraulic design and analysis. Although SRH-2D is not a State DOT requirement, we do recommend it as the best tool for transportation-related hydraulic analyses.

Why SRH-2D?

Prior to SRH-2D, FHWA (and DOTs) primarily used 1D modeling, with some application of an older 2D model (e.g., FST2DH). The FST2DH model was challenging to use because of stability issues and a cumbersome process of developing a successful simulation. In 2013, the FHWA partnered with Reclamation to further develop SRH-2D to provide FHWA with additional 2D model options that incorporate hydraulic structure analysis.

–continued

– Federal Highway Administration continued

FHWA also initiated the development of a custom interface for SRH-2D in the SMS software package. The SRH-2D program was more stable and robust than other 2D model codes. For over 10 years, FWHA and Reclamation have had a very favorable and mutually beneficial relationship. Along with support from Aquaveo (makers of the SMS surface-water modeling system), many new features and improvements have been added to both the SRH-2D program and the SMS user interface.

How has FWHA contributed to SRH-2D training?

FHWA is ultimately interested in helping State DOT hydraulic engineers and their consultants to efficiently and effectively apply 2D hydraulic modeling to transportation hydraulic projects. Although 2D modeling has been available to practitioners since the late 1980s, until the past 5–7 years, it has not been practical for routine use. Between the code and PC processor speed limitations, the simulation times were not reasonable. In addition, the lack of a user interface and instructions on how to perform 2D hydraulic modeling simulations made application challenging. Both obstacles have changed significantly in recent years, and much of the advancement is a result of the Reclamation/FHWA partnership.

Reclamation has continued to improve the SRH-2D code capabilities and speed, while FHWA continues to develop the user interface and provide training resources for new and existing users.

Continued Learning for 2D Model Users–

FHWA started a 2D Hydraulic Modeling User's Forum to provide updates on the latest SMS and SRH-2D developments, 2D modeling best practices, and general tips and tricks for using SMS. Since 2015, 2D forum webinars are offered about every two months, and recording links are available to access previous webinars.

FHWA-developed resources include:

- 2D Hydraulic Modeling Reference Document
- 2D Hydraulic Modeling Training Course (NHI 135095)
- Numerous SRH-2D/SMS training tutorials
- YouTube training videos (2017 and 2020)
- SRH-2D Sediment Transport Videos

Partnership with the Taiwan Water Resources Agency

By Kuowei Wu, Senior Engineer, Water Resources Agency, Department of Economics, Taiwan
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History of the SRH-2D Collaboration

When the development of the Sedimentation and River Hydraulics Two-Dimensional Model (SRH-2D) started at U.S. Bureau of Reclamation (Reclamation) in 2004; a collaborative agreement for technical assistance in water resources was quickly established between the Taiwan Water Resources Agency (TWRA) and Reclamation. The TWRA needed an advanced and reliable 2D model for river and reservoir projects—and in 2005 the "Appendix 8 Agreement" was signed to establish a joint development of the model.

The Appendix 8 Agreement continues today and to develop state-of-the-art techniques using SRH-2D for TWRA areas of interest, including: river hydraulic and sediment processes, soft bedrock erosion, riverbank erosion, reservoir turbidity current processes, river basin runoff, soil erosion and sediment delivery to reservoirs, and estuary and near-shore coastal processes. In the next five years, TWRA plans to integrate all SRH numerical models (1D, 2D, 3D, watershed and coastal models) into a single modeling platform suitable for Taiwan's project evaluation of integrated watershed management and adaption planning.

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What types of TWRA projects utilize SRH-2D?

TWRA has applied SRH-2D in the following projects:

- Hydraulics and sediment processes on most major Taiwan river reaches administered by the central government (TWRA)
- 2D hydraulic characteristics of disaster-prone river sections (Sanxia River and Beigang River)
- Soft-rock river bed stabilization analyses (Da'an River, Dajia River, Zhuoshui River, and Bazhang River)
- Extreme typhoon-induced flood risk analyses (Zhuoshui River, Chenyoulan River, and Xiuguluan River)
- Flooding analyses caused by landslide/mudflow (Baishi River and Laonong River)
- River restoration alternatives assessment (Qijiawan Creek)
- Fish habitat index mapping (Da'an River and Bie Creek)
- Sediment sluicing alternatives evaluation at reservoirs for the turbidity currents (Shihmen Reservoir, Zengwen Reservoir, and Wushe Reservoir)
- Design and optimization of river stabilization measures (Zhuoshui River and Qingshui River)
- Data and result extension of physical model results (Density current sluicing test of the Shihmen Reservoir, fundamental experiment of bank scour and protection, structure stability test on Shuiwei embankment in Da'an River)
- Analyses of multi-measure water withdrawal planning (Shirgaon Dam)
- Water diversion facility improvements for agricultural water use (Dajin water intake in Zhuokou River)
- Evaluation of pumping station modification plans (Guangfu Pumping Station and Taliaokeng Pumping Station)
- Hydraulic evaluation of cross-stream structures (new bridge piers of No.74 freeway intersection, Beishi Bridge of Houlong River)

Why SRH-2D?

TWRA was an early partner due to the mode development philosophy that the state-of-the-art technology was researched and developed and practical use in various water resources projects was emphasized. TWRA has gained practical experience of using SRH-2D in the past 18 years; and found the following benefits: (a) model maturity due to years of research and development, (b) continuous technical advancement and model improvements, (c) emphasis of field validation and applications, (d) free availability, (e) superior model stability and robustness, (f) a wide range of functionalities, and (g) good technical support (through FHWA and Aquaveo LLC).

Through active technical collaborations with Reclamation and FHWA, TWRA is adopting SRH-2D as an officially recommended numerical model, used in technical specifications and reference manuals.

How TWRA has contributed to SRH-2D?

In addition to funding contributions, TWRA has made effort to advance SRH-2D in model accuracy, user-friendliness, practical applications, and training.

Under the Appendix 8 program, Reclamation has applied SRH-2D to various projects in Taiwan and the model was validated against the field data collected by TWRA. Additionally, since 2009, TWRA has established a series of internal projects focused on verifying and demonstrating model capabilities and functionalities, ensuring applicability to TWRA projects, and developing training classes. The model development and validation results were presented and published at many international conferences and scientific papers.

TWRA has also conducted a series of SRH-2D training classes in Taiwan and provided technical consultation to Taiwan's users. The model has been applied extensively to projects in Taiwan related to river hydraulic analyses, flood inundation forecast, project alternative evaluation, river erosion and aggradation estimates, instream and cross-stream structural impact analyses, and reservoir turbidity current prediction.

Featured Faces

Yong Lai, Hydraulic Engineer, Bureau of Reclamation

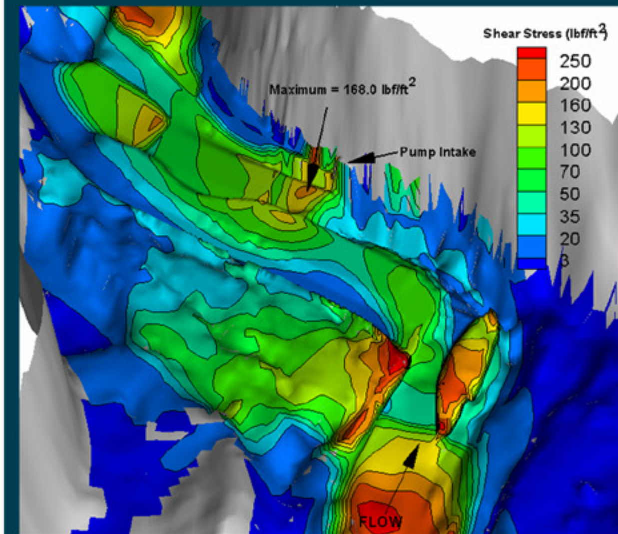
Yong Lai is a hydraulic engineer at Reclamation's Technical Service Center in Denver, Colorado. Dr. Lai obtained his Ph.D. in 1990 at the Arizona State University. He has since been involved in a wide spectrum of research, development, and engineering projects. Prior to joining Reclamation in 2003, his professional career included working for consulting companies, a research institute, and IIHR (Hydroscience and Engineering, the University of Iowa). Dr. Lai has published over 60 journal papers and hundreds of full conference papers in diverse engineering disciplines. Dr. Lai currently serves as an associate editor of the ASCE Journal of Hydraulic Engineering and is a member of the Scientific Advisory Board for several international conferences.

Benjamin Abban, Hydraulic Engineer, Bureau of Reclamation

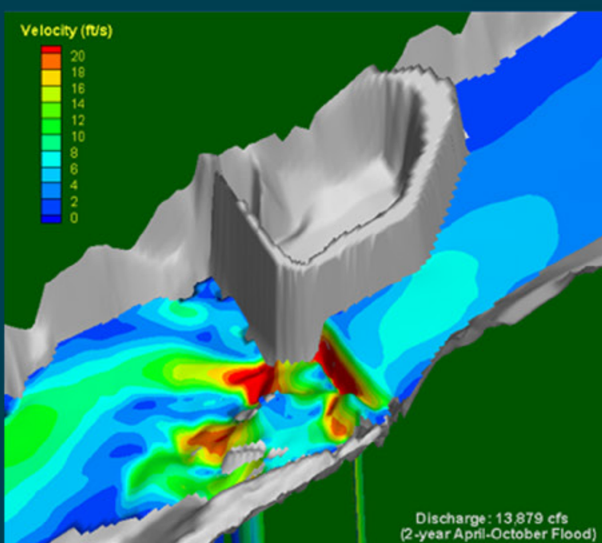
Benjamin Abban is a hydraulic engineer with the Technical Service Center's Sedimentation and River Hydraulics group. He holds a Ph.D. in Water Resources Engineering from the University of Tennessee Knoxville and is a fellow of the National Science Foundation's Geoinformatics for Environmental and Energy Modeling and Prediction (GEEMaP) program at the University of Iowa. He has been involved in the development of several numerical models since 2007 and is presently a co-developer of SRH-2D, focusing on the representation of watershed hydrologic and hydraulic processes in terrestrial, in-stream, and groundwater domains, and the exchange of fluxes between them. Dr. Abban has been involved in numerous riverine and watershed projects over his career and is particularly interested in flux propagation across different spatiotemporal scales and the impacts of both anthropogenic and natural driven changes on the landscape.

Scott Hogan, Hydraulic Engineer, Federal Highway Authority

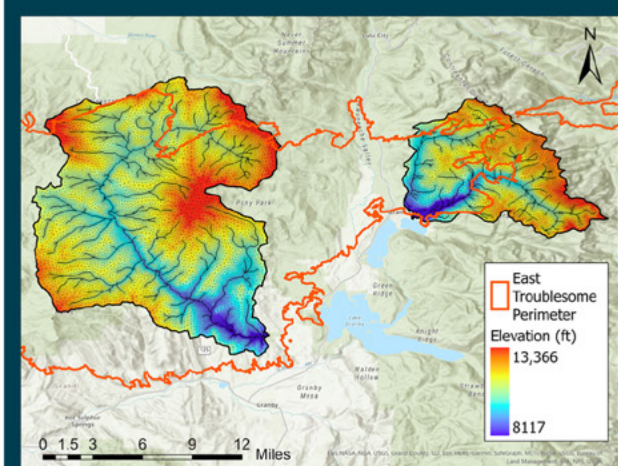
Scott Hogan has spent over 30 years focused on the field of river engineering hydraulics. For the past 16 years, he has worked with the U.S. Federal Highway Administration (FHWA) and was a consulting engineer prior to that. He graduated from Colorado State University with a B.S. and M.S. in Civil Engineering. Mr. Hogan specializes in bridge hydraulic modeling and design, scour analyses, sediment transport, counter measure design, and floodplain analysis. For more than 25 years he has been an instructor for several hydraulics training courses through the FHWA National Highway Institute (NHI). He has a sincere passion for hydraulic engineering and advancing the state of our practice. Mr. Hogan is currently the Geotechnical & Hydraulic Engineering team lead of FHWA's Resource Center.



Elwha Diversion Dam



Savage Rapids Dam



Willow Creek Watershed