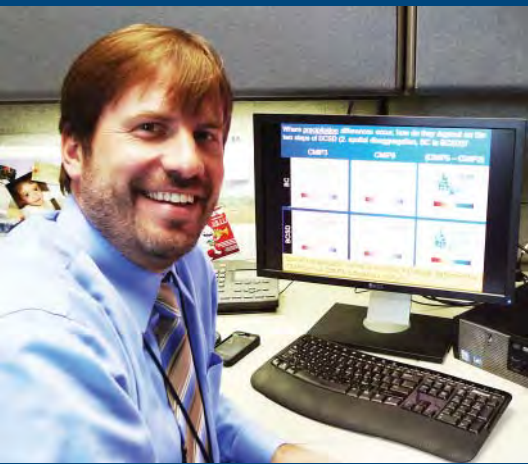
RECLAMATION *Managing Water in the West*

October 2013
Research and Development Office
Newsletter 2014-01

The Knowledge Stream

Climate Variability and Research Updates Issue

Levi Brekke,
Water and Climate Research Coordinator, Ph.D., P.E.



Since March 2011, Levi Brekke has served as our Research Coordinator for Water and Climate. Levi develops research strategy with Federal and non-Federal water and climate science partners, oversees an annual portfolio of climate change and variability research, and serves as our liaison to various climate science organizations, including the U.S. Department of the Interior's Climate Science Centers and the National Oceanic and Atmospheric Administration's Regional Integrated Sciences and Assessments.

—continued in "Featured Faces" on page 9

Levi Brekke, Water and Climate Research Coordinator, Ph.D., P.E. served as principal editor for this issue.

Director's Message

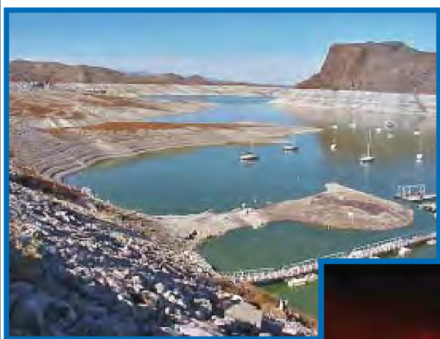
The 2013 fire season in the Rocky Mountains started much too early—in March, historically one of the snowiest month. Soon there were record fires across the West. In July, Secretary of the Interior, Sally Jewell, signed an interagency agreement with the USDA Forest Service to collaborate on fire mitigation in the watersheds that provide so much of the West's water supply. In August, Reclamation projected that the 2014 water delivery to the Lower Colorado River Basin from Lake Powell would be the smallest since the reservoir first filled. September in the Rockies started with record heat. But then a stationary low in the Southwest, coupled with high pressure over the plains, dragged an "atmospheric river" of moisture up from the tropics and slammed it into the Colorado Front Range—and held the fire hose there for 3 days. Up to 21 inches of rain fell in places that would normally not get that much in a year. Widespread floods and flash floods destroyed many roads and homes. Thousands were evacuated and 12 Colorado counties were declared disaster areas.

Is this the future in the West? Drought, fire, AND floods?

Scientists have warned us that a warming atmosphere can lead to longer and more intense droughts. But they have also said that a warmer atmosphere carries more water, potentially producing more intense rainfall. Can we really expect declining snowpack, longer droughts, AND more extreme storms in the West?

This edition of the Knowledge Stream describes Reclamation's dynamic collaboration with climate scientists and water managers from many agencies to help answer these questions and better manage our water projects in the face of changing climate averages and climate extremes.

Curt Brown, Director, Research and Development



(left) Elephant Butte Reservoir, Rio Grande River, New Mexico, during 2003 drought; (middle) West Fork Fire Complex, southwestern Colorado, 2013; (right) Highway 7, South St. Vrain River Canyon, September 2013. Photograph By Helen H. Richardson/The Denver Post.

Print Options and Instructions

This document is designed to be read either electronically via PDF or printed in color or black and white. Please forward it to your colleagues and friends.

You have three options for printing parts or all of this document:

1. Print individual research updates on one sheet of paper, print double-sided for the two-page updates.

2. Print the whole document double-sided, corner stapled on 8.5 x 11-inch paper.

3. For magazine-style, instruct your print professional to print the document double-sided, head-to-head, saddle-stitched on 11 x 17-inch paper.

Your suggestions for improvements are always welcome. Please email them to jakervik@usbr.gov.

Thanks,

Jake Akervik
Communication and Information Systems Coordinator,
Research and Development Office

Contents

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"The process of compiling many comments on large documents often takes 2 months of tedious cutting and pasting. DREW can perform the same task in a few seconds."

Jim Cornwell, P.E.
IT Developer and creator of DREW, Reclamation's Mid-Pacific Region

Jim has many favorite Drews besides DREW, including Barrymore, Brees, Carey, and Bledsoe, to name a few. The only place he can get away from Word, Excel, and Visual Basic is on a boat in the middle of the ocean, as pictured.

DREW: Document Comment Aggregation Tool Saves Reclamation and Partners Time, Money, and Sanity

When documents are sent to stakeholders for review, the job of compiling the comments that come back can be tedious, time-consuming, and expensive. But a Reclamation employee from the Mid-Pacific Region has developed a new tool that is already paying big dividends.

Jim Cornwell developed **DREW**, or **D**ocument **R**eview to **E**xcel **W**orkbook, which aggregates comments made in separate Word documents into a spreadsheet, and then compiles the many individual spreadsheets into one master spreadsheet.

DREW not only saves administrative costs, but puts the data into Excel, a tool that most know and use. This allows data to be quickly and easily mined and sorted without the added time and expense of creating and training people on a new software program.

DREW has been used for National Environmental Policy Act reviews and on the Lake Shasta Water Resources Investigation Project, and is drawing serious interest from Reclamation partners such as the California Water Plan and the U.S. Forest Service.

DREW was developed in Visual Basic and is free for anyone to use. Jim is also working on **BEST**, a **B**udget **E**stimation and **S**cheduling **T**ool.

DREW is available at: www.usbr.gov/mp/mp700/tools.html.

Contact: Jim Cornwell, 916-978-5077, jcornwell@usbr.gov.

Nine Projects Selected to Share $1.1 Million for Desalination and Water Purification Research

More cost-effective and efficient water desalination methods envisioned.

Reclamation Commissioner, Michael L. Connor, announced that nine entities will share more than $1.1 million in awards in support of laboratory and pilot-scale research studies in the field of water desalination and purification. Through required cost shares of up to 75 percent, Reclamation's funding will be leveraged to support a total of $3 million in research.

"Desalination and other advanced water treatment technologies have the potential to provide new water sources for communities," Commissioner Connor said. "This research effort will examine innovative technologies that have the potential to reduce the cost of treating brackish water—helping to create new tools for addressing future water challenges."

Read the full News Release at:
www.usbr.gov/newsroom/newsrelease/detail.cfm?RecordID=44425.

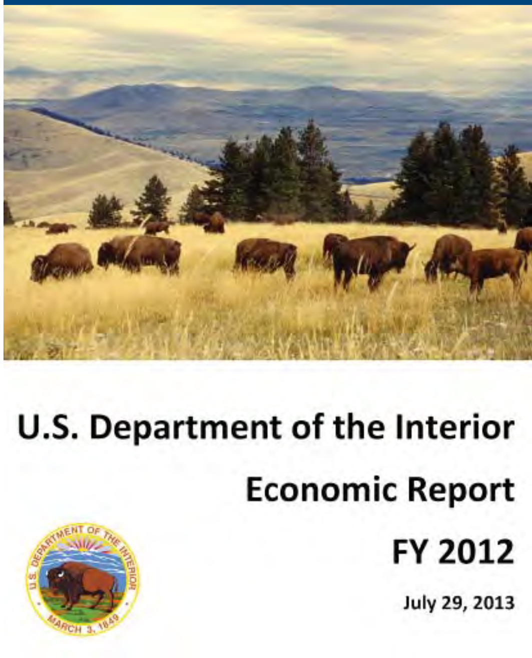
Contact: Yuliana Porras-Mendoza, 303-445-2265, yporrasmendoza@usbr.gov.

U.S. Department of the Interior Economic Report Recognizes Commercialization of Reclamation Technologies as an Important Stage in the Process of Innovation

In some cases, government research and development activities might follow a path from basic research, to applied research, to the development of specific technologies that can be transferred to the private sector, resulting in commercial applications. Such activities may be undertaken collaboratively between the U.S. Department of the Interior and external entities such as industry, universities, trade associations, and State and local governments. Arrangements such as Cooperative Research and Development Agreements (CRADAs) help facilitate partnerships between the Federal Government and non-Federal entities, as well as the efficient transfer of Federally conceived or developed technology into the private sector. One such agreement was entered into between Reclamation and Marrone Bio Innovations who, together, conducted field trials of Zequanox, an innovative solution to controlling invasive mussels that have caused billions of dollars in damages to the economy. This product is now commercially available.

Read more about Reclamation research and development and technology transfer in the *U.S. Department of the Interior Economic Report FY 2012* at: http://www.doi.gov/ppa/economic_analysis/upload/FY2012-DOI-Econ-Report-Final-2013-09-25.pdf

Contact: Chuck Hennig, 303-445-2134, chennig@usbr.gov.


U.S. Department of the Interior

Economic Report

FY 2012

July 29, 2013

U.S. Department of the Interior Economic Report FY 2012.

Reclamation's Hydraulics Laboratory: The Birthplace of Innovation

The Hydraulic Investigations and Laboratory Services Group in Reclamation's Technical Service Center is a unique facility combining physical and numerical modeling capabilities with field data collection and analytical evaluations of waterflow and associated hydraulic phenomenon.

Located on the Denver Federal Center in Colorado, the hydraulics laboratory includes more than 1½ acres of indoor laboratory space and a variety of specialized facilities, including a large (quarter of a million gallon) reservoir of water and a variety of pumps, flumes, meters, and other related structures and instrumentation.

Utilizing the expertise of 18 full-time staff members, including engineers and craftsmen, the hydraulics laboratory has provided hydraulic modeling, data collection, and engineering analysis services to Reclamation and partner organizations since 1930. The types of hydraulic evaluations offered by the laboratory are as diverse as Reclamation's facilities, including dams, spillways, diversion structures, canals, and fish protection facilities.

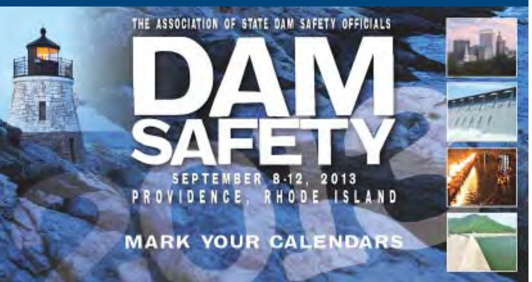
Learn more at: www.usbr.gov/pmts/hydraulics_lab.

Read more about Reclamation research and development in the July 2013 issue of Reclamation's *ETA (Efficiency, Transparency, Accountability)* newsletter at: www.usbr.gov/eta/docs/ETA%20July2013.pdf.

Contact: Bob Einhellig, 303-445-2142, reinhellig@usbr.gov.

Spillway and plunge pool modeling in Reclamation's Hydraulics Laboratory.

Recent Events



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The list of events below is intended 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.

Find our most recent list of events at: www.usbr.gov/research/events.

The Association of State Dam Safety Officials—Dam Safety 2013 Conference
September 8 - 12, 2013, Providence, Rhode Island.
Reclamation presenters included Robert Rinehart, who presented a poster entitled, "Intelligent Compaction for Earthen Water Retaining Structures."
Contact and additional conference information:
Robert Rinehart (rrinehart@usbr.gov),
www.damsafety.org/conferences/?p=db47b764-cd84-4a17-a014-a96c6cebab34.

WateReuse Association—28th Annual WateReuse Symposium
September 15 - 18, 2013, Denver, Colorado.
The keynote address, "Colorado River Myths and Realities: The Coming Conflict," was given by Brad Udall, the Director of the Getches-Wilkinson Center for Natural Resources, Energy, and Environment at the University of Colorado School of Law.
PowerPoint presentation available at: http://tinyurl.com/l5xbxd6.
Contact and additional symposium information:
Brad Udall (Bradley.udall@colorado.edu), www.watereuse.org/conferences.

The Geological Society of America (GSA)—GSA's 125th Anniversary Annual Meeting & Exposition
October 27 - 30, 2013, Denver, Colorado.
See http://community.geosociety.org/2013AnnualMeeting/Home.

American Institute of Chemical Engineers (AIChE)—2013 AIChE Annual Meeting, "Global Challenges for Engineering a Sustainable Future"
November 3 - 8, 2013, San Francisco, California.
Reclamation presented papers on water treatment and management options for rural communities using advanced water treatment strategies.
See www.aiche.org/conferences/aiche-annual-meeting/2013.

International Petroleum Environmental Conference (IPEC)—20th IPEC/IPEC 2013
November 12 - 14, 2013, San Antonio, Texas.
Reclamation presented information on water management planning guidelines and produced water treatment facilities for water reuse.
See http://ipec.utulsa.edu/conferences.htm.

Upcoming Events

2013

CEATI International—Hydropower Operations & Planning Workshop, "Renewable Energy Supply Reliability: Forecasting Uncertainties of Water, Wind and Solar"
November 14 - 15, 2013, San Diego, California.
See www.ceati.com/Meetings/HOPIG2013/index.html.

American Geophysical Union (AGU)—AGU Fall Meeting
December 9 - 13, 2013, San Francisco, California.
Reclamation's David Gaeuman will be presenting, "A flume experiment to constrain bedload adaptation lengths" (www.usbr.gov/research/projects/detail.cfm?id=3054) in the session, "Morphodynamic characteristics of non-normal flow conditions."
Contact and additional meeting information:
David Gaeuman (dgaeuman@usbr.gov), http://fallmeeting.agu.org/2013.

2014

Climate Change and Water Working Group—2nd Annual Progress Meeting on Reclamation Climate and Hydrology Research (also available via webinar)
January 29 - 30, 2014, Denver, Colorado.
A progress meeting focused on collaborative Climate Change and Water Working Group (CCAWWG) projects addressing climate change impacts on hydrology, with special focus on flood hydrology and extreme storm events. Last year's progress meeting participants represented 18 Federal, State, and local organizations; more than half of them participated remotely via webinar.
Contact and additional progress meeting information:
Levi Brekke (lbrekke@usbr.gov), www.ccawwg.us/index.php/annual-progress-meeting-on-reclamation-climate-and-hydrology-research.

American Meteorological Society (AMS)—94th/2014 AMS Annual Meeting, "Extreme Weather—Climate and the Built Environment: New Perspectives Opportunities, and Tools"
February 2 - 6, 2014, Atlanta, Georgia.
See http://annual.ametsoc.org/2014.

American Water Works Association—Sustainable Water Management Conference
March 30 - April 2, 2014, Denver, Colorado.
Presenting solutions for balancing the benefits of conservation with the costs, managing infrastructure, developing robust supply models and watershed management plans, water reuse, resource management, green infrastructure, and more.
See www.awwa.org/conferences-education/conferences/sustainable-water-management.aspx.

National Ground Water Association (NGWA)—NGWA Groundwater Summit
May 4 - 7, 2014, Denver, Colorado.
See https://ngwa.confex.com/ngwa/2014gws/cfp.cgi.

Featured Faces

James Prairie, Reclamation Researcher, M.S., Ph.D.

James Prairie is a Hydraulic Engineer who has worked for Reclamation's Upper Colorado Region since 2000. He is stationed at the University of Colorado's Center for Advanced Decision Support for Water and Environmental Systems (CADSWES). He has extensive experience in leading hydrology workgroups; directing and coordinating research, development, and modeling projects; directing and leading long term planning studies technical teams; and acting as a subject matter expert.

Jim earned a Bachelors (Cum Laude) in Environmental Resource Engineering from the State University of New York College of Environmental Science and Forestry. In addition, he attained a Masters of Science and a Doctorate in Civil Engineering from the University of Colorado at Boulder. He was awarded the J. Ernest Flack Graduate Fellowship in 2002. In 2007, he was chosen as Reclamation's Engineer of the Year.

Since 2008, Jim has led the Colorado River Hydrology Workgroup in its efforts to position Reclamation's Lower Colorado Region as a leader in water management and planning by integrating quantitative climate variability and change in both mid-term operations and long-term planning for the Colorado River Basin. In addition, Jim has directed multiple research activities at four universities, as well as with AMEC Earth and Environmental, Inc., a contracted consulting firm, to develop climate change based projections for use in Reclamation's long-term planning model, Colorado River Simulation System (CRSS). He has led and collaborated on several Reclamation Science and Technology Program research projects and is an expert in nonparametric stochastic time series analysis and generation.

Jim's interagency coordination includes serving as an advisor on Colorado River Basin natural flow development using state-of-the-art techniques to measure consumptive use and loss. Additionally, he coordinated with the Colorado River Basin Forecast Center to facilitate research in using advanced forecasting methods for operational modeling to surpass present forecasting operations. He also served as a coordinator for a joint Environmental Defense Fund and The Nature Conservancy research project to develop environmental flow metrics, which were then applied to Colorado River Basin model results.

Jim has participated in several National Environmental Policy Act studies including the Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lake Powell and Mead, Aspinall Unit Environmental Impact Statement (EIS), and the Long-Term Experimental Management Plan EIS for the operations of Glen Canyon Dam. In recent years, he has participated in the Colorado River Basin Study. Currently, Jim is co-leading the Tribal Basin Study and the Basin Study Next Steps Process. He is a subject-matter expert for the BiNational Study with the Republic of Mexico. He has published numerous peer reviewed journal publications and proceedings and has been invited to speak at several conferences and lectures.

Jim and his wife have two young boys and a faithful pup, which Jim considers his first child. His family enjoys hiking in the mountains, camping, biking, and trips to the farmer's market. Jim also enjoys back country skiing and scaling the high peaks throughout Colorado.

Marketa McGuire Elsner, Hydrologic Engineer, B.S., M.S., P.E.

Marketa McGuire Elsner is a Hydrologic Engineer with the Water Resources Planning and Operations Support Group within the Water and Environmental Resources Division of Reclamation's Technical Service Center. Marketa has 15 years of experience in evaluating the hydrology of mountain watersheds throughout the Western United States (U.S.), including the effects of climate change.

Marketa is a licensed professional engineer and graduated from the University of Colorado at Boulder in 1999 with a Bachelors of Science in Civil Engineering and from the University of Washington in 2004 with a Masters of Science in Civil Engineering. She first became interested in water resources management through a study abroad program through the University of Colorado, which took her to Austria, Zimbabwe, and Egypt to study major international river systems.

Marketa joined Reclamation in 2012 and has worked on a number of basin studies in support of the Basin Studies Program, which aims to fulfill Reclamation's obligations for meeting the SECURE Water Act. Marketa has also been involved in a number of projects with our office, including: (1) evaluating meteorological datasets used in hydrologic modeling, (2) organizing and helping to teach a training course on the development of hydro-climate scenarios to be used in climate change impacts studies, and (3) strategic planning for Reclamation's Cooperative Agreement with the National Center for Atmospheric Research.

Before joining Reclamation, Marketa worked as a Research Scientist with the Climate Impacts Group at the University of Washington, where she coordinated a number of large-scale climate change impacts studies, including the Washington State Climate Change Impacts Assessment (2009), which was influential for defining climate adaptation policy in Washington State. She has significant experience modeling surface water hydrology, with a focus on climate change impacts and decision support.

Marketa has over 15 peer reviewed publications. In 2006, she received a "best research oriented paper" award from the American Society of Civil Engineers for her thesis work, which evaluated ways to improve streamflow forecasting in the Snake River Basin using satellite data.

Marketa loves exploring the outdoors with her husband, 3-year-old son, and two dogs. She has hiked, skied, and climbed many peaks in the Western U.S., including Mount Rainier in Washington State. Marketa has raced triathlons for many years, including completing Ironman USA in Lake Placid, New York.

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"Levi Brekke, Water and Climate Research Coordinator, Ph.D., P.E."

(from page 1)

In the past, Levi worked in Reclamation's Technical Service Center and Mid-Pacific Region, with a focus on coordinating and implementing reservoir systems analyses and hydroclimate studies. Prior to joining Reclamation, Levi spent time in the private sector, where he worked in the areas of wastewater and water treatment engineering.

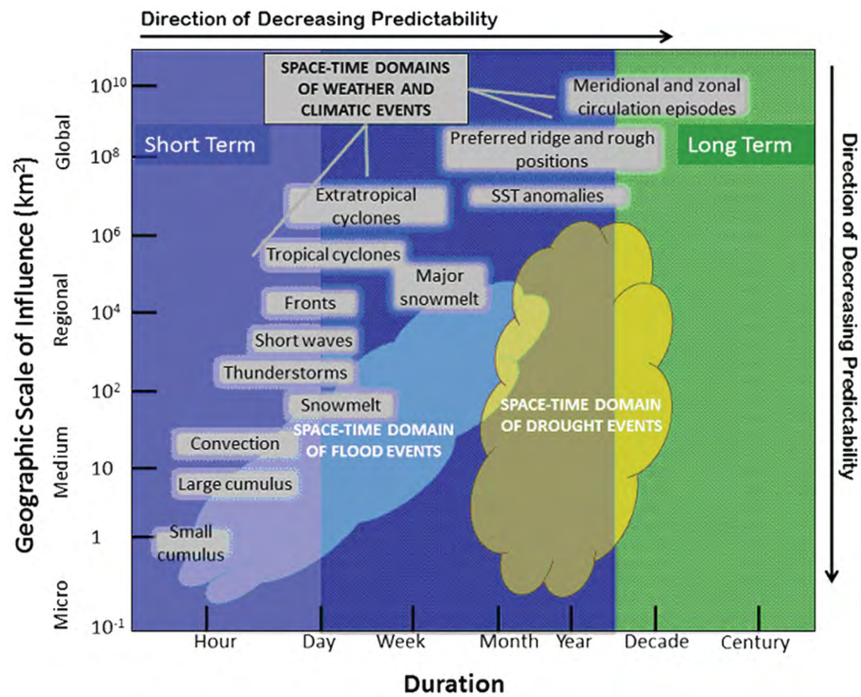
Levi holds a B.S.E. degree in Civil Engineering from the University of Iowa, an M.S. degree in Environmental Science and Engineering from Stanford University, and a Ph.D. in Water Resources.

Climate Change and Variability

Incorporating information on long-term climate change and short-term climate variability into Reclamation's water resource management infrastructure and operations is critical. Climate change involves a shift in the envelope of climatic variations, usually measured over a span of several decades. Climate variability involves fluctuations in weather and climatic conditions during the coming days to years. Improving our ability to forecast and use climate change and variability information would greatly enhance the ability of water managers and water users to plan their short-term operations and water delivery.

Climate Change and Variability (CCV) research is one of several priority areas in Reclamation's Science and Technology Program. Since 2011, the Science and Technology Program has provided 1.5 to 2 million dollars annually and leveraged resources from other agencies to support various projects designed to improve knowledge, methods, and tools in the area of CCV. Investing in CCV efforts includes:

- Collaborative research roadmapping with Federal and non-Federal water science and management agencies to identify science gaps and priorities.
- Annual calls for CCV proposals from Reclamation principal investigators through the Science and Technology Program Call for Proposals (i.e., competed research).
- Annual engagement with external research collaborators to support research that addresses high-priority science gaps that are underrepresented in the proposals submitted through the Science and Technology Program Call for Proposals (i.e., directed research).
- Periodic meetings with science providers and users to take stock in research accomplishments and update menu of gaps and priorities.



Space and time domains of climate and weather phenomena related to water resources management (source: after Hirschboeck,1988, in Climate Change and Water Working Group, 2013).

As mentioned, research roadmapping is a collaborative process conducted with other agencies. The sponsor group for these roadmapping processes is the Federal Climate Change and Water Working Group (CCAWWG, www.ccawwg.us). CCAWWG was established in 2008 to provide engineering and scientific collaborations in support of water management under a changing climate. It is an effective working-level forum among Federal agencies that fosters communication, operational, and research partnerships around user needs across the water resources and science communities of practice. Two CCAWWG-sponsored needs assessments currently frame Reclamation's CCV science investment priorities:

- Reclamation and U.S. Army Corps of Engineers. 2011. *Addressing Climate Change in Long-Term Water Resources Planning and Management: User Needs for Improving Tools and Information*. Authored contributions from other Federal, non-Federal, and non-government entities. Available at: www.ccawwg.us.
- Reclamation and U.S. Army Corps of Engineers. 2013. *Short-Term Water Management Decisions: User Needs for Improved Climate, Weather, and Hydrologic Information*. Authored contributions from other Federal, non-Federal, and non-government entities. Available at: www.ccawwg.us.

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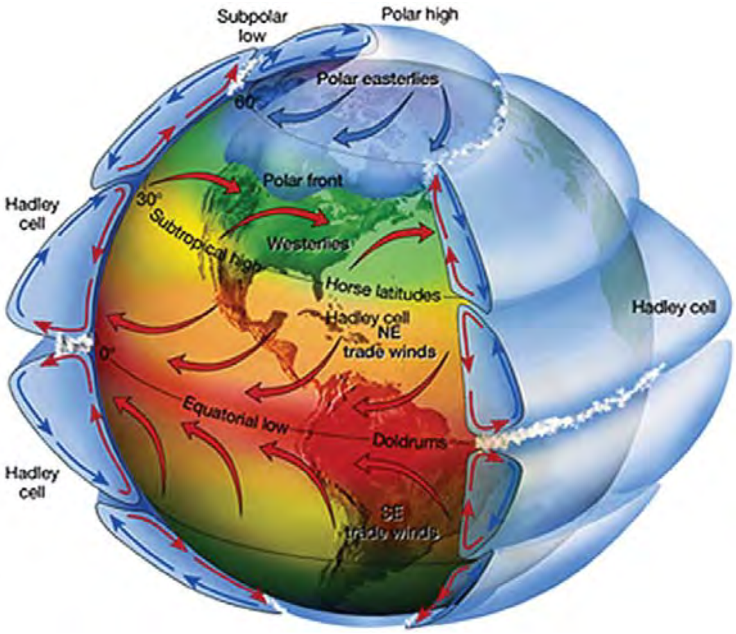
The following list of fiscal year 2013 CCV-funded efforts demonstrates the mix of long-term climate change and short-term climate variability efforts the Reclamation Science and Technology Program supports. Projects marked with an "(*)" are highlighted later in this Knowledge Stream issue.



Atmospheric general circulation and its global to regional features that affect climate in the Western U.S.

- Adaptation of Western U.S. Agriculture to Climate Change Induced Water Scarcity (ID 7430) (competed; with University of California Riverside)
- Airborne Snow Observatory—Value of Information (directed; with Reclamation's Upper Colorado Region and National Aeronautics and Space Administration's Jet Propulsion Laboratory)
- Back to the Future, Part 2: Innovative Tree Ring Analysis to Reconstruct Paleoclimate and Streamflows for Improved Urban Water Planning Under Climate Change (ID 1967) (competed; with Utah State University)
- Comparison of Methods for Simulating Watershed Evapotranspiration and Runoff Under Changing Climatic Conditions (ID 2024) (competed; with Reclamation's Mid-Pacific Region, Desert Research Institute, Stockholm Environment Institute US, University of California Davis, and Columbia University)
- Climate Science and Water Resources Distance Learning Efforts and Customized Workshops (directed; with Climate Change and Water Working Group and University Corporation for Atmospheric Research COMET)
- Design and Development of a Prototype Tool for Integrated Climate Downscaling and Streamflow Prediction Using Open Source Geographic Information System Software (ID 9449) (competed; with U.S. Forest Service, Brigham Young University, and University of Idaho)
- (*) Diagnosing the Moisture Sources for Extreme Precipitation Events in the Intermountain West (directed; with National Oceanic and Atmospheric Administration, and Cooperative Institute for Research in Environmental Sciences)
- (*) Downscaled Climate and Hydrology Projections Development and Web Service (directed; with Climate Analytics Group, Climate Central, Lawrence Livermore National Laboratory–Green Data Oasis, Santa Clara University, Scripps Institution of Oceanography, U.S. Army Corps of Engineers, and U.S. Geological Survey)
- (*) Evaluating Climate-Induced Runoff and Temperature Change on Stream Habitat Metrics for Endangered or Threatened Fish (ID 6507) (competed; with Reclamation's Pacific Northwest Region, Yakama Nation, Idaho State University, Wild Fish Conservancy, University of Colorado, University of Washington, and U.S. Geological Survey)
- (*) Evaluating the Relevance, Trustworthiness, and Applicability of CMIP5 Climate Projections for Water Resources and Environmental Planning (directed; with Reclamation's Mid-Pacific Region, National Oceanic and Atmospheric Administration, Cooperative Institute for Research in Environmental Sciences, and U.S. Army Corps of Engineers)

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- Flood Frequency Variability on Seasonal to Multidecadal Time Scales in the Western U.S. and Implications for Infrastructure Planning (ID 1916) (competed; with University of Colorado Boulder)

- (*) Improving Extreme Precipitation Estimation and Climate Change Projections Using Regional and High-Resolution Model Simulations (directed; with National Oceanic and Atmospheric Administration and Cooperative Institute for Research in Environmental Sciences)

- Ingredients-Based Climatology and Future Projections of Extreme Precipitation Events Using a Numerical Weather Prediction Framework (ID 6917) (competed; with University Corporation for Atmospheric Research's National Center for Atmospheric Research)

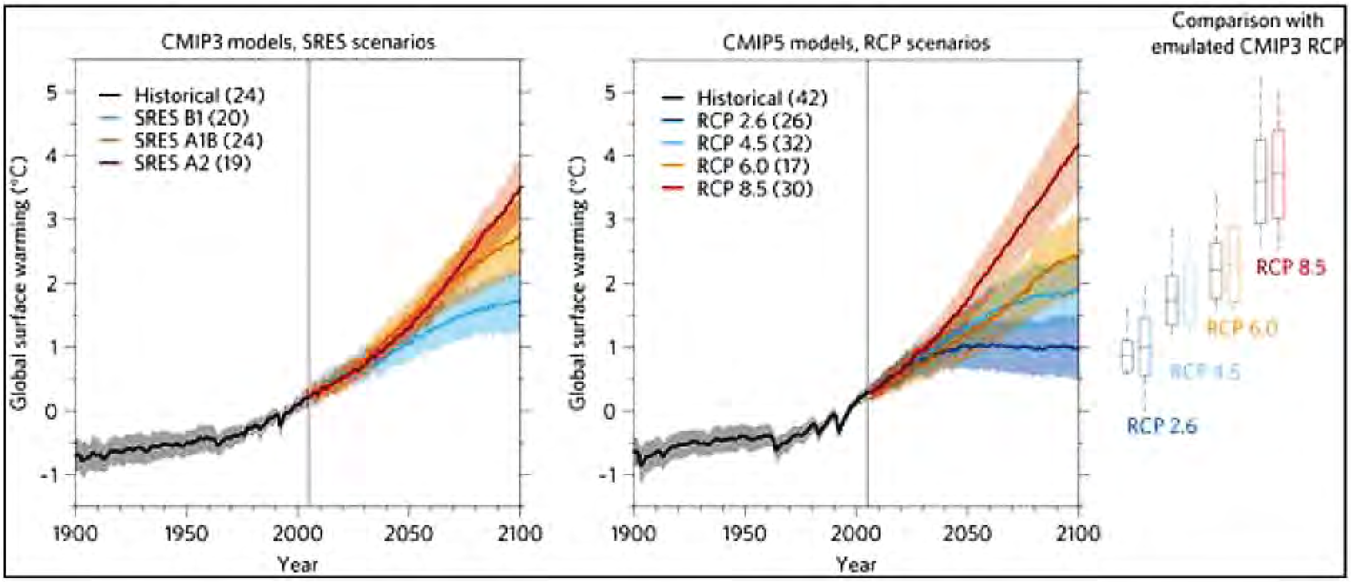
- (*) Literature Synthesis on Climate Change Implications for Water and Environmental Resources (directed; with National Oceanic and Atmospheric Administration–Regional Integrated Science and Assessment Centers)

- Methodology and Data for Quantifying Extreme Precipitation Events in a Changing Climate (ID 1385) (competed; with U.S. Army Corps of Engineers, Nuclear Regulatory Commission, and Reclamation's Dam Safety Office)

- (*) Sensitivity of Hydrologic Impacts Assessment to Downscaling Methodology and Spatial Resolution (ID 1646) (directed and competed; with U.S. Army Corps of Engineers, University Corporation for Atmospheric Research's National Center for Atmospheric Research, Reclamation's WaterSMART Basin Studies Program, and University of Colorado)

- (*) The Predictability of Streamflow Across the Contiguous United States (directed; with U.S. Army Corps of Engineers, University Corporation for Atmospheric Research's National Center for Atmospheric Research)

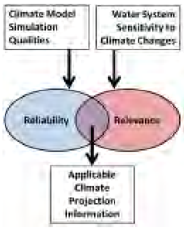
- Vulnerability Analysis of Western Water Resources to Climate Variability and Change (directed; with Colorado State University)

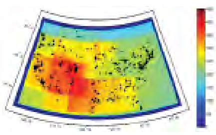


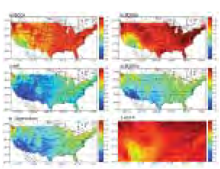
Knutti, R. and J. Sedlácek. 2012. "Robustness and uncertainties in the new CMIP5 climate model projections." Nature Climate Change, DOI:10.1038/nclimate1716.

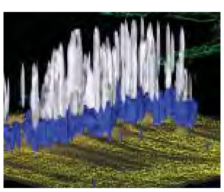
Climate Change Research Updates

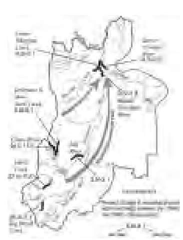
	Bulletin Title, Quote, and Website	Page











RECLAMATION *Managing Water in the West*

September 2013
Research and Development Office
Bulletin 2013-18

The Knowledge Stream

Research Update

How Do We Determine Reliable and Relevant Climate Projections for Planning?

Reclamation's diverse set of planning and management situations requires a flexible framework for judging climate projections applicability across our collection of adaptation decisions

Bottom Line

Approaching the question from the dual perspectives of information relevance and reliability can narrow the problem and ease the judgment of how climate projections may inform decisions.

Better, Faster, Cheaper

This information resource will support information reliability across a wide variety of situations—reducing planning and assessment costs for Reclamation and partners. The framework for merging reliability and relevance considerations will focus on study scoping and potentially lead to streamlined processes for planning and decisionmaking.

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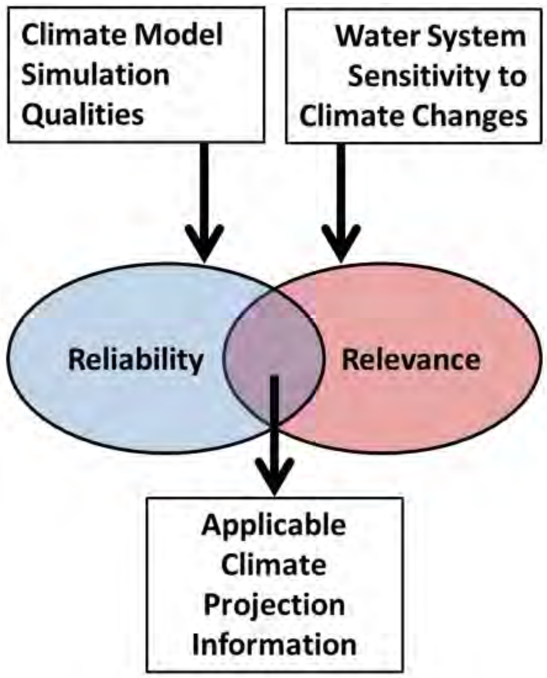
Collaborators

- **Reclamation's Mid-Pacific Region**
- **USACE**
- **NOAA**
- **University of Colorado**

Problem

Driven by recent trends in administration priorities, Reclamation is increasingly compelled to mainstream climate change considerations into its broad spectrum of mission activities. A common challenge facing planners and study teams across these activities is judging which aspects of climate projection information are relevant, reliable, and, therefore, applicable to their decisions, which may be very diverse (e.g., developing long-term water and environmental management criteria, informing investments in climate-resilient infrastructure, supporting efforts in river restoration and species recovery).

Reclamation, in collaboration with researchers and study partners from around the Western United States (U.S.), has made significant progress in developing the technical methods required to evaluate water supply and demands and assess system vulnerability under projected future climate conditions. As we pivot from vulnerability assessments to adaptation action and investment, managers will require sharper understanding of which aspects of climate are *relevant* to a given system or management context and which aspects of climate projection information are *reliable* enough given climate model uncertainties in order to determine which aspects of climate change information are *applicable* to a given decision context.



Conceptual framework for identifying climate projection information applicable to an individual planning or decisionmaking situation.

Solution

Reclamation is partnering with the National Oceanic and Atmospheric Administration (NOAA), U.S. Army Corps of Engineers (USACE), and the University of Colorado's Cooperative Institute for Research in Environmental Sciences to develop a framework for assessing the relevance, reliability, and applicability of climate projection information to individual planning and decisionmaking situations. Relevance and reliability are evaluated separately, and then considered jointly to inform judgments of applicability.

- Relevance is based on analyses of how the given water management situation is sensitive to different types of climate changes. The goal is to identify the

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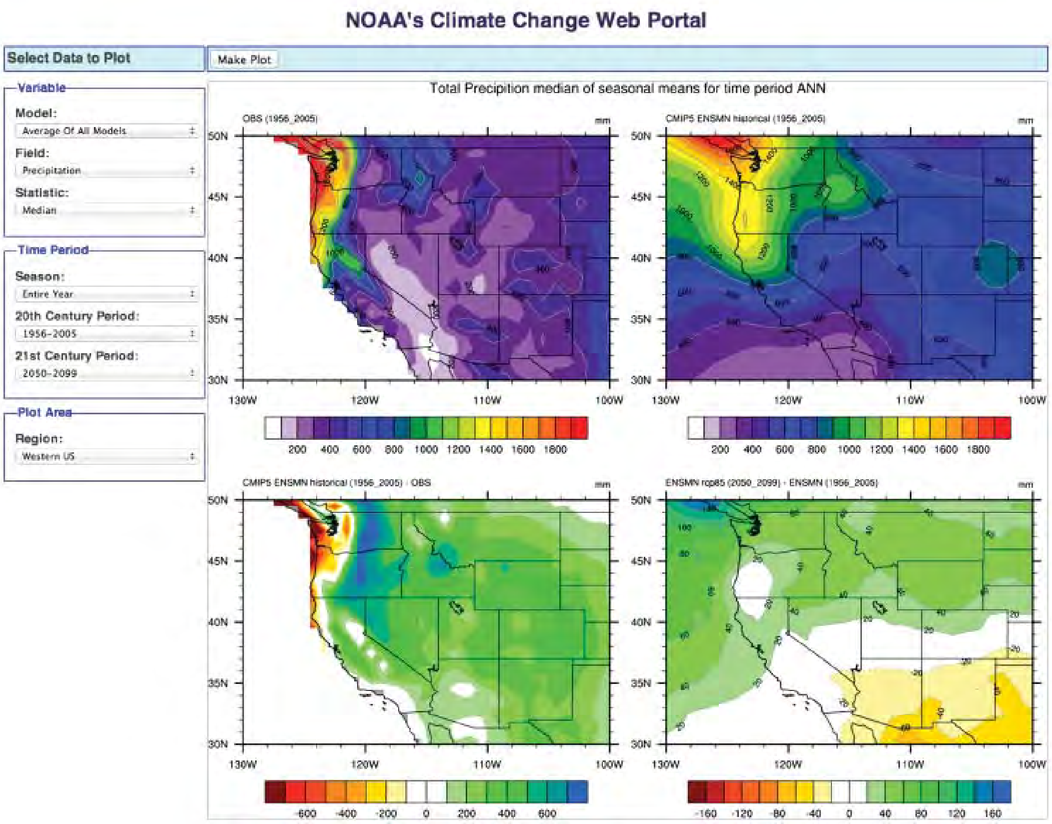
most critical and relevant types of change, which may vary by climate variable, time scales from annual to daily, space scales from region to local catchment, and climate statistic (e.g., averages, variability, and extremes). The study team is demonstrating the relevance analysis using the California Sacramento-San Joaquin Basins as a case study region, evaluating how various measures of Reclamation, State and local reservoir systems performances are sensitive to different types of climate change.

- Reliability is based on evaluation of climate models that provide future projection information, focusing on their skill in simulating historical climate. If climate models are found to simulate a given climate aspect reliably (e.g., models are found to accurately reproduce observed 20th century conditions) this supports judgment that the models can project future changes in that climate aspect. As Reclamation's mission activities depend on many climate aspects, this skill evaluation is being conducted across a large suite of climate variables and statistics. The team is building the reliability information resource to have global coverage so that it can flexibly serve any planning and assessment situation considered by USACE or Reclamation. Results from this evaluation are being packaged for distribution through a free and easy-access web portal.

"Outcomes from the scoping pilot are expected to inform opportunities to refine this framework, ease scoping processes, and enhance planning and decisionmaking under future climate uncertainty"

Levi Brekke
Water and Climate Research Coordinator



Climate model evaluation portal developed by NOAA partners to facilitate evaluation of climate model reliability (www.esrl.noaa.gov/psd/ipcc/cmip5/ccwp.html).

Future Plans

The study team plans to have a beta version of the reliability web portal online by early 2014. Shortly thereafter, the study team plans to collaborate with Reclamation's Mid-Pacific Region and host a mock scoping pilot where relevance and reliability information are merged to inform applicability judgments. Participants will include technical representatives and planning process experts familiar with leading feasibility studies and other planning assessments. Participants will be tasked with judging information applicability for a given mock study based on dual consideration of relevance and reliability, results from the Central Valley Project's reservoir systems' relevance analysis, and information from the reliability web portal.

RECLAMATION *Managing Water in the West*

September 2013
Research and Development Office
Bulletin 2013-19

The Knowledge Stream

Research Update

Downscaled Climate and Hydrology Projections Website

New daily climate and Western United States hydrology projections are now available

Bottom Line

Downscaled climate and hydrology projections help users answer local questions about daily climate, streamflow, and water resources. Researchers and planners can use these projections to evaluate potential future climate and hydrology, assess societal impacts, and explore adaptation options.

Better, Faster, Cheaper

Via the website, Reclamation makes downscaled climate and hydrology projections available to scientists and engineers quickly and easily. Using this web service reduces assessment costs and supports risk-based climate adaptation planning.

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Collaborators

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- **Technical Service Center**
- **WaterSMART Basin Studies Program**

Climate Analytics Group

Climate Central

LLNL–Green Data Oasis

Santa Clara University

Scripps Institution of Oceanography

U.S. Army Corps of Engineers

U.S. Geological Survey

Problem

Global climate models (GCM) are used to simulate future climate responses to scenario increases in atmospheric greenhouse gases. While GCMs simulate a variety of climate responses, including changes in surface temperature and precipitation, they are spatially coarse and not adequate for evaluating local climate impacts.

Users need to quickly and easily access GCM output translated to locally relevant resolution (i.e., "downscaled"). They also need this output to be finely resolved in time so that they may address monthly to daily climate questions (e.g., precipitation amounts, reoccurrence of wet and dry weather patterns, daily temperature range). Users also need:

1. A way to correct for the GCM's bias towards erroneously simulate climate as too warm or cool and/or too wet or dry; and

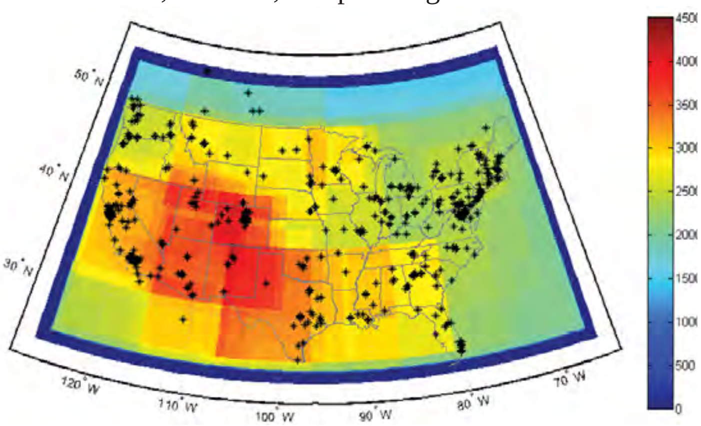
2. Understanding what these climate projections mean for local hydrology (e.g., streamflow, snowpack, water supplies).

Initial Solution

In 2007, Reclamation collaborated with Santa Clara University and Lawrence Livermore National Laboratory (LLNL) to apply a proven technique called "Bias Correction Spatial Disaggregation" (BCSD) to 112 contemporary global climate projections made available through the World Climate Research Program Couple Model Intercomparison Project, Phase 3 (WCRP CMIP3). These projections represent 16 GCMs simulating climate responses to 3 greenhouse gase scenarios from multiple initial climate system conditions.

The effort produced 112 monthly temperature and precipitation projections over the continental United States (U.S.) at 1/8 degree (12 kilometers) spatial resolution for a 1950 through 2099 climate period. These projections were the first information resources on the website.

Following its launch, the website served information requests for a variety of educational, research, and planning efforts.



Website supports customized user requests from across the U.S.—Since 2007, the archive has served more than 1,400 users submitting greater than 21,000 data requests. Map shows the spatial distribution of data requests (color shading) and unique user locations (asterisks). In total, the archive has served 55 terrabytes of data from full-file FTP and customized subset web services.

New Needs, New Solutions

Daily Climate Projections and Western United States Hydrologic Projections

In 2011, the archive received two significant information additions:

1. Responding to users suggestions to include additional information on projected daily temperature range (important for ecological studies) and potential changes in daily precipitation conditions (important for flood hydrology studies). The collaboration expanded in 2010 to leverage a technique developed at Scripps Institution of Oceanography, U.S. Geological Survey, and Santa Clara University, "Bias Correction Constructed Analogs" (BCCA), which operates on daily GCM output. It was applied to 53 of the 112 BCSD projections during 3 sub-periods: 1961 - 2000, 2046 - 2065, and 2081 - 2100.

2. To consistently support assessment of climate change impacts on hydrology for all of Reclamation's water systems, Reclamation (Science and Technology Program, WaterSMART Basin Studies Program, and the Technical Service Center) collaborated with the University of Washington's Climate Impacts Group (CIG) and the National Oceanic and Atmospheric Administration's National Weather Service Colorado Basin River Forecast Center to generate hydrologic projections over the Western U.S., corresponding to the monthly BCSD climate projections contained at this website.

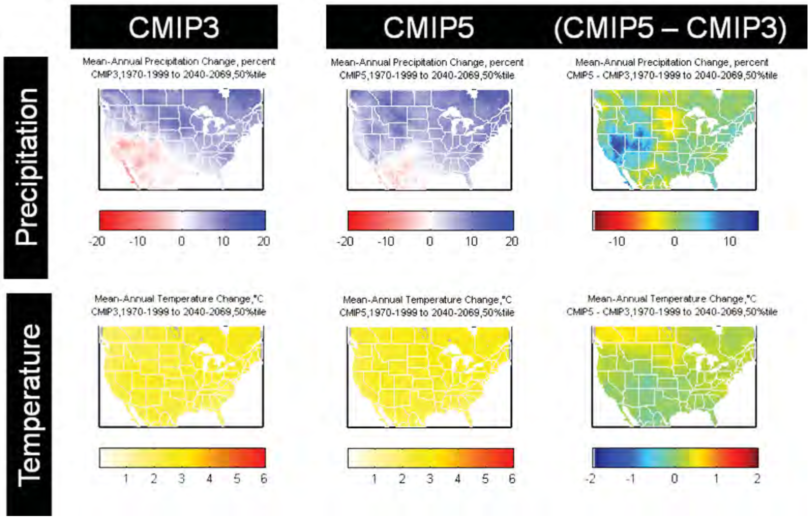
A New Generation of Global and Downscaled Climate Projections (CMIP5)

The WCRP develops global climate projections through its CMIP roughly every 5 to 7 years. Results from CMIP3 were released in 2007 and later used in Reclamation research and assessments including the 2011 SECURE Water Act Report and WaterSMART Basin Studies completed in the Colorado, Yakima, and St. Mary River-Milk River Basins. Results from the WCRP CMIP5 efforts were released during 2012 and represent more comprehensive global climate models, updated greenhouse gas emissions scenarios and a broader set of experiments to address a wider variety of climate science questions.

Reclamation and its collaborators recognized user interests to quickly be able to access and evaluate this new information, responding by applying BCSD and BCCA to a large collection of daily and monthly CMIP5 projections of precipitation, average temperature, and daily temperature ranges. These data were issued in May 2013.

Future Plans

In 2014, archive collaborators plan to develop and issue hydrologic projections for the contiguous U.S. associated with BCSD CMIP5.



BCSD CMIP5 and CMIP3 are broadly similar, but with some significant regional differences.

"Reclamation and its partners are taking leading roles to develop an understanding on how this new information complements previous climate projections made available through CMIP3, and on how CMIP5 projections should be considered in water planning and management."

Michael L. Connor
Commissioner, Reclamation

More Information

Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections available at:

http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/

CMIP3:

http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php

CMIP5:

http://cmip-pcmdi.llnl.gov/cmip5/

Downscaled Climate Projections:

http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/#About

Western U.S. BCSD CMIP3 Hydrology Projections:

www.usbr.gov/WaterSMART/docs/west-wide-climate-risk-assessments.pdf

RECLAMATION Managing Water in the West

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The Knowledge Stream
Research Update

Getting a Handle on Streamflow Prediction Skill

What are the sources of uncertainty in streamflow predictions and how do these vary?

Bottom Line

The project helps quantify the importance of knowing current watershed conditions versus having accurate meteorological forecasts to support skillful streamflow predictions in different seasons and indicates the relative value of efforts to improve watershed knowledge and meteorological forecasts from the perspective of water resources management.

Better, Faster, Cheaper

Streamflow forecasts at daily to seasonal lead times are a critical component of the information used to manage water in the U.S. Understanding variations in the skill and uncertainty of streamflow predictions will help water managers make more informed use of predictions and guide strategic investments toward filling key information and prediction gaps.

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- **NCAR**
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Problem

Every day, streamflow forecasts are used to support decisions by reservoir operators and water managers in the United States (U.S.), who must balance a range of competing objectives. At local scales, these decisions might include preventing floods by capturing water, maintaining cool stream temperatures for fish by releasing water, or delivering water to irrigators through scheduled releases. At large regional scales, decisions to store or release water may affect the available supply and water markets for large U.S. cities or growing regions situated hundreds of miles from the water's headwater source, or even have international treaty implications. The need for better short-term forecasts—from minutes to seasons—is perennially raised in studies related to water management. However, identifying the research necessary to improve hydrologic monitoring and prediction products requires identifying the overlap between user needs and opportunities to improve hydrologic monitoring and prediction products.

Solution

A User Needs Assessment

To address the first challenge—identifying user needs—Reclamation and the U.S. Army Corps of Engineers (USACE) recently joined with the National Oceanic and Atmospheric Administration's National Weather Service (NWS) to develop a report entitled, "Short-Term Water Management Decisions: User Needs for Improved Weather and Climate Prediction Information" Raff, et al., 2013 (ST Doc). The ST Doc defined how different weather and hydrologic information products are currently used to support different water management decisions and highlighted information gaps identified by water managers in the two agencies.

Boulder Creek near Folsom Street (Boulder, Colorado) during the September 2013 flood event. These floods were remarkable because of both their large geographical extent and long duration of heavy precipitation. This project will help identify opportunities to improve prediction of events such as this. Photograph by Pablo Mendoza.

Steps Toward Understanding Hydrologic Predictability

To begin to confront the second challenge—identifying opportunities to improve hydrologic monitoring and prediction products—the National Center for Atmospheric Research (NCAR), Reclamation, and USACE are undertaking a comprehensive predictability assessment to quantify and document the major sources of skill and uncertainty in hydrologic prediction products. The design of the proposed project centers on quantifying the impact of different sources of uncertainty on different types of forecasts (e.g., daily to weekly flow forecasts, 3-month volume forecasts), at different forecast initialization times throughout the year (e.g., forecasts starting on October 1st versus April 1st), and in different hydroclimate regions (e.g., regions with or without substantial snow storage or regions with varying degrees of climate

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predictability). Contrasting the Reclamation-USACE assessment of user needs in the ST Doc with an assessment of the opportunities to improve hydrologic prediction products can help frame future research priorities that will ultimately provide better forecasting inputs for decisionmaking.

Application

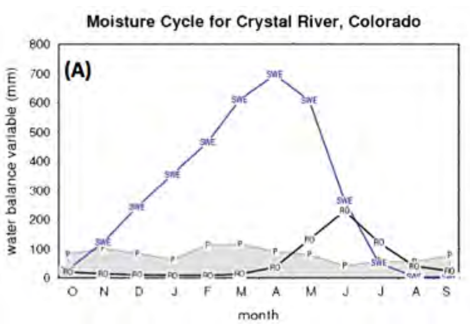
Hydrologic forecast skill depends on both the accuracy of the basin initial watershed condition estimates and their impact on the basin streamflow response and the accuracy of the weather and climate forecasts. An existing framework to quantify the influence of accuracy in these areas (Wood and Lettenmaier, 2008) contrasts the effects of complete (climatological) uncertainty versus perfect knowledge in each predictability component, recognizing that these are merely end-points between which operational predictions lie. That is, real-world forecasts have imperfect knowledge of watershed initial conditions and of weather to climate forecasts.

The predictability study expands this framework to explore the impacts of different levels of initial condition and future forcing uncertainty on streamflow prediction skill, using an assessment of retrospective forecasts ("hindcasts"). The project focuses on approximately 600 relatively unimpaired watersheds across the contiguous U.S. These basins are of "intermediate" size (typically between 1,000 and 10,000 square kilometers), and provide a good sampling of the differences in climate, vegetation, topography, and soils throughout the contiguous U.S. The NWS hydrologic forecast model (Sacramento/Snow17) has been calibrated to these basins using objective methods, and seasonal hindcasts initialized on the first day of each month are being run.

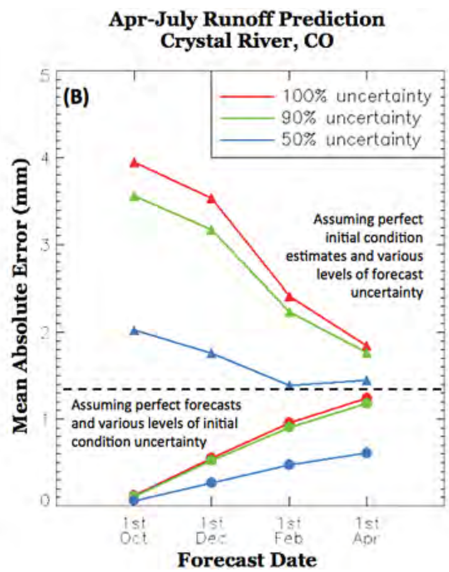
Initial findings agree with earlier work and operational wisdom—for instance, that seasonal streamflow prediction skill depends strongly on initial conditions in the winter and spring, and on weather and climate forecasts in the late summer through the fall, in the snowmelt driven basins of the Western U.S. The work has also suggested new insights—for example, one unexpected finding is that even minor improvements in climate forecast skill can have proportionally larger benefits for streamflow prediction, depending on the time of year and location.

Future Plans

The idealized predictability assessment described above will lay the groundwork for the project's next steps: using state-of-the-art weather and climate predictions and an assessment of actual forecast model to untangle and quantify current actual levels of uncertainty in weather and climate forecasts and initial conditions, and to target the most beneficial areas for efforts to reduce uncertainty. A series of case studies will examine the potential impact of such efforts for water management decisions, and provide insights for strategic decisions on forecasting or monitoring research to operations transition efforts.



(A) The western US water cycle, in which winter precipitation (P) winter accumulates as snow (SWE) and later melts as runoff (RO), means that minor improvements in forecast skill can add up. (B) Even a 10 percent reduction in forecast uncertainty (diamonds) early in year can have larger impact than improving initial watershed condition estimates by the same percentage (circles) throughout most of the water year.



"Understanding sources of skill in streamflow prediction, from basin observations to weather and climate forecasting, will help steer our investments in streamflow forecasting improvements to benefit water users."

Levi Brekke
Water and Climate
Research Coordinator

More Information

Wood, A.W. and D.P. Lettenmaier. 2008. *An ensemble approach for attribution of hydrologic prediction uncertainty*. Geophysical Research Letters, Article Number L14401, DOI:10.1029/2008GL034648.

Raff, D., L. Brekke, K. Werner, A. Wood, and K. White. 2013. *Short-Term Water Management Decisions: User Needs for Improved Climate, Weather, and Hydrologic Information.* Technical Report CWTS-2013-1. Bureau of Reclamation, U.S. Army Corps of Engineers, and National Oceanic and Atmospheric Administration. Available at:

http://ccawwg.us/docs/Short-Term_Water_Management_Decisions_Final_3_Jan_2013.pdf)

Crystal River, Colorado (source: http://growingupfortcollins.com).

RECLAMATION Managing Water in the West

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The Knowledge Stream
Research Update

Assessing the Assessment Methods: Climate Change and Hydrologic Impacts

Are our perceptions about adaptation needs sensitive to our methods for assessing future weather and hydrologic impacts?

Bottom Line

This project identifies strengths and weaknesses of current techniques for downscaling climate projections and assessing hydrologic conditions that inform adaptation planning and investments. Results from this evaluation steer research and development investments to develop improved techniques.

Better, Faster, Cheaper

The comprehensive analysis of methodological shortcomings provides the user community with guidance on appropriate methods for climate impact assessments. It also informs research to develop improved downscaling and hydrologic modeling approaches that will both improve handling of uncertainty in climate change assessments and more effective support of adaptation planning and decisionmaking.

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Collaborators

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- **Technical Service Center**
- **WaterSMART Basin Studies Program**

National Center for Atmospheric Research (NCAR)

U.S. Army Corps of Engineers

University of Colorado

Problem

Reclamation, U.S. Army Corps of Engineers (USACE), and other water management agencies have an interest in developing reliable, science-based methods for incorporating climate change information into longer-term water resources planning. Such planning assessments must quantify projections of future climate and hydrology. The common practice is to begin by developing relationships between current observed climate and climate projections over the assessment region. Because the spatial resolution and biases of climate projections developed by global climate models is not adequate for local to regional hydrologic assessments, this step relies on some form of spatial downscaling and bias correction, which produces watershed-scale weather information to drive simulations of hydrology and other water resource management conditions (e.g., water demands, water quality, environmental habitat).

Water agencies continue to face decisions about the selection of downscaling method(s), the selection and configuration of hydrological models, and of observational datasets. There is a critical need to understand the ramification of these methodological decisions, as they affect the signal and uncertainties produced by climate change assessments and, thus, the effectiveness of these results to support adaptation planning and decisionmaking.

Solution: Assessment of Uncertainties

The project has found that there is indeed reason for concern over methodological choices. Initial results indicate that selection of downscaling methods and the selection and configuration of hydrologic models can substantially alter the portrayal of climate change impacts on hydrology. Specifically,

1. The choice of methods to produce historical, spatially distributed weather estimates over the Western United States (U.S.)—which is foundational for guiding climate

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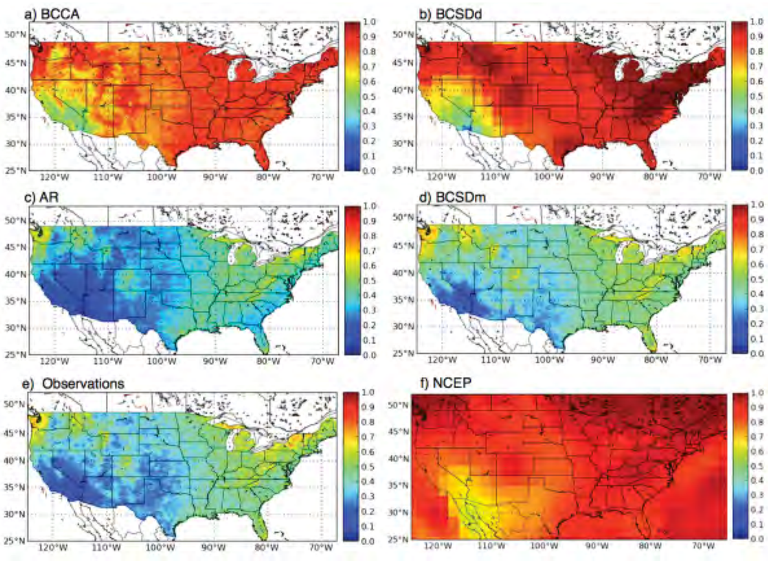

Historical fraction of wet days from four statistical downscaling techniques (plots a-d), all of which have different wet day fractions compared to observations (plot e). The low-resolution data they are downscaled from are provided for reference (plot f). Figure from Gutmann, et al., 2013.

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projection downcaling and hydrologic model application—can have as large an impact on projected hydrologic outcomes as the climate change signal. Compounding the issue, hydrologic model calibration yields model parameter sets that inappropriately compensate for the biases in the model forcing data (different model parameter sets for different model forcing data), influencing climate change sensitivities in unappreciated ways.

2. Many statistical downscaling methods that are popular in the water management community produce hydroclimate representations with too much drizzle, too small extreme events, and improper representation of spatial scaling characteristics that are relevant to hydrology. These deficiencies vary by method, significantly impacting results.

3. The choice of statistical versus dynamical downscaling is important: the climate sensitivities obtained from 4-kilometer (km) dynamically downscaled simulations from the Weather Research and Forecasting (WRF) model differ from current statistically-based guidance being provided to water managers. WRF shows wintertime increases in precipitation in the Colorado River Headwaters that are consistent with a warmer and moister atmosphere, and occur when topography is adequately resolved by the regional climate model.

4. The resolution used in dynamical downscaling matters. While the 4-km WRF simulations match observed precipitation well, WRF simulations at 12- and 36-km have a poor correspondence to observations and, importantly, the coarser-resolution WRF simulations have very different change signals compared to the 4-km WRF simulations. The impact of WRF resolution on hydrology is primarily due to differences in precipitation among multi-resolution WRF simulations, although differences in the spatial resolution of the hydrology model are still important.

5. The choice of hydrologic model also affects projection outcomes, though less so if a hydrology model is well calibrated. Calibration is successful in reducing climate change impact uncertainty, particularly for metrics that are closely related to the objective function used in calibration, thus the use of uncalibrated hydrology models, as is common in regional or larger-scale assessments, is ill-advised. There is a clear need to implement comprehensive (multi-objective) calibration schemes that consider multiple, application-relevant attributes of hydrologic model behavior.

6. Finally, outcomes depend significantly on subjective decisions made in calibrating hydrologic models, such as the choice of forcing data, the choice of calibration scheme, and the choice of objective function. Work is continuing to quantify the effect of calibration decisions in more detail.

Taken together, the methodological sensitivities found thus far reveal that the current practice of impact assessment unwittingly includes an array of unintended effects—artifacts resulting from the method, data, and model choices—prompting practitioners to seek a new path.

Future Plans

The project team is currently scoping follow-on efforts to develop and demonstrate improved downscaling methods and hydrologic modeling applications. On downscaling, the effort will consider advanced hybrid statistical-dynamical downscaling methods to provide a realistic depiction of physical processes at a low computational cost. These methods improve hydrologically relevant metrics, such as the spatial representation of extreme precipitation events, and can be applied to a large range of climate scenarios. On hydrologic assessment, the effort will employ a multi-model approach with multiple advanced calibration strategies to reduce simulation errors and improve characterization of uncertainty in hydrologic models. Improved hydrologic models and more physically realistic downscaling implementation will lead to more dependable projections, and ultimately improve decision support.

"Water resource managers are significantly increasing their use of hydrologic models forced by climate-changed future conditions in our planning for responding to climate change. The need for better understanding uncertainties in the models used for assessments is acute, and that understanding can be put to immediate use."

Jeff Arnold
Co-Director, Climate and Global Change Programs, U.S. Army Corps of Engineers

More Information

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RECLAMATION Managing Water in the West

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Bulletin 2013-22

The Knowledge Stream

Research Update

Do Atmospheric Rivers Cause Heavy Downpours in the Intermountain West?

Detecting and modeling moisture sources associated with winter storms in Arizona, Colorado, and Idaho

Bottom Line

Determining potential pathways and sources for extreme precipitation events can help inform decisions about dam safety, flood hydrology, and future monitoring.

Better, Faster, Cheaper

The trajectory and modeling analyses performed here indicate winter storm attributes that result in extreme precipitation in Western States, which have applications to hydrologic hazard studies for dam safety and potentially for short-term (1- to 2-day) predictions at dam sites.

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Collaborators

- **FHCG in Reclamation's Technical Service Center**
- **NOAA's Earth System Research Laboratory**
- **Cooperative Institute for Research in Environmental Sciences (CIRES)**

Problem

Extreme precipitation events (abnormally heavy rainfall over 1 to 3 days) can quickly cause severe flooding, leading to safety and infrastructure problems. Determining how these events occur in the Intermountain West (between the Sierra Nevada/Cascade Mountains and the Continental Divide) would help water managers, emergency planners, and others better prepare for these extreme precipitation events. Growing recognition that we are living in an era of changing climate and potentially changing extremes underscores our urgency in advancing this understanding.

The Intermountain West has a complex topography, and moisture from the Pacific Ocean travels a great distance to fuel these storms. It is not clear how these large volumes of water reach their destination. Since flow over mountain causes air to cool and thus hold less moisture, air parcels may take unique pathways and/or have multiple moisture sources to retain enough water to have intense precipitation events in States such as Arizona, Colorado, and Idaho.

Atmospheric rivers (ARs)—long narrow bands of enhanced water vapor transport—are the dominant mechanism for generating intense precipitation events along the west coast of the United States (U.S.) during winter. While studies over the past 10 years have extensively explored the impact of ARs on the precipitation and temperature west of the Sierra Nevada/Cascade Mountains, their influence on the weather in the Intermountain West remains an open question.

The Flood Hydrology and Consequences Group (FHCG) in Reclamation's Technical Service Center estimates extreme precipitation event (and hydrologic response) probabilities for Reclamation dam sites across the Intermountain West for Reclamation's Dam Safety Office. One technique to provide these estimates requires selection of storms that occurred somewhere in the greater region, situating them over the study basin of interest (called transposing), and then maximizing them within physical reason. Transposing the storms is done with substantial uncertainty; a common question is whether the resituation of such storms to a new location imposes a disconnect from the moisture sources required to fuel them.

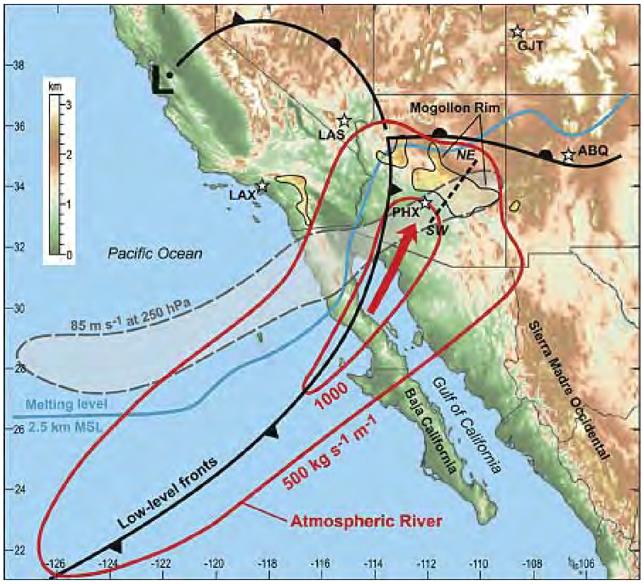

Figure 1. Schematic of conditions leading to heavy precipitation over central Arizona on January 21, 2010.

Solution

Reclamation's Science and Technology Program and the FHCG teamed up with the Cooperative Institute for Research in Environmental Sciences (CIRES), a joint

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institute of the National Oceanic and Atmospheric Administration (NOAA) and University of Colorado at Boulder, to help understand the processes of these extreme precipitation events. The approach includes:

- Identifying historical extreme wintertime precipitation events in the Intermountain West.
- Diagnosing processes contributing to extreme precipitation events and ARs using trajectories that track the path of air parcels.
- Analyzing weather patterns using modern reconstructions of historical atmospheric conditions through a process called re-analysis, where observations are integrated into a historical atmospheric simulation.
- Performing high-resolution atmospheric simulations on several extreme events and exploring sensitivity to event ingredients.

Application and Results

As a first step, a sophisticated network of observations and high-resolution model experiments was used to deconstruct an individual winter storm that brought heavy rain and flooding to central Arizona on January 21, 2010. The storm contained a very strong AR ahead of the cold front (Figure 1) a portion of which crossed southern Baja California, where the mountains are lower and thus the air retained more moisture as the AR moved into Arizona. Once the AR reached central Arizona it encountered the steep cliffs of the Mogollon Rim at nearly the optimal angle to produce the most precipitation. This study demonstrated that ARs can penetrate inland from the Pacific Ocean to central Arizona resulting in heavy rains, snow at higher elevations, and flooding.

A second step sought to identify the moisture sources that contributed to heavy precipitation events near Boise, Idaho, over the watersheds for the Arrowrock and Anderson Ranch Dams. The top 150 precipitation events since 1978 were identified and then trajectories (similar to the path balloons would take as they are carried by the wind), were computed over the 5 previous days to determine where the moist air parcels originated. While the trajectory paths reaching southwest Idaho were very diverse, the greatest number crossed northern California, just to the north of the highest portion of the Sierra Nevada Mountains (Figure 2). The preferred pathway was confirmed using a statistical method to determine the dominant patterns of moisture transport. This method indicated that the most common pattern is associated with a strong AR coming onshore over northern California and/or Oregon, then moving eastward across Idaho, northern Nevada and Utah, and dissipating in Wyoming. Other important pathways include: southern California across Arizona and into southwest Colorado; over southern Baja California into Arizona and along the U.S.-Canadian border.

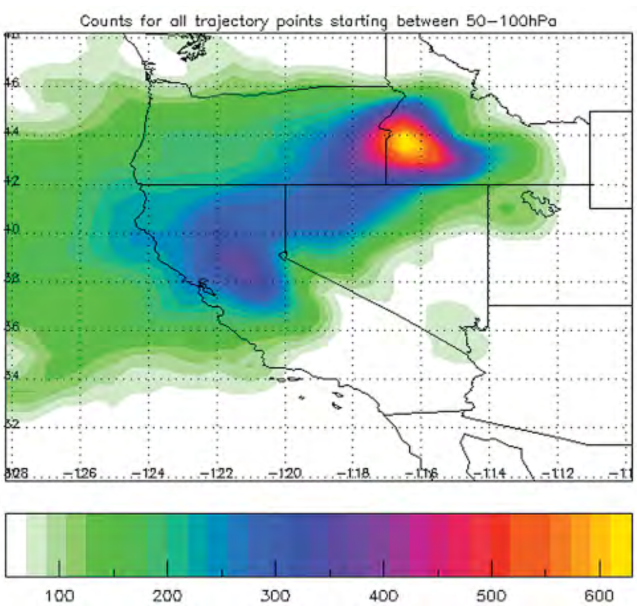

Figure 2. Number of trajectories passing through a given location that terminate in southwest Idaho during periods of heavy precipitation.

"Developing a better understanding of the long and complex pathways that winter storms use to deliver moisture to the Intermountain West is useful to water managers."

John England
Hydraulic Engineer,
Reclamation's Technical Service Center

Future Plans

- **Transfer the knowledge, methods, and data generated from this research to the FHCG.**
- **Enhance the statistical methods to classify and group extreme events.**
- **Develop the capability to make a large set of simulations of extreme events to explore the upper range of potential precipitation amounts in key watersheds.**
- **Document AR characteristics including their seasonality and duration, and examine how climate variability and change may influence ARs and their impact on precipitation in the Western U.S.**
- **Derive realistic temporal and spatial probable maximum storm distributions for regions in the Western U.S.**

More Information

www.usbr.gov/research/projects/detail.cfm?id=1740

RECLAMATION *Managing Water in the West*

September 2013
Research and Development Office
Bulletin 2013-23

The Knowledge Stream

Research Update

Will extreme rainfall change in Colorado's future?

Using high-resolution models to understand extreme summer precipitation events and assess possible future changes in Colorado

Bottom Line

Combining improved understanding of what past extreme precipitation events look like in space and time with projected future climate conditions can help inform decisions about dam safety, flood hydrology, and future monitoring needs.

Better, Faster, Cheaper

Out-dated historical records can be updated using a high-resolution model to represent how heavy precipitation is distributed in space and time, while also providing the potential to incorporate climate change in long-term planning applications.

Principal Investigators

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Collaborators

Reclamation:

- **FHCG, Technical Service Center**
- **Dam Safety Office**

Cooperative Institute for Research in Environmental Sciences (CIRES)

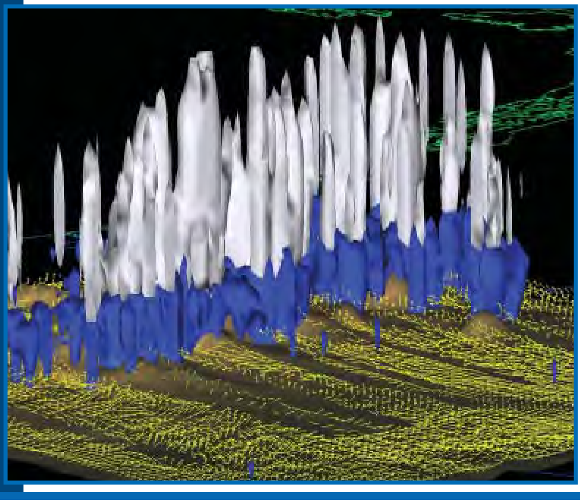
Problem

The Flood Hydrology and Consequences Group (FHCG) in Reclamation's Technical Service Center, as well as Reclamation's Dam Safety Office (DSO), are tasked with evaluating flood risk and the potential for heavy rainfalls for site-specific studies and projects. Estimating heavy precipitation potential in the Western United States is a particularly great challenge for Reclamation. Legacy methods and information resources support decisionmaking, but modern datasets and modeling technology provide an opportunity to improve these current tools. For example, knowledge of floods and short-term extreme precipitation events is limited by sparsely distributed observations of when and where storms occurred. One approach to estimating precipitation in areas of sparse station data is to smooth available data using interpolation, which often underestimates intensity in mountainous regions. A lack of such key data leads to greater reliance on approximations and outdated estimation methods that may not provide realistic information about the potential for heavy rainfall and flooding.

One possible way to improve extreme event estimation is through a dynamical weather model, but these can be computationally expensive to run. They also require a carefully designed setup in order to adequately support analysis and evaluation of extreme precipitation possibilities. Integrating a numerical weather model into FHCG's extreme precipitation assessment procedures has been discussed, but not adequately explored until this point.

Solution

Reclamation's Science and Technology Program, DSO, and FHCG teamed up with the Cooperative Institute for Research in Environmental Sciences (CIRES), a joint institute of the National Oceanic and Atmospheric Administration and the University of Colorado at Boulder to help understand the processes of summer extreme precipitation events in the Colorado Front Range region from both a historical and future climate perspective.



Example of high-resolution model output from a heavy precipitation event: surface winds (yellow arrows), three-dimensional rain isosurface (blue), and three-dimensional hail isosurface (white).

The approach featured application of a community weather and climate prediction tool, the Weather Research and Forecasting (WRF) model (www.wrf-model.org/index.php). Although many climate models are typically applied at a spatial resolution that is too low to adequately represent heavy precipitation events, in this study WRF was applied at a relatively fine resolution to permit event-scale simulation, focusing on historical events of interest to Reclamation.

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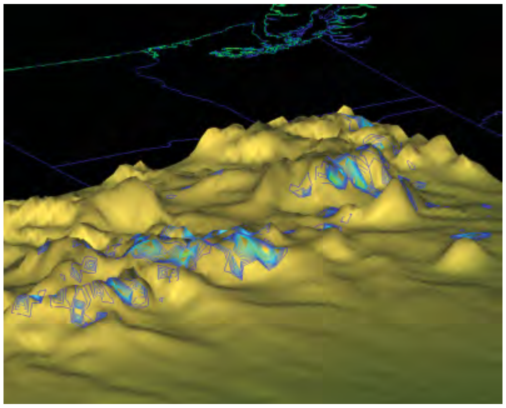
The high-resolution simulations offer improved insight into the fine-scale detail of heavy precipitation events, a more realistic understanding of their intensity, and which physical processes are realistically represented in coarser-scale climate models.

Using the model results, precipitation intensities were evaluated and intercompared, with an indepth focus on some specific Reclamation study sites (i.e., Green Mountain Dam). Assessments of possible climate change impacts on storms across Colorado were also evaluated, both from a regional-scale climate perspective as well as a higher-resolution, weather-event perspective.

Application and Results

The study identified several key findings regarding extreme summer precipitation events in Colorado, specific to the advantages of using a numerical modeling framework:

- Improved understanding of the impact of regional atmospheric conditions on individual storm events.
- Insight into the potential phase change of precipitation in future climates (e.g., snow versus rain or rain versus hail).
- Demonstration of WRF's ability to generate improved spatial and temporal patterns of extreme precipitation events for application in hydrologic models.



Example of high-resolution model output of surface runoff (colored contours) from a heavy precipitation event over the model topography (in Colorado).

In addition, regional climate model results suggest decreased mean warm-season rainfall with less agreement with respect to the potential for extreme precipitation events. The higher-resolution modeling effort suggests that chances of extreme events becoming more or less frequent are about equal overall in Colorado, but that local, heavy precipitation magnitudes will increase or remain large. One study finding also suggests that small hail (which is now common in high elevations in our current climate) may decrease in warmer future climates and instead fall as rain.

Relevant Publications

Alexander, M., J.D. Scott, K.M. Mahoney, and J. Barsugli. 2013. *Greenhouse Gas Induced Changes in Summer Precipitation Over Colorado in NARCCAP Regional Climate Models.* Journal of Climate, DOI:dx.doi.org/10.1175/JCLI-D-13-00088.1.

Mahoney, K.M., M.A. Alexander, J.D. Scott, and J. Barsugli. 2013. *High-Resolution Downscaled Simulations of Warm-Season Extreme Precipitation Events in the Colorado Front Range Under Past and Future Climates.* Journal of Climate, DOI:dx.doi.org/10.1175/JCLI-D-12-00744.1.

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Sankovich, V., J. Caldwell, and K. Mahoney. 2012. *Green Mountain Dam Climate Change*. Dam Safety Office Technology Development Program, Report DSO-12-03.

Green Mountain Dam, Colorado (one of the key sites studied in phase 1 of this research).

"High-resolution models provide a novel approach to evaluating the character of historical and future extreme precipitation events, offering improved representation of the timing, magnitude, and spatial distribution of precipitation events for input to hydrologic models for dam safety studies."

Jason Caldwell
Meteorologist, FHCG in Reclamation's Technical Service Center

Future Plans

Future plans for this work will focus on increasing the number of high-resolution simulations to better represent the extreme precipitation potential for a given region. This will be explored through "ensembles" of model simulations. The ensembles will use a variety of atmospheric conditions, including projected future climate conditions, along with different model configurations to provide a range of potential future spatial and temporal patterns of precipitation for dam safety applications. Considerable effort will be directed toward incorporating the high-resolution gridded precipitation products into both current FHCG hydrology products and models, as well as exploring the use of new hydrological models. The main goal will be to understand which of these experimental approaches and resultant data sets offer promise to near-term improvements to current FHCG procedures.

More Information

www.usbr.gov/research/projects/detail.cfm?id=6917

www.usbr.gov/research/climate/abstracts/pace.html

RECLAMATION Managing Water in the West

September 2013
Research and Development Office
Bulletin 2013-24

The Knowledge Stream
Research Update

Managing Future Water Resources in the Upper Deschutes Basin, Oregon

Applying existing tools to simulate integrated surface and ground water response to climate change

Bottom Line

By incorporating climate change models and local models, this study predicts how ground water responses to potential climate change will vary in the Upper Deschutes Basin, depending on the location, and spatial scale of the flow systems and their aquifer characteristics.

Better, Faster, Cheaper

This study provides a predictive tool to help water resource managers and water users in developing effective resource management strategies for adapting to potential hydrologic changes.

Principal Investigators

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Collaborators

- **U.S. Geological Survey (USGS)**
- **Portland State University, Oregon**

Problem

Water resource management typically relies on records of historical streamflows. However, this approach assumes that future streamflows will resemble past streamflows, which may be problematic in light of global warming and the changing climate.

Ground water plays a key role in determining the response of stream systems to climate change, and understanding how an aquifer system changes locally to climate change as these responses will also affect surface water. However, the relation between aquifer system scales (and diffusive characteristics) and the response to climate change has not previously been analyzed. Projected warming is anticipated to shift precipitation toward more rain and less snow in mountainous areas in the Pacific Northwest. This would result in smaller winter snowpack and in a shift in the timing of runoff to earlier in the year over the next century. This would cause changes in recharge timing and distribution through the ground water system that lead to changes in the timing and volume of ground water discharge to springs and streams.

Analyzing how local ground water recharge responds climate change is significant because many of the largest rivers in the Pacific Northwest originate in seasonal snow-dominated regions of the Cascade Range, where ground water-fed streams are common. Anticipated changes in snow hydrology, therefore, have important consequences for water supplies and aquatic ecosystems in the region.

In the Upper Deschutes Basin in Oregon's Cascade Range, for example, most precipitation now starts as snowpack in mountainous areas, which leads to substantial aquifer recharge during spring-snowmelt period, with higher recharge efficiency under snowmelt conditions compared to what would occur during winter rainfall-runoff events. As climate warming occurs, questions emerge about not only shift of recharge timing from spring to winter, but also efficiency as recharge is supported more by rainfall rather than snowmelt.

Changes in recharge and runoff in the Upper Deschutes Basin could markedly affect ground water levels, ground water discharge, and streamflow—which in turn affects water operations (modifying storage reservoirs to accommodate changes in ground water inflow timing) and ecosystems (changing timing for ground water-fed wetlands). Water managers need to understand and plan for these changes.

Solution

To provide insights into the way regional ground water systems that span spatial scales might respond to climate change, future climate projections were applied to water balance and ground water flow models in the Upper Deschutes Basin. To explore a range of possible future climate conditions in the study area, investigators used downscaled climate projections provided by the University of Washington from eight different global climate models and climate forcing scenarios spanning lower to higher greenhouse gas emissions.

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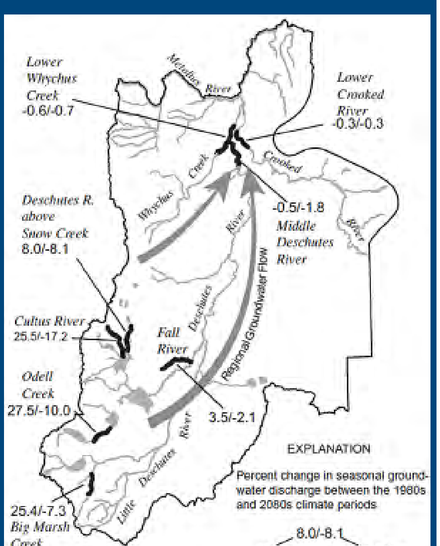

Percent changes in winter and summer ground water discharge to spring-fed streams and stream reaches in the Upper Deschutes Basin between the 1980s and 2080s climate periods.

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To simulate surface hydrology, runoff, and aquifer recharge in the Upper Deschutes Basin, a daily mass and energy balance model, the Deep Percolation Model (DPM), was used with historical daily climate data from weather stations in the basin to drive the model. To simulate aquifer discharge to streams, the recharge from DPM was used to drive a regional ground water simulation model, the U.S. Geological Survey's MODFLOW, which was applied to the Upper Deschutes Basin. Future runoff, recharge and discharge conditions were assessed by creating climate-adjusted weather inputs for the DPM model corresponding to the downscaled climate data.

Application Results

In general, the analysis showed that changes in the seasonal distribution of ground water discharge to springs and streams will be more prominent (relative to mean discharge) in upland areas near recharge areas where ground water flow paths are relatively short. Conversely, changes in seasonality of ground water discharge will be less prominent relative to mean discharge to major discharge areas at the terminal ends of regional ground water flow systems. As in-place seasonal recharge timing shifts earlier, smaller streams near the Cascade Range margin and in the upper portion of the basin, will likely experience shifts in timing of peak discharge through the 21st century in response to warming. Springs-feeding streams in the northern and central portions of the basin, such as the Deschutes River, lack a prominent seasonal signal.

Ground water discharge to streams varies, depending on the scale of the ground water system (length of flow path) and location. About 80 percent of the annual discharge of the Deschutes River, which drains most of the east side of the Cascade Range, originates as ground water discharge. This flow comes from discharge at a wide range of spring locations from small high-elevation spring complexes with relatively short flow paths (100 to 101 kilometers [km]) as well as large high-volume regional spring complexes with long flow paths (101 to 102 km) in the interior parts of the basin.

The response of aquifer systems to climate-driven changes in the seasonality of recharge will vary with spatial scale. Simulation results show that short flow path ground water systems, such as those providing baseflow to many headwater streams, will likely have substantial changes in the timing of discharge in response changes in seasonality of recharge. Regional-scale aquifer systems with long flow paths, in contrast, are much less affected by changes in seasonality of recharge. Flow systems at all spatial scales, however, are likely to reflect interannual changes in total recharge.

Bend Diversion Dam on the Deschutes River. It diverts water for the North Unit and Pilot Butte Canals.

Crooked River (tributary of the Deschutes River) near Crooked River Ranch several miles above Lake Billy Chinook.

Fall River Headwater Spring is a spring-fed tributary of the Deschutes River with a mean annual flow of about 150 cubic feet per second.

Quinn Creek is a spring-fed stream in the Upper Deschutes Basin that flows into Hosmer Lake. All photographs by Marshall Gannett, U.S. Geological Survey.

"More accurate predictions of hydrologic changes will help water managers more effectively plan water operations over the next century. Insights from the Upper Deschutes Basin have general applicability to other regional ground water systems with mountainous recharge areas."

Marshall Gannett
Hydrologist, U.S. Geological Survey

Future Plans

Understanding the impacts of climate change on aquifer systems is important because of the potential effects on a range of boundary flows (such as discharge to streams, springs, and wetlands), and implications for ground water users, human infrastructure, and water management. These coupled models can be used in future work as a predictive tool to help water resource managers make resource strategies and decisions. Results from these analyses provide valuable insights into the possible impacts of climate change to other regional aquifer systems, and the streams they support, where discharge points represent a range of flow system scales.

More Information

Waibel, M.S., M.W. Gannett, H. Chang, and C.L. Hube. 2013. *Spatial Variability of the Response to Climate Change in Regional Groundwater Systems–Examples From Simulations in the Deschutes Basin, Oregon*. Journal of Hydrology 486 (2013) 187 - 201.

Waibel, M.S. 2011. *Model Analysis of the Hydrologic Response to Climate Change in the Upper Deschutes Basin, Oregon*. Masters thesis, Geology:Geohydrology, Portland State University.

www.usbr.gov/research/projects/detail.cfm?id=2885

Climate Change Activities

Evaluating Climate Change Implications for Runoff, Water Temperature, and Habitat Metrics for Endangered or Threatened Fish

For many species recovery programs, habitat suitability for threatened or endangered fish depends on water temperatures during low-flow periods in late summer and fall. As our climate system continues to warm, it is expected that stream temperatures will approach upper tolerable thresholds—increasing concerns about this habitat dependency.

Restoration programs have a need to better understand the magnitude and timing of climate change impacts on streamflow, water temperature, and habitat metrics—and how these changes relate to ongoing channel rehabilitation activities. This study is developing a model framework to help predict the short- and long-term effects of climate change and resource management actions on river hydraulics and water temperature. The model framework will add the capability of linking watershed climate change data with two-dimensional reach-scale hydraulic and water temperature models. The reach-scale output can then be integrated into biological models being developed by a partnership between Reclamation and the U.S. Geological Survey (USGS). These biological models will predict age-specific and life stage-specific fish production based on habitat and food availability.

Initial project work focused on developing methods for modeling daily and subdaily stream temperatures under different climate regimes (Caldwell, et al., 2013). Reclamation also partnered with USGS to develop the biological modeling tools and assist with temperature data collection protocols. Reclamation is using multiple techniques to capture the spatial and temporal variability in water temperature to provide inputs to, and perform verification of, the models. Ongoing work includes testing the model framework on an unregulated system in the Methow River Basin in Washington State and a regulated, highly modified system in the San Joaquin River Basin in California.

Setting up a temperature logger (left) for deployment on a raft equipped with a Real Time Kinematic Global Positioning System (right) that was used on the Methow River to test data collection methods for input to a two-dimensional hydraulic model. Data collection included surface and bottom temperature collection, while floating with the ambient flow of the river and attempting to row cross-sections to document lateral changes across the river.

More Information

Caldwell, R.J., S. Gangopadhyay, J. Bountry, Y. Lai, and M.M. Elsner. 2013. *Statistical Modeling of Daily and Subdaily Stream Temperatures: Application to the Methow River Basin, Washington.* Water Resources Research, 49:4346-4361, DOI:10.1002/wrcr.20353. Available at: http://onlinelibrary.wiley.com/doi/10.1002/wrcr.20353/pdf.

Contact: Jennifer Bountry, 303-445-3614, jbountry@usbr.gov.

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Developing Climate Change Training Capacity

The Federal Climate Change and Water Working Group (CCAWWG), which is a collaboration between Reclamation and other Federal agencies such as the U.S. Geological Survey, U.S. Army Corps of Engineers, and U.S. Environmental Protection Agency, to name just a few, is working with the University Corporation for Atmospheric Research COMET Program and Western Water Assessment to develop a new COMET Professional Development Series, "Assessing Natural Systems Impacts under Climate Change." This series is designed to provide technical training to water resources professionals on how to incorporate climate change science and uncertainties into a variety of natural resource impacts assessments, including those related to surface water hydrology, crop irrigation requirements, water temperature, river and reservoir sedimentation, water quality, and land cover. Collaborators are currently focused on developing and delivering pilot course offerings to a mix of Federal and non-Federal students (e.g., residence courses on hydrology and crop irrigation requirement impacts were delivered in 2013; a virtual course on hydrology is scheduled in 2014; and residence offerings on water temperature and river/reservoir sedimentation impacts are being planned for 2014 and 2015, respectively). These pilot course offerings are being evaluated to identify effective course delivery and to inform requirements for a sustainable business model to support future delivery and maintenance of this professional development series.

To complement instructor-led residence or virtual course experiences, collaborators are also working with COMET to develop online, self-paced learning tools. An example is the online course developed as a common prerequisite to all residence and virtual courses, "Preparing Hydro-climate Inputs for Climate Change in Water Resource Planning." Available at: https://www.meted.ucar.edu/training_module.php?id=959.

Learning objectives include:

- Recognizing general science and terms associated with global climate models.
- Understanding how global climate model outputs are made regionally applicable through bias correction and downscaling.
- Determining climate change scenarios based on climate projections and selecting specific projections to inform each scenario.
- Developing climate-adjusted weather inputs associated with each climate change scenario.

See www.ccawwg.us/index.php/education.

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Literature Synthesis on Climate Change Implications for Water and Environmental Resources, Third Edition

Many types of water resources and environmental studies require up-to-date summaries of literature pertaining to climate change trends and implications. To help planners keep track of the latest peer-reviewed information, Reclamation publishes a biannual report entitled, "Literature Synthesis on Climate Change Implications for Water and Environmental Resources." The scientific data are organized around the five Reclamation regions, which correspond roughly with the Columbia River Basin, Sacramento-San Joaquin River Basins, Upper Colorado River Basin, Lower Colorado River Basin, and the Great Plains.

This report summarizes recent literature on the past and projected effects of climate change on hydrology. It also describes what has been studied regarding climate change implications for water and environmental resources in the 17 Western States. "This information will provide a foundation for water resources planning by providing consistent, peer-reviewed material to staff throughout Reclamation and water managers throughout the West," said Reclamation Commissioner, Michael L. Connor, about the report's first edition released in 2009. This report was originally developed following discussions by the CCAWWG, a collaboration partnership between Reclamation and other Federal agencies. This group identified that water managers and planners needed consistent, credible material that could provide a background for many kinds of operational and environmental studies.

The third edition of this report has just recently been published. The Water Resources Planning and Operations Support Group in Reclamation's Technical Service Center led the development and publishing of the report. All editions are peer reviewed by staff from the National Oceanic and Atmospheric Administration–Regional Integrated Science and Assessment Centers located in the Western United States. Reclamation's Denver Library maintains electronic copies of most of the articles cited in this report for use by Reclamation staff.

See www.usbr.gov/research/climate/docs/ClimateChangeLiteratureSynthesis3.pdf.

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Recent Climate Change Research Products

To get the information generated by research quickly into the hands of end users and the broader public, our researchers and partners publish their results in peer-reviewed journals, technical memoranda, research reports, and other venues.

Journal Publications

Alexander, M., J.D. Scott, K.M. Mahoney, J. Barsugli. 2013. *Greenhouse Gas Induced Changes in Summer Precipitation over Colorado in NARCCAP Regional Climate Models.* Journal of Climate, DOI:http://dx.doi.org/10.1175/JCLI-D-13-00088.1.
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doug_andersen@usgs.gov

Andersen, D.C. and S.M. Nelson. 2013. *Soil Temperature and Ground Water Depth Effects on First-Year Growth of a Dryland Riparian Phreatophyte, Glycyrrhiza lepidota (American licorice).* Southwestern Naturalist. In press.
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doug_andersen@usgs.gov

Glycyrrhiza lepidota (American licorice).

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Kelly.Mahoney@noaa.gov

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See www.usbr.gov/research/projects/detail.cfm?id=310.
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Recent Climate Change Research Products

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In Review

Elsner, M.M., S. Gangopadhyay, T. Pruitt, L. Brekke, N. Mizukami, and M. Clark. 2013. *How Does the Choice of Distributed Meteorological Data Affect Hydrologic Model Calibration and Sensitivity Analysis?* Journal of Hydrometeorology. In review.
See www.usbr.gov/research/projects/detail.cfm?id=675.
melsner@usbr.gov

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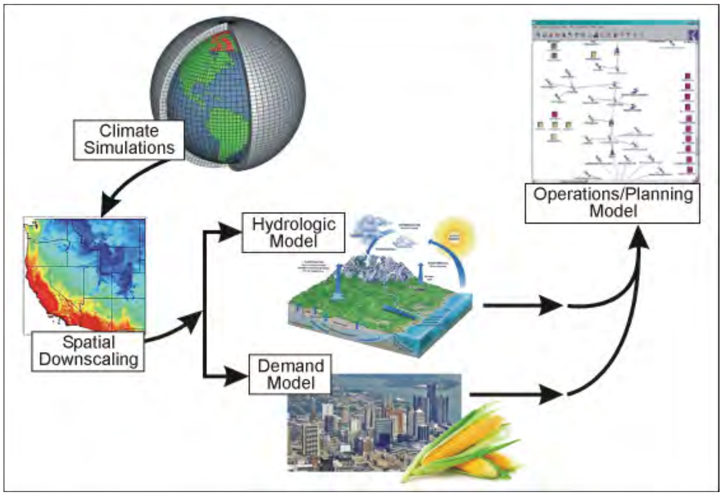
gutmann@ucar.edu

Rasmussen, R., et al. 2013. *Climate Change Impacts on the Water Balance of the Colorado Headwaters: High-Resolution Regional Climate Model Simulations.* Journal of Hydrometeorology. In review.
rasmus@ucar.edu



Modeling and analytical steps involved in the development of local hydrologic projections.

Reclamation Reports

Brekke, L.D., et al. 2013. *Downscaled CMIP3 and CMIP5 Climate Projections–Release of Downscaled CMIP5 Climate Projections, Comparison with Preceding Information, and Summary of User Needs.*
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lbrekke@usbr.gov

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jspears@usbr.gov

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snelson@usbr.gov

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david.a.raff@us.army.mil

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Research Updates

Bulletin Title, Quote, and Website | **Page**

RECLAMATION *Managing Water in the West*

September 2013
Research and Development Office
Bulletin 2013-25

The Knowledge Stream
Research Update

Improving Evapotranspiration Estimates for Better Water Management

Measuring evapotranspiration rates for wetlands and open water in the Upper Klamath Lake, Oregon

Bottom Line

ET is an important element in any water budget, and more accurate measurements can help provide more effective water management and planning. To improve ET estimates in the Upper Klamath River Basin, as recommended by the 2007 National Research Council, this study provided two seasons of detailed, measured data for estimation of wetland ET and open water evaporation.

Better, Faster, Cheaper

These high-quality data and analyses will be invaluable for future planning use (e.g., climate change, water rights transfer, improved water management) in the Klamath River Basin, as well as other areas in the Western United States.

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Collaborators

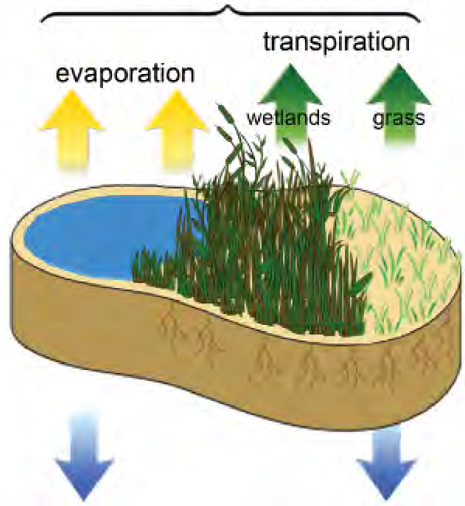
U.S. Geological Survey

Problem

The health and well-being of many ecosystems and water for agriculture, people, and cities depend on effective water management planning, including water allocations and water budgets. These water budgets cover more than inflows and outflows from rivers and reservoirs, they must also account for evaporation from open water and transpiration from plants—"evapotranspiration" (ET). Knowing how much water is lost to ET from various sources (e.g., shallow water, wetlands, grasses, and croplands) is key for deciding optimal water-use strategies. Yet ET estimates have been elusive and are usually lumped together with other substantial water-budget components.

In the Upper Klamath Basin, California and Oregon, water allocation has become difficult in recent years as droughts have increased in the face of continued high water demands. Upper Klamath Lake is central to water distribution, supplying water downstream to the Klamath River and irrigation diversions, as well as providing habitat for various species within the lake and surrounding wetlands. Potential land changes (from croplands to wetlands) and climate changes are among the water management challenges in this contentious basin that make quantifying ET losses even more critical in future planning to:

- Understand future changes in the marsh ET in view of potential climate changes.
- Determine the amount of water wetlands would require in re-establishing wetlands.



How evapotranspiration works.

Solution

To improve understanding of ET losses from open water on the Upper Klamath Lake and wetlands at the Upper Klamath Lake National Wildlife Refuge on the northwest side of the lake, this Reclamation's Science and Technology Program research project teamed up with the U.S. Geological Survey. ET was measured from May 2008 through September 2010. Two wetland sites that were almost 100 percent influenced by the wetland, rather than other factors like shoreline or water, were carefully chosen: (1) a monoculture of bulrush and (2) a mixture of bulrush, cattail, wocus, other vegetation, and open water. To continuously monitor ET at the wetland sites, the eddy-covariance method was used. To monitor open water lake evaporation at two additional sites during the warmer months, the Bowen-ratio energy-balance method was used. Reference ET (ETr, a standardized rate for a reference crop such as alfalfa or grass) was also calculated and the wetland ET rates were divided by ETr to develop crop coefficients (Kc). The Kc values can now be used to estimate wetland ET at other sites

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in the future as a function of ETr (ET=Kc x ETr). The wetland ET values were also compared to ET for alfalfa and pasture grass, two crops that are prevalent in the area. Application and Results: Wetland ET rates varied with the annual life cycle, increasing through the spring and early summer to a late summer peak, and then dropping off into the fall. Seasonal patterns of open water evaporation were similar to those of wetland ET, but with less of a seasonal cycle. Overall, measured open water evaporation was 20 percent greater than wetland ET during the same periods. The table below compares the mean 2008 through 2010 ET in meters (m) to that for alfalfa and pasture grass:

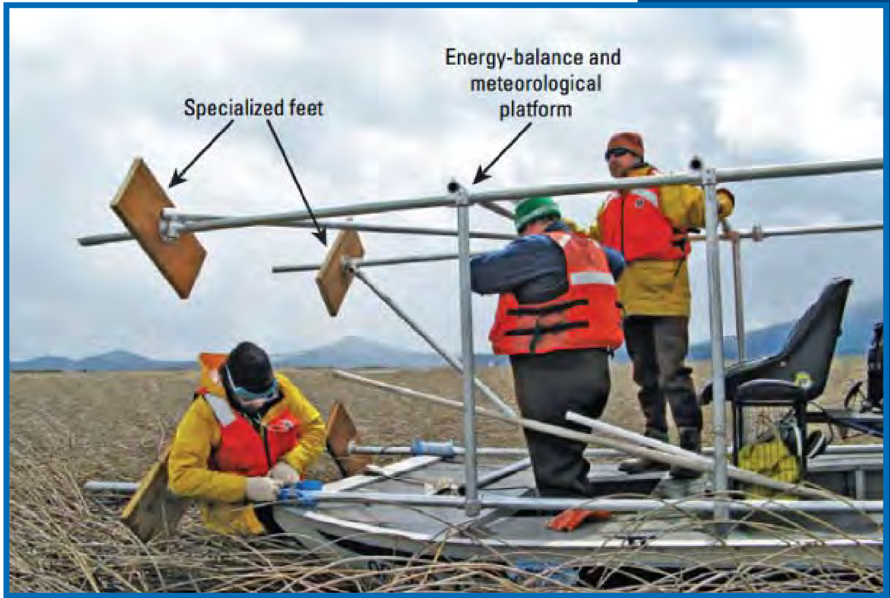
	Alfalfa Comparison (190-day average growing season)		Pasture Comparison (195-day average growing season)	
	Alfalfa ET	Wetland ET	Pasture ET	Wetland ET
Growing Season	0.838	0.779	0.671	0.789
Non-Growing Season	0.159	0.159	0.149	0.149
Annual	0.997	0.938	0.820	0.938

"Knowing the ET from the lake and surrounding wetlands will improve our planning ability, as now we can more accurately include this information to analyze and predict the physical response of the watershed to measured conditions in the basin."

Mark Spears
Hydraulic Engineer, Reclamation's Technical Service Center

During the 190-day average alfalfa growing season, wetland ET (0.779 m) is about 7 percent less than alfalfa reference ET (0.838 m). During the 195-day average pasture growing season, wetland ET (0.789 m) is about 18 percent greater than pasture ET (0.671 m). ET from the wetland during 2008 through 2010 (0.938 m) is about 43 percent greater than the fallowed cropland ET (0.655 m) measured in a 2000 study.

For example, replacing pasture with a wetland would require more water, as in a growing season. This is important to consider when taking croplands out of production and converting to marshes.



Setting up the ET monitoring equipment for the wetland. Specialized feet support the platform for equipment that measures available energy and meteorological data needed to calculate ET.

Future Plans

This information can now be used as input for models that can simulate ground water/surface water interactions and water quality analysis. These models will allow Reclamation to analyze various water delivery management scenarios and changing land use by analyzing the potential changes, in light of changing water demands, land use, and climate variability. In basins with high levels of controversy, these high-quality data will be invaluable for planning and demonstrating compliance with proposed mitigation measures.

Data gathered in this study will be used locally in the Klamath River Basin Study to understand water demands for wetlands and the Upper Klamath Lake. These data will also be used in broader study areas, such as the Westwide Climate Risk Assessment, as information for wetlands and shallow lake evaporation in similar conditions.

More Information

Stannard, D.I., M.W. Gannett, D.J. Polette, J.M. Cameron, M.S. Waibel, and J.M. Spears. 2013. *Evapotranspiration from Wetland and Open-Water Sites at Upper Klamath Lake, Oregon, 2008 – 2010.* U.S. Geological Survey Scientific Investigations Report 2013 - 5014, 66 p. Available at:

http://pubs.usgs.gov/sir/2013/5014.

www.usbr.gov/research/projects/detail.cfm?id=6485

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The Knowledge Stream

Research Update

How Large Woody Debris in Streams and Rivers Can Help Habitats

Developing the priorities for Reclamation's research into habitat enhancement with large woody debris

Bottom Line

A facilitated technical workshop with experienced professionals in the field of large wood and river restoration identified priority gaps in tools that are needed to improve understanding of large wood roles and processes in riverine environments.

Better, Faster, Cheaper

Better tools for understanding the role of large woody debris in habitats will increase the effectiveness of Reclamation's habitat restoration and rehabilitation programs.

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- **U.S. Army Corps of Engineers**

Problem

Historically, many rivers had abundant riparian vegetation and large wood. Removing these natural features can disrupt river environments and contribute to species decline. Re-establishing large wood features is frequently recommended as a component in river restoration projects to reestablish flow patterns, enhance habitat, and help recover species. However, guidelines and processes for designing and analyzing the benefits and risks of large woody debris have not been fully established. Moreover, research into this effort needs to be prioritized to meet Reclamation's mission and specific project goals.

Solution

To determine research needs in this field, Reclamation and the U.S. Army Corps of Engineers held an interagency workshop in February 2012. In the workshop, experts, who are currently designing and implementing large wood projects in river restoration, examined current tools and identified future large wood research needs and priorities. Reclamation's Science and Technology Program requested a tailored roadmap of large wood research concepts specific to Reclamation to help analyze future research proposals in this area of river restoration. The research roadmap was tailored to meet Reclamation's mission and project goals.

Development of the large woody debris research roadmap.

Top priority large wood research areas for Reclamation include:

- Develop technical guidelines on designing, implementing, analyzing scour, and monitoring.
- Communicate the value of large wood and risks.
- Design criteria to make safer structures.
- Develop more robust modeling techniques and interdisciplinary connections.

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- Develop tools to evaluate biological benefits, hydraulic effects, and potential consequences.
- Develop tools to evaluate interactions among multiple wood structures.

Application

The criteria in the table below was used to categorize research ideas into high, medium, and low priority groups based on technical merit, collaboration opportunities, and relevance to risk and safety.

Category	Technical Merit (Proposed research is a critical step commonly used in standard-of-practice design, analysis, or monitoring)	Collaboration Opportunity (Partnerships with academia, agencies, etc.)	Risk and Safety (Technical evaluation of liability associated with constructed features)
High Research Level	Poor surrogate tools are available and there is an immediate need to address a major data gap in the field of large wood design, analysis, or monitoring protocols.	Known opportunity exists to work with technical partners already working on identified data gap.	Research topic addresses safety and/or risk of constructed wood features, and would help inform whether to implement a large wood project.
Medium Research Level	Reasonable surrogate tools available for technical method, but lacking specific data for large wood.	Potential opportunity exists to work with technical partners, but have not started research.	Proposed research does not address safety or risk.
Low Research Level	Not a critical technique currently utilized, but may benefit design, analysis, or monitoring in the future.	Collaboration opportunities not yet identified; good candidate for scoping level proposal.	Proposed research does not address safety or risk.

"Using large wood as treatment to rehabilitate geomorphic processes and form for dependent species requires a thorough understanding of how to measure the associated risks and benefits. Research in this field will help us gain understanding for this evolving science and explore the most effective way to use large woody debris in our rehabilitation projects."

Sean Kimbrel
Hydraulic Engineer, Reclamation's Technical Service Center

Future Plans

Future Reclamation plans are to continue collaboration with partners to generate large wood analysis and implementation guidelines, along with modeling tools that incorporate the more complex hydraulics associated with large wood features.

More Information

www.usbr.gov/research/projects/detail.cfm?id=3775

North Wind's Weir site where King County, Washington, and U.S. Army Corps of Engineers have been placing earth-anchored log clusters in fine-grained soil to improve tidal backwater conditions at an urban site near Seattle that has local cultural significance. Photograph by Connie Svoboda, Reclamation's Technical Service Center, February 2012.

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The Knowledge Stream

Research Update

Sedimentation and River Hydraulics Modeling

Understanding river hydraulics and sediment processes for better river restoration, infrastructure design, and water management planning

Bottom Line

These research projects improve Reclamation's ability to simulate river behavior to better design hydraulic structures and river restoration projects.

Better, Faster, Cheaper

Modeling flow interactions and bank erosion provides more effective planning and design.

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Collaborators

- **U.S. Department of Transportation's Federal Highway Administration**
- **U.S. Department of Agriculture's Agricultural Research Service**
- **Taiwan Water Resources Agency**

Problem

River channels and habitats change, depending on erosion and deposition of sediments. Sediment builds up behind dams and other structures. Tracking how rivers transport water and sediment is crucial to understanding the ever-changing landscape of our waters. Thus, modeling water and sediment as dynamic systems is critical to water management planning, rehabilitating and protecting streams and river habitat, understanding reservoir sedimentation, and determining impacts of infrastructure changes, (e.g., dam removal; diversion dams modification).

Solution

The Sedimentation and River Hydraulics–Two-Dimensional Model (SRH-2D) developed by Reclamation is a model for river systems for two-dimensional (2D) analysis of hydraulic, sedimentation, temperature, and vegetation changes in river systems. It has been widely used and tested under a variety of river engineering tasks, from analyzing flow around fish screens to bank erosion of fish habitat on floodplains. SRH-2D solves 2D dynamic wave equations (i.e., the depth-averaged St. Venant Equations). Modeling applications include flows with in-stream structures,

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Channel restoration project on the Trinity River near Upper Junction City, California. A constructed side channel for the purpose of increasing salmon rearing habitat is in the foreground and an eroding bank is behind it.

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through bends, with perched rivers, with side channel and agricultural returns, and with braided channel systems. SRH-2D is well suited for modeling local flow velocities, eddy patterns, flow recirculation, lateral velocity variation, and flow over banks and levees.

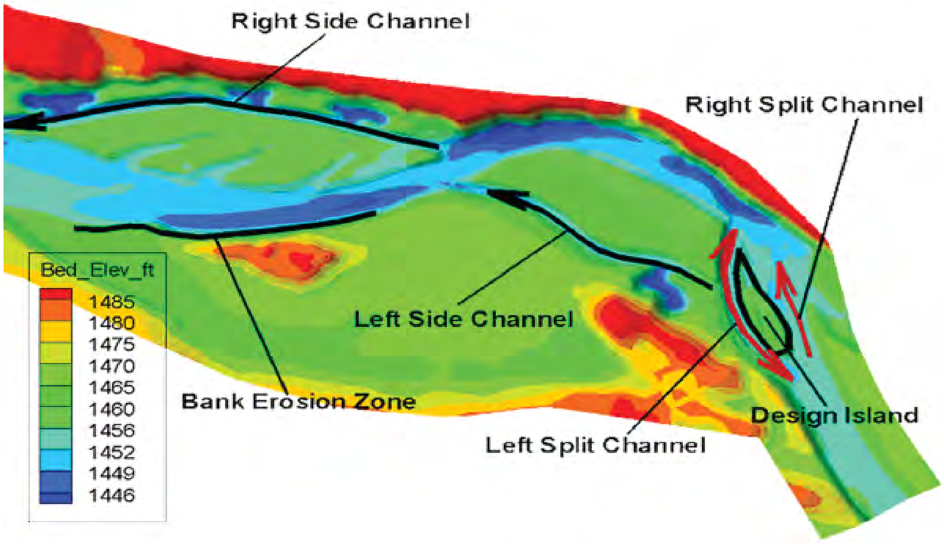
Reclamation's Science and Technology Program has several research projects designed to improve SRH-2D. SRH-2D has also received financial support from the Water Resources Agency in Taiwan to further develop its sediment transport ability and the U.S. Department of Transportation, Federal Highway Administration's ability to simulate hydraulics near bridges.

Predicting the Interactions Between Flow, Sediment, and Riparian Vegetation (ID 1368)

The survival of riparian vegetation within managed river systems is a growing challenge due to the increasing priority of maintaining or restoring ecosystem function while balancing the need for water supply and flood protection. Establishment, growth, and decay of riparian vegetation is largely determined by local hydraulics; conversely, characteristics of in-channel and floodplain vegetation affect hydraulics at the reach scale. Despite a wealth of prior research concerning the mechanics and biology of flow-vegetation interactions, the need for practical engineering tools for making quantitative predictions remains. SRH-2D provides this practical tool for decisionmaking. Vegetation simulation was integrated into a new SRH-2DV package that incorporates (1) a module that simulates spatially distributed establishment, growth, and mortality of riparian vegetation and (2) a module that simulates the effect of vegetation on river and floodplain hydraulics. These model abilities were tested on the San Joaquin River as part of the San Joaquin River Restoration Project.

Prediction of Bank Erosion to Improve River Restoration Strategies and Reservoir Sediment Management (ID 6606)

A predictive model of bank erosion in river channels and reservoirs was developed to improve designing river restoration strategies, planning river infrastructure, and managing reservoir sediment. This model builds on SRH-2D and adds the U.S. Department of Agriculture, Agricultural Research Service bank erosion module. This model was applied to the Trinity River near Upper Junction City, California, to estimate channel evolution and bank erosion impacts of river habitat improvement projects. It is also currently being used to estimate erosion from Lake Mills resulting from the removal of Glines Canyon Dam, Washington.



"SRH-2D has the best combination of flexibility and accuracy among two-dimensional models."

Yong Lai
Hydraulic Engineer,
Reclamation's Technical Service Center

More Information

SRH-2D:

www.usbr.gov/pmts/sediment/model/srh2d/index.html

Bank Erosion in SRH-2D:

www.usbr.gov/research/projects/detail.cfm?id=6606

Interactions between Flow, Sediment, and Riparian Vegetation:

www.usbr.gov/research/projects/detail.cfm?id=1368

SRH-2D Model of Bank Retreat Simulation at the Upper Junction site of the Trinity River, California, in support of the Restoration Project.

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The Knowledge Stream

Research Update

Rehabilitating Habitat Complexes in Side Channels

Understanding a case history of channel changes downstream of Yellowtail Dam will help facilitate the restoration of side channels

Bottom Line

This study provides a comprehensive history of side channel formation and loss and associated channel changes before and after the construction of Yellowtail Dam and Afterbay, Montana, to determine the cause of habitat loss in side channels of the Bighorn River.

Better, Faster, Cheaper

This information will help improve river management of aquatic habitat by determining the cause of habitat loss and the most effective means of restoring side channels.

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Collaborators

Reclamation's

- **Montana Area Office**
- **Science and Technology Program**

Western Area Power Administration

Montana Fish, Wildlife and Parks

Problem

Side channels provide critical spawning and rearing habitat for fish, including endangered species and sport fish. Not only do side channels provide critical habitat for fish such as juvenile salmonids, side channels also provide refuge for fish during floods and important habitat for riparian vegetation and wildlife.

Side channel habitat has been lost due to a combination of sediment deposition at side channel entrances, decreased flow magnitudes, loss of sediment supply, and vegetation encroachment. Previous studies on the downstream effects of large dams document decreases in flood peaks, sediment concentrations, and suspended load as well as degradation of channel beds, channel armoring, and increases in vegetation along river channels (e.g., Williams and Wolman, 1984). These changes tend to concentrate flow in the main channel while side channels are dewatered or receive flow only seasonally during larger flow releases, which may or may not be the corresponding time of year for spawning and rearing. Solutions are needed to rehabilitate side channels that have been progressively abandoned downstream from Reclamation structures and to prevent further losses of side channel habitat.

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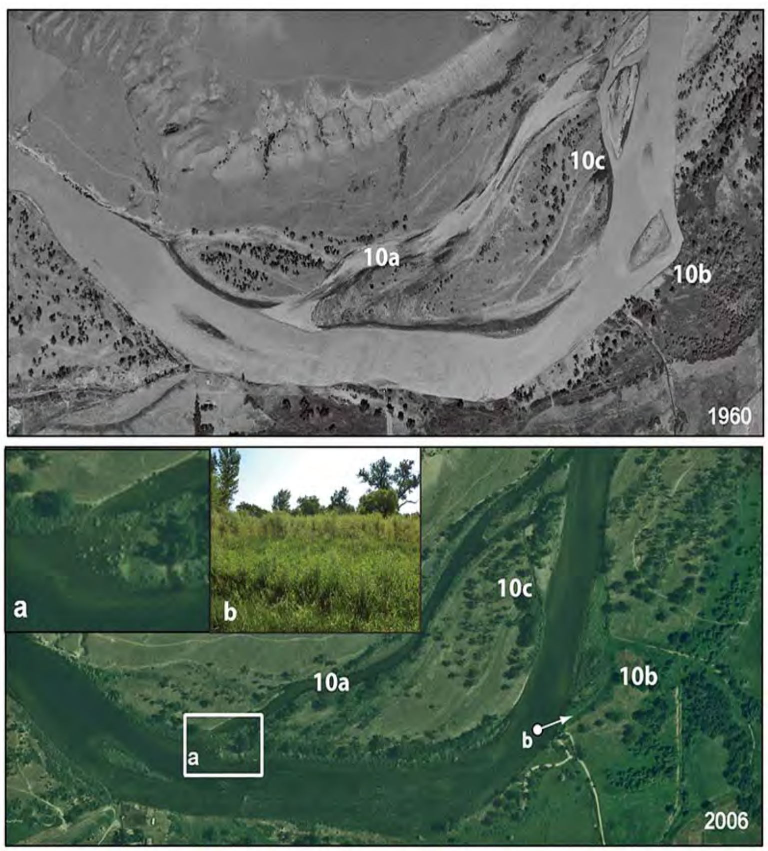

Channel changes at side channel complex 10 showing a comparison between 1960 and 2006; (a) vegetation establishment and sediment deposition in side channel 10a entrance; (b) vegetation growth in side channel 10b entrance.

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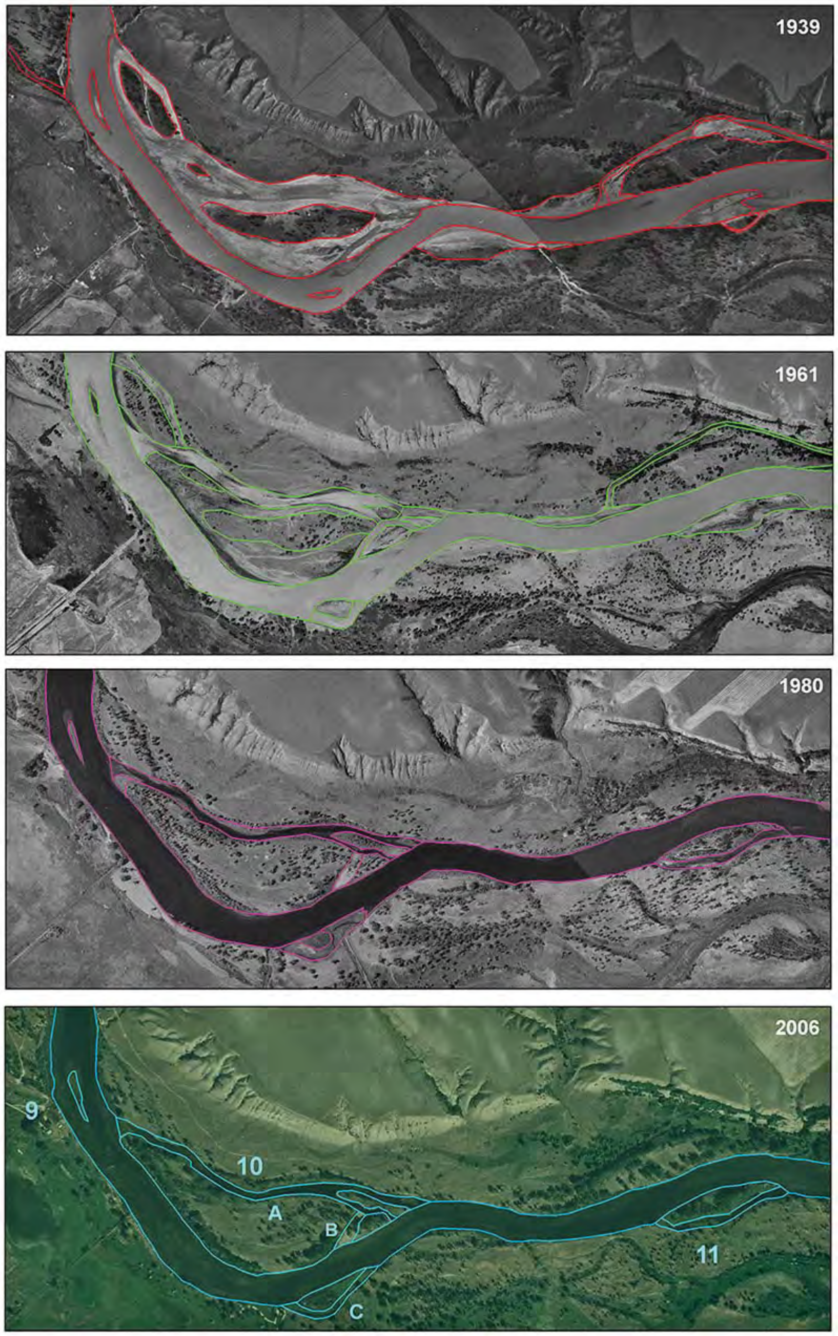
Solution

This Reclamation Science and Technology Program research project investigated ways to rehabilitate abandoned side channel habitat complexes through geomorphic investigations and hydraulic modeling. Potential solutions to reconnect abandoned side channels to the main stem included using in-stream structures, flow releases, gravel augmentation, and mechanical lowering of side channel entrances, etc. While these techniques have been applied on various rivers, there is still much that needs to be learned about the most effective method for a specific river system and, particularly, for river systems that have been impacted by the construction of dams.

The study was facilitated by a Memorandum of Understanding among multiple agencies and nonprofit groups including the National Park Service, Western Area Power Administration, State of Montana, State of Wyoming, Friends of the Bighorn River, Friends of the Bighorn Lake, Bighorn River Alliance, and Trout Unlimited.



Historical channel mapping for side channel complexes 9, 10, and 11 from 1939 to 2006.

"The research provided a case study of side channel abandonment and the solutions developed to address the loss of critical habitat downstream from a Reclamation structure. These solutions can be applied to other river systems that have experienced loss of side channel habitat as a result of dam construction."

Jeanne Godaire
Geologist, Reclamation's Technical Service Center

More Information

Science and Technology Program

www.usbr.gov/research/projects/detail.cfm?id=6257

Yellowtail Dam, Montana.

Yellowtail Reservoir at full pool in May. Photograph by Chuck Heinje.

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The Knowledge Stream
Research Update

Coating and Lining Resistance to High-Pressure Jets Used to Remove Invasive Mussels

Ensuring jets can remove mussels while keeping protective coatings and linings intact

Bottom Line

This research helped determine the optimal jet operating criteria to successfully remove mussel colonization without damaging existing and new coatings on hydraulic equipment (e.g., pipelines, trashracks, and gates).

Better, Faster, Cheaper

Water jetting is a valuable tool for removing mussels because it may be used on a variety of hydraulic infrastructure, including inside pipes and in between trashrack bars where removal is difficult. Understanding operation limits could save costs by reducing pumping required for jet flow and avoiding coating damage.

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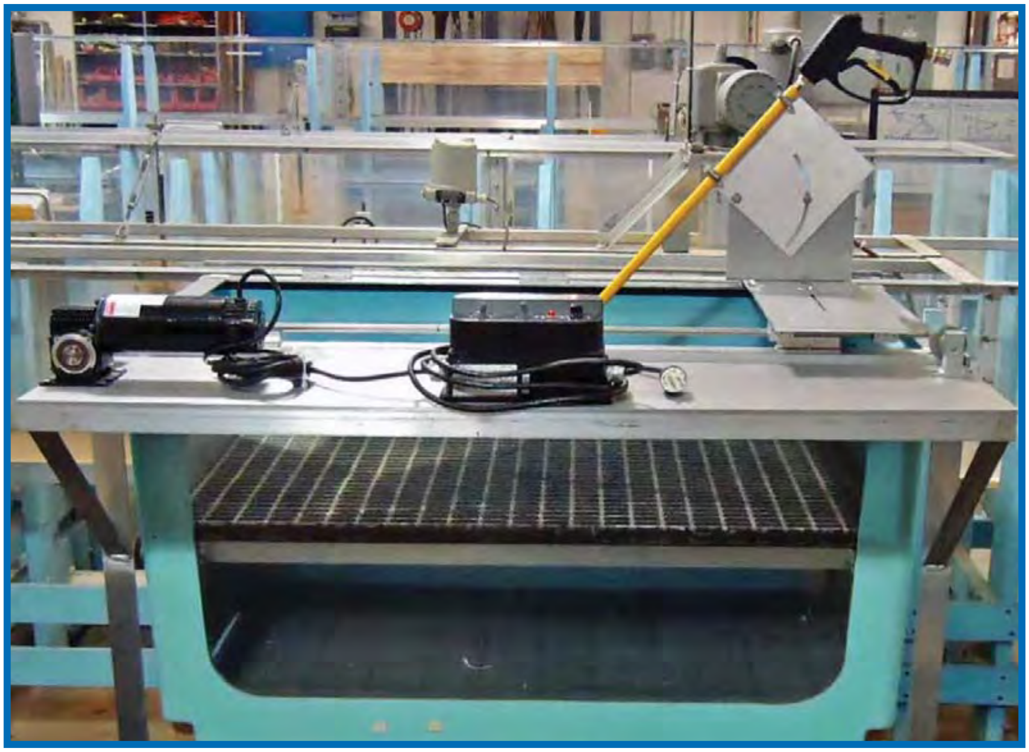
Reclamation

- **Materials Engineering and Research Laboratory in Reclamation's Technical Service Center**
- **Parker Dam, Arizona**

Problem

Invasive mussels pose many problems for Reclamation's infrastructure and operations, degrading facilities, clogging pipes, and fouling water. Developing new technology or using existing technology in new ways is needed to remove mussels. For example, Reclamation researchers recently developed a high-pressure water jetting nozzle that removes mussels that have attached to pipeline walls when operated with 5,000 to 10,000 pounds per square inch pump pressure. However, this much pressure also removes valuable coatings and linings that protect the pipes from corrosion, mussel attachment, and other degradation.

Another method to combat mussels, foul release coatings, deter mussels from attaching by using surface chemistry to significantly weaken the potential chemical bond between the organism and the substrate. However, their durability remains a concern. Using these coatings together with water jetting can enhance their effectiveness, but there is a fine balance between effectiveness and damage. High velocity jets could cause cavitation as eddies form and pressure drops. While submerged water jetting is not new, its effectiveness on, and impacts to, coatings are unknown.



Test apparatus used for coating durability and mussel release testing in both the laboratory and the field.

Solution

This Reclamation Science and Technology Program research project developed a test procedure to determine the pressures needed for a jet to remove attached quagga mussels without damaging the surface coating or material. Fourteen different existing and newly developed coating systems were tested, including recently developed foul release coatings. To determine the optimal operating range for jets to remove mussels from each coating, the coatings were tested in the laboratory for durability and damage, and in the field for live mussel detachment.

As there were high velocities and heavy cavitation associated with water jet cleaning, impact pressure testing was also performed to define the relationship between pressure and jet hydraulics (distance and velocity).

Application and Results

The pressure needed to detach mussels did not vary with the coatings, as the jetting impact pressure did not affect the coating. Rather, the pressure tore the mussels' byssal threads (the threads mussels use to attach to a surface). Byssal threads remained attached to the surface for all tests and could not be completely removed with the jetting system used in the current study. While leaving threads on the coating surface is not desirable, these threads do not protrude enough to significantly change flows or water pressure and, thus, we considered this a successful method to remove invasive mussels.

Test apparatus used for initial mussel removal testing at Parker Dam, Arizona, December 2011.

The jet stream's ability to remove invasive mussels was tested at Parker Dam near Lake Havasu City, Arizona, where live quagga mussels were attached to the coatings. The amount of mussels attached to the experimental plates varied widely—in general, more mussels were attached to bare metal samples or conventional coatings than the foul release coatings. Often, mussels would attach in clumps and would be 2 or 3 mussels thick. While the pressure required to remove mussels did not seem to vary with the amount of attached mussels, plates with fewer mussels were cleaner after jetting.

In every case, the damage impact pressures were higher than the pressures required to remove attached mussels. This gap in pressures allows a range of effective operation without exceeding the jetting durability limits for each specific coating or material. Within this range, measureable hydraulic parameters can be used to design and size a water jetting system that is effective and compatible with multiple coatings.

"Testing in this study has helped determine the operational limits and effectiveness of submerged jetting to remove mussels from coatings without causing damage. We will be looking at developing a hybrid jetting/ coating system initially for trashracks and possibly other hydraulic infrastructure."

Josh Mortensen
Hydraulic Engineer,
Reclamation's Technical Service Center

Future Plans

This new test procedure will allow the durability of future coatings and materials to be tested quickly and cheaply. These newly developed design and operating guidelines will be used as coatings are applied to existing infrastructure with the possibility of using a hybrid submerged water jetting system to keep the surface mussel free.

More Information

Reclamation. 2013. *Resistance of Protective Coatings to High Pressure Water Jets for Invasive Mussel Removal.* Hydraulic Laboratory Technical Memorandum PAP-1074.

www.usbr.gov/research/projects/detail.cfm?id=1740

RECLAMATION Managing Water in the West

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The Knowledge Stream
Research Update

Using Salt-Loving Plants to Treat Concentrates

Long-term testing for halophyte irrigation for concentrates from a desalination treatment using slowsand filtration and reverse osmosis.

Bottom Line

We can treat Colorado River water by managing salts through a combination of RO treatment and using the concentrate to irrigate salt-tolerant crops for agriculture and landscapes.

Better, Faster, Cheaper

This is a low-cost, environmentally friendly treatment that produces high quality water. SSF can be used by rural areas, for example on Native American reservations.

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Northwest Water Providers Partners

- **Metropolitan Domestic Water Improvement District**
- **Flowing Wells Irrigation District, Marana Water**
- **Oro Valley Water**

Tucson Water

University of Arizona

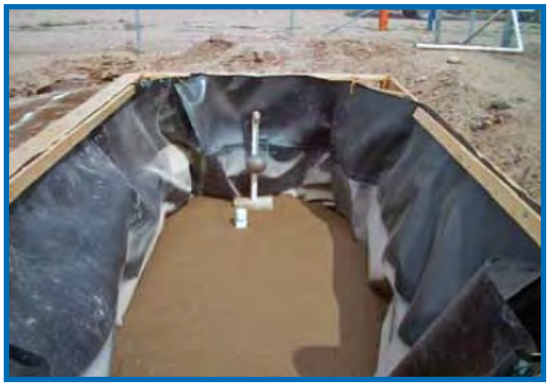
Problem

Increasingly stringent water quality treatment regulations, along with the long-term impacts of increased salinity in the Colorado River have caused water providers in the arid regions of the Western United States (U.S.) to focus on treatment technologies that will avert long-term problems. Local water quality concerns with Central Arizona Project (CAP) water have delayed full use of CAP water in Pima County, Arizona.

Current problems with arsenic, perchlorate, and salinity in Phoenix, Arizona; Las Vegas, New Mexico; southern California; and El Paso, Texas, offer compelling evidence that finding long-term water treatment solutions is critical to sustaining our Nation's future water supplies. Developing a low-cost, environmentally friendly treatment that produces high quality water will pay dividends for generations. This technology can be transferred to many cities and towns across the Western U.S.

Solution and Results

Reclamation's Science and Technology Program teamed up with the University of Arizona at the Marana Pilot Project to study all parts of a reverse osmosis (RO) treatment for CAP water—from pretreatment to managing the brine (the concentrate left after extracting treated water). Each of these areas was aggressively investigated through field site operations, data acquisition and monitoring, performance evaluation, technology assessment, and systems analysis. A long-term test was conducted at Reclamation's Mobile Treatment Facility, which has been in operation at the Cortaro Marana Irrigation District/ Central Arizona Water Conservation District turnout in Marana, Arizona, since 2007.



Slowsand filter after draining water.

Pretreatment

RO, an effective desalination treatment, requires high quality pretreatment to operate economically. Pretreating raw (or source) water is absolutely necessary to preserve the RO membrane integrity, prevent fouling of the membranes, and extend membrane life. Typically, this is done with chemicals, which can introduce unwanted byproducts, or with expensive filtration processes. The

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Slowsand filter after being filled up.

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Marana Pilot Project tested slowsand filtration (SSF) as an inexpensive pretreatment for RO. A slowsand filter consists of a tank containing a fine sand on top of a layer of gravel. Raw water flows in from the top and percolates by gravity through the sand. Organic material is removed by a biological layer called "schmutzdecke," which forms at the top of the sand layer. When the now clean water reaches the bottom of the filter, it is collected through a drain consisting of a perforated pipe under the gravel.

SSF and microfiltration (MF) was compared as pretreatment technologies for desalination by RO. These two pretreatment alternatives were studied previously, leading to a conclusion that both methods performed adequately but that, land permitting, SSF was much less expensive. However, as RO membrane post mortems indicated that SSF may have left clay particles on the RO membranes, MF pretreatment was reevaluated.

Side-by-side comparison of the pretreatment options suggests that MF is capable of outperforming SSF based on silt density index values in reactor effluents. Results suggest that the quality of MF-treated water may be superior to that SSF effluent for downstream RO separation of water-soluble components.

Treatment

The long-term RO performance was monitored over a period to compare interseasonal effects and establish limits to membrane life. It was found that very high recoveries, on the order of 99 percent, are feasible when RO is carried out using a presoftened water in combination with the deployment of the vibratory shear enhanced process.

Concentrate Management

Managing the "waste" stream from RO is difficult and expensive. Ways were examined to eliminate the need for evaporation ponds—which present environmental concerns due to high concentrations of certain constituents—by growing salt-loving plants (halophytes) and using the concentrate to raise fish.

Salt Loving Plants

Halophytes can be harvested for additional value. It was found that Atriplex lentiformis (a halophyte) can be irrigated with RO concentrate from CAP water in Tucson, Arizona. These plants can be used for livestock feeding, as the proximate analyses show Atriplex lentiformis to be comparable to conventional forage in protein and other digestables, but higher in salt. The halophytes, were irrigated with varying volumes of concentrate to measure the maximum amount of concentrate that could be used to grow the halophytes. Drainage below the root zone can be managed to provide for aquifer protection; the study indicates that lining to prevent water movement to the deeper aquifer may not be necessary.

Atriplex lentiformis

Fish

The concentrate can also be used to help raise food fish. A number of bench top bio-assays was conducted to determine viability of aquaculture species (shrimp and Tilapia) on concentrate. Survivability and growth rate on both RO and VSEP concentrate are being evaluated.

"The Marana Pilot Project demonstrates the ability of local utilities, academia, and the Federal Government to work together to produce real-world innovations. It has proven that SSF can be an effective and cost-saving pretreatment for RO of CAP water. It has also shown that unsightly evaporation ponds can be replaced attractive plantings, converting a troublesome waste product into a useful resource."

Eric Holler
Tucson Field Office Manager, Reclamation's Lower Colorado Region

More Information

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Recent Research Products

To get the information generated by research quickly into the hands of end users and the broader public, our researchers and partners publish their results in peer-reviewed journals, technical memoranda, research reports, and other venues. Contact the authors for information about these documents or research projects.

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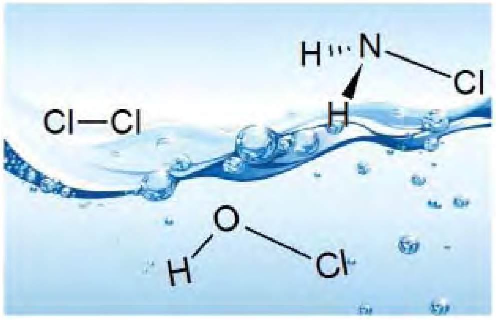
— *continued*

Bar rack at the entrance to the Red Bluff fish refugia panel in dewatered condition.

Red Bluff fish refuge panel with blocked section. The direction of riverflow is from right to left.



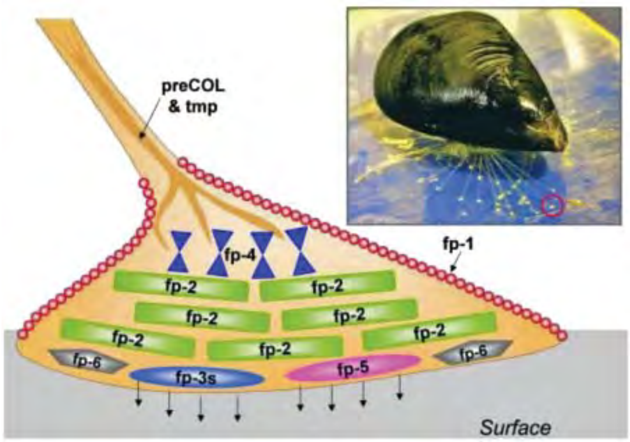
"Effect of Chlorine vs. Chloramine Treatment Techniques on Materials Degradation in Reclamation Infrastructure."

Photographs of Oxnard Wetland Stages, City of Oxnard, California— Stage 1: Horizontal Subsurface Flow.

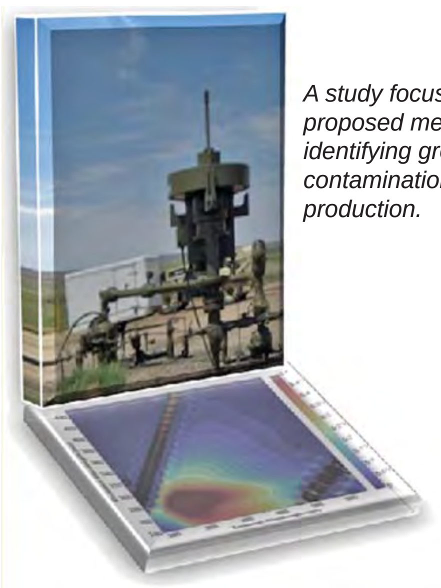
Stage 2: Vertical Subsurface Upflow.

Stage 3: Surface Flow Marsh and Open Pond.

Large Wood Research Workshop, February 2012, Seattle, Washington.



Organization of mussel foot proteins within the mussel plaque (reprinted from Hwang, et al., 2010).



A study focusing on a proposed method of identifying ground water contamination from gas production.

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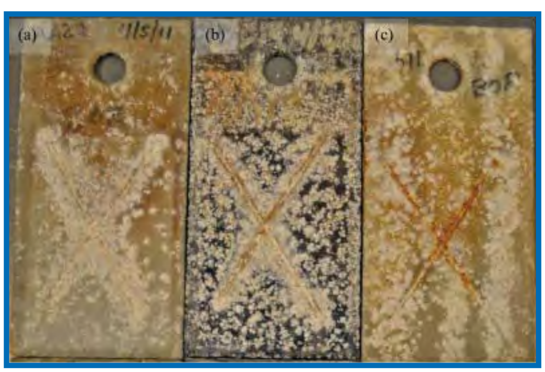
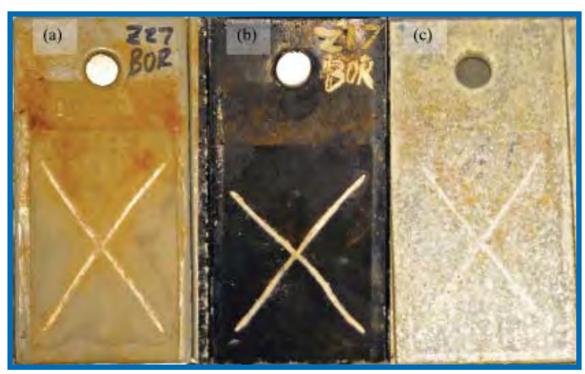


Effect of thick seal coat: Zinc systems tested in the Reclamation cycle after 5,040 hours. (a) Amercoat seal, (b) Metco seal, (c) unsealed.



Effect of thin seal coat: Aluminum/Al2O3 systems tested in the Reclamation cycle after 5,040 hours. (a) Amercoat seal, (b) Metco, (c) unsealed.

West Fork Fire Complex in southwestern Colorado, June 2013.

East Peak Fire, on East Spanish Peak, Heurfeno County, Colorado, June 2013.

The San Acacia Diversion Dam peaked the morning of September 16, 2013, at more than 7,000 cubic feet per second. The dam is on the Rio Grande River in San Acacia, 15 miles north of Soccoro, New Mexico.

Dille Diversion Dam, near the mouth of the Big Thompson Canyon just west of Loveland, Colorado, is a small facility that is part of Reclamation's larger Colorado-Big Thompson supplemental water supply project.

Colorado-Big Thompson Project Flooding: This is a photograph of the mouth of the Big Thompson Canyon. This is the siphon for the Charles Hansen Feeder Canal as it transports water to Horsetooth Reservoir; it carries the water over the river.