RECLAMATION Managing Water in the West

July 2013
Research and
Development Office
Newsletter 2013-04

The Knowledge Stream

Advanced Water Treatment Issue

Our New Advanced Water Treatment Research Coordinator

Yuliana Porras-Mendoza is our new Research Coordinator for Advanced Water Treatment, replacing Kevin Price who served as Reclamation's lead for several years until his recent retirement.

Yuliana has been with Reclamation for 12 years. She has a Bachelors of Science in Chemical Engineering and a Masters in Environmental Science and Engineering from the Colorado School of Mines, as well as a Masters in Technology Commercialization from the University of Texas.

Yuliana is Reclamation's technical lead on Chlorine Resistant Reverse Osmosis Membrane. She also serves on the Board of Directors of the Society of Hispanic Professional Engineers.

Katharine Dahm, PhD, and Katie Guerra, PhD, served as principal editors for this issue.

Director's Message

Direct potable reuse of wastewater. Treatment of oil and gas "produced waters." Removal of endocrine-disrupting human pharmaceuticals. Desalination of seawater.

These issues, and many more, make the field of Advanced Water Treatment (AWT) one of the most dynamic, important, and sometimes controversial areas of contemporary water management. AWT encompasses all of the engineering, science, and technology we use to make the most seriously degraded water a useful resource in a water-short world. These high-tech methods—like reverse osmosis, nanofiltration, membrane bioreactors, advanced oxidation, forward osmosis, and membrane distillation—go beyond the traditional water treatments of the past to enable removal of high concentration of salts, biological contaminants, and organic compounds. AWT also includes taking low-tech, natural systems—like wetlands—and engineering them to meet demanding water treatment challenges, such as removal of toxic metals and human pharmaceuticals.

To meet the water management needs of the West, and address associated environmental concerns, Reclamation maintains a diverse portfolio of AWT research and development, ranging from laboratory scale up to field tests of pilot treatment plants. Some of the research is closely tied to operation of Reclamation's Yuma Desalting Plant, one of the largest reverse osmosis desalination plants in the world, or occurs at our Brackish Groundwater National Desalination Research Facility (BGNDRF) in Alamogordo, New Mexico (see photograph).

In carrying out AWT research, Reclamation works with many partners, including states concerned about emergency drought supplies, cities seeking to reduce the volume of brine discharge from their desalting plants, and industry seeking to reuse waters contaminated with hydrocarbons. This issue of the Knowledge Stream highlights Reclamation's array of AWT activities involving many technologies, partners, and facilities, all in service of making new water supplies available at lower cost, using less energy, and with fewer environmental impacts.

Curt Brown
Director, Research and Development

Bobby Granados, Engineering Technician; Randy Shaw, Facility Manager; and Steve Holland, Electronic Technician at BGNDRF in Almagordo, New Mexico (see page 19).

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

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AWT Around Reclamation

"Reclamation researchers are exploring a number of innovative materials to ensure new water supplies. AWT and water reuse can be used to increase the current water supply by treating unused or underutilized impaired sources. AWT processes separate constituents (such as salts, micro-organisms, suspended solids, and chemicals) from water.

Treatment technologies include membranes and other separation technologies such as thermal, adsorption, and ion exchange; advanced oxidation processes; and constructed wetlands."

Yuliana Porras-Mendoza
Advanced Water Treatment Research Coordinator

Reclamation's Role in Advanced Water Treatment Research

The Federal Government plays an important role in the sustainable use of water resources.

Investments in Advanced Water Treatment (AWT) research lead to new usable water supplies, new tools for water reuse and conservation, and help ecosystem restoration efforts that help ensure water supplies for the future. Reclamation recognizes the growing importance of unconventional water sources and makes AWT research and development a priority.

Using Advanced Water Treatment

Reclamation's programs and projects partner with academic, government, water utility, and commercial sectors to promote innovation and adoption of new AWT technologies:

- **Increase Water Supplies.** Understanding the extent of the unconventional sources and required treatment. Supporting appraisal, feasibility, and design for conservation, reuse, and desalination.
- **Reduce Cost.** Identifying new processes and improvements in existing technology to reduce life-cycle costs by lower capital and operating costs. Reducing treatment costs makes water treatment an attractive alternative in locations where traditional sources of water are inadequate.
- **Reduce Environment Impacts.** Identifying methods to reduce environmental impacts of AWT technologies, especially those areas related to energy use and concentrate disposal.
- **Identify Institutional Barriers.** Helping to address barriers related to guidelines, standards, and regulations. Helping to provide updated information on AWT system performance.

Kay Bailey Hutchison desalination plant in El Paso, Texas.

Innovation: The Research Process

Steps In the Process

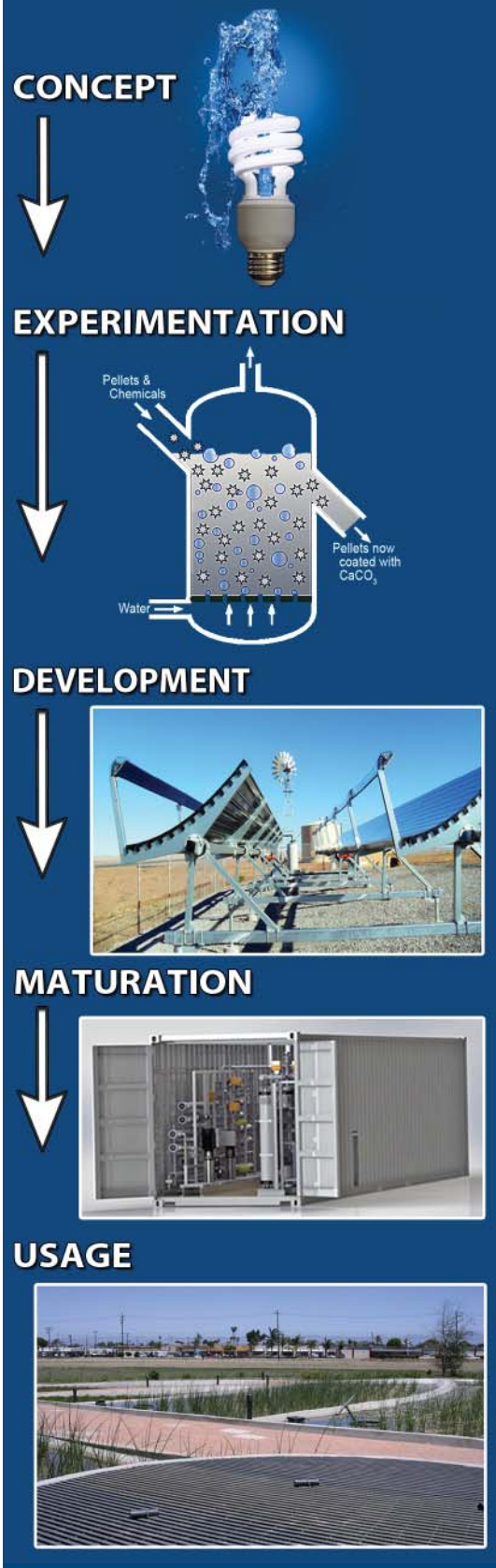
Research studies highlighted in this Knowledge Stream issue include technologies and research projects in Advanced Water Treatment (AWT) that cover the entire spectrum of technology development:

- **Concept.** Generating a new concept resulting in new or improved technology that can be applied to increase water supplies.
- **Experimentation.** Conducting experiments and proof-of-concept laboratory testing to validate a treatment process or application.
- **Development.** Testing the concept at the pilot scale to gain real-time operating data in a field setting
- **Maturation.** Demonstrating the concept on a larger scale to verify scalability, economic feasibility, and technical validity
- **Usage.** Incorporating successful concepts into engineering design activities, full-scale treatment plants, and deploying commercial products.

Technologies Advancing Through the Development Process

Reclamation worked with a wide range of partners in one or more steps for many desalination concepts that are now maturing or being used at full scale, including:

- Biotreatment for Selenium Control
  www.usbr.gov/research/docs/updates/2012-23-san-joaquin-selenium.pdf
- Hollow Fine Fiber Membranes
  www.usbr.gov/research/AWT/reportpdfs/report040.pdf
- Indirect Potable Reuse
  www.usbr.gov/WaterSMART/title/index.html
- Membrane Bioreactor (MBR)
  www.usbr.gov/research/AWT/reportpdfs/report103.pdf
- Membrane Distillation
  www.usbr.gov/research/AWT/reportpdfs/report099.pdf
- Membrane Sizes (From 8 to 16 Inches)
  www.usbr.gov/research/AWT/reportpdfs/report114.pdf
- Seawater Reverse Osmosis
  www.usbr.gov/research/docs/updates/2012-10-reverse-osmosis-energy-savings.pdf
- Slantwell Subsurface Ocean Intakes
  www.usbr.gov/research/AWT/reportpdfs/report153.pdf



Driving a concept to usage.

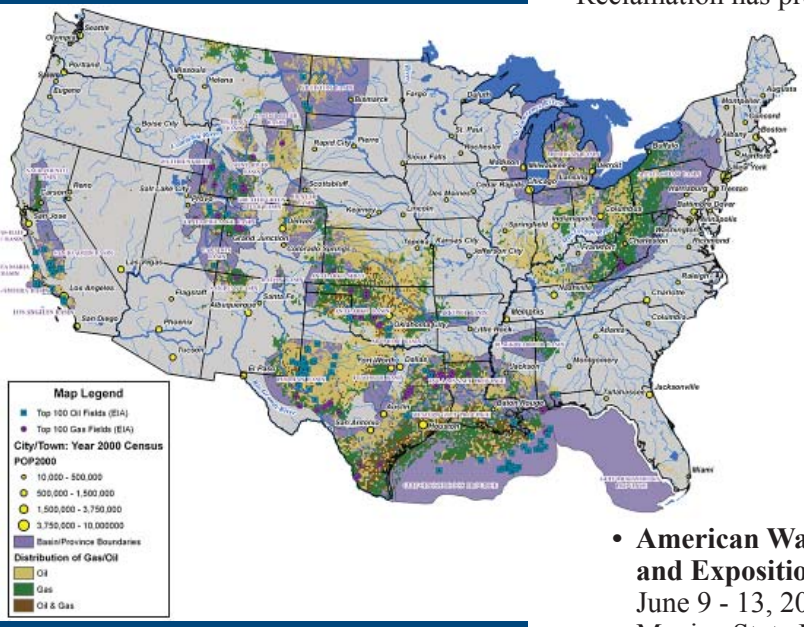
Recent Events

Fabiano Silva and Mônica Campos from Minas Gerais, Brazil, visiting the Reclamation's Invasive Mussel Research Laboratory.

Checking on Neighboring Invasive Mussels

The golden mussel (*Limnoperna fortunei*) is an invasive mussel similar to zebra and quagga mussels. However, as this mussel tolerates a wider range of salinity, low pH values, and higher temperatures than the zebra and quagga mussels do, golden mussels could invade a broader range of habitats. The species was introduced into Argentina from Asia in the early 1990s, and by 2006 it had spread to Uruguay, Paraguay, Bolivia, and Brazil. The golden mussel is considered an invasive species in South America and is expected to spread further. Forecasting its spread and determining control methods are essential to protecting South America's water management infrastructure and environment.

Two visitors from Minas Gerais, one of Brazil's 26 states, came to Reclamation's Invasive Mussel Research Laboratory to learn about our innovative detection and control methods for zebra and quagga mussels. Fabiano Silva and Mônica Campos from the Centro de Bioengenharia de Espécies Invasoras de Hidrelétricas (CBEIH) and the Fundação Centro Tecnológico de Minas Gerais (CETEC). The Brazilians are interested in developing an early detection laboratory similar to the one here at Reclamation. Reclamation's Invasive Mussel Research Laboratory had analyzed test samples from Brazil, using both microscopic and polymerase chain reaction (PCR) (tests to sequence DNA). The Brazilian visitors spent 2 days in Denver discussing the methods and procedures that we use for early detection of mussels. They also toured other Reclamation testing facilities in Denver, including the hydraulics laboratory. This collaborative effort will result in developing a similar early detection laboratory in Brazil.



National oil and gas production.

Presenting Advanced Water Treatment Research Results

Reclamation has presented research results at various conferences recently, including:

- **American Water Works Association Sustainable Water Management Conference**
  April 7 - 10, 2013, Nashville, Tennessee. Reclamation presented a paper, "Guidance for the Evaluation of Produced Water as an Alternative Water Supply." See www.awwa.org/conferences-education/conferences/sustainable-water-management.aspx.

- **Produced Water Management in the West**
  May 21 - 22, 2013, Denver, Colorado. Reclamation presented guidelines and case studies. Researchers discussed water management techniques and options for the oil and gas industry to minimize water use through water treatment in water scarce areas of the Western United States (U.S.) (see page 30). See www.euci.com/events/?ci=1928.

- **American Water Works Association ACE[13] Annual Conference and Exposition**
  June 9 - 13, 2013, Denver, Colorado. Reclamation partnered with New Mexico State University (NMSU) on the paper, "Demonstration of a Hybrid Photovoltaic-Reverse Osmosis System for Off-Grid Desalination" and the Texas Water Development Board on, "Optimized Membrane Selection to Reduce the Cost of Inland Desalination in Texas." We also hosted a booth to highlight Advanced Water Treatment research activities at the Brackish Groundwater National Desalination Research Facility, NMSU, and Reclamation. See www.awwa.org/conferences-education/conferences/ace13-annual-conference.aspx.

Upcoming Events

Planning More Advanced Water Treatment Presentations

Reclamation will also be participating in two conferences in November 2013:

- **American Institute of Chemical Engineers (AIChE) Annual Meeting: Global Challenges for Engineering a Sustainable Future**
  November 3 - 8, 2013, San Francisco, California.
  Reclamation will co-chair "Desalination and Water Management for Rural Communities." In this session, Reclamation will give two oral presentations:

  1. Chapman, M., A. Tiffenbach, and F. Leitz. "Variable Salinity Desalination."

  2. Akbar, L., L. Karimi, and K. Guerra. "Photovoltaic-Powered Reverse Osmosis."

See www.aiche.org/conferences/aiche-annual-meeting/2013.

- **International Petroleum Environmental Conference (IPEC)**
  November 12 - 14, 2013, San Antonio, Texas.
  Reclamation will present two papers:

  1. Dahm, K. and K. Guerra, 2013. "Guidance for Oil and Gas Water Management to Create Alternative Water Supply."

  2. Guerra, K. and K. Dahm, 2013. "Application of Treatment Technologies in the Oil and Gas Industry." Centralized Waste Treatment Facility Approach to Produced Water Treatment and Beneficial Use."

See http://ipec.utulsa.edu/conferences.htm.

Featured Faces

People are what make any organization great, and Reclamation is no exception.

Randy Shaw describing features of BGNDRF.

Randy Shaw, BGNDRF Facility Manager

At the Brackish Groundwater National Desalination Research Facility (BGNDRF) in Alamogordo, New Mexico (see page 19), Randy Shaw's can-do attitude spills over into his many roles, including:

- **Outreach and Presentations.** Randy represents BGNDRF in a myriad of venues, from conferences and presentations to civic organizations, to newsletters and collaborative meetings. His most current community outreach includes partnering with the New Mexico Museum of Space History to demonstrate to kids in a summer camp how water can be purified during a space mission.

- **Facility Use.** Randy finds innovative ways to use BGNDRF; for example, investigating the possibilities of using BGNDRF as a part-time regional training center for desalination plant operators.

- **Facilitating Clients' Research.** As clients range from university students and post-doctoral researchers to other government agencies and companies, needs vary considerably. Randy works closely with existing and potential clients to make sure that they can conduct their research effectively and save as much money and time as possible. This includes opening the facility on nights and weekends, ensuring equipment setup, and concentrate disposal processes are as easy as possible—even guiding clients through permitting processes.

- **Connecting Clients.** Randy strives to be a hub for contacts and expertise. He connects people with ideas and needs with people whose expertise can transform these concepts into reality. He also connects distant clients with local experts and students who can assist with the research at BGNDRF without requiring the client's full-time presence. International interests are accommodated as well, including the Netherlands, Canada, Israel, Spain, and South Africa.

Randy has had a long career in innovation and management. At Lockheed Engineering and Management Services Company (LEMSCO), Randy was one of three inventors who received a patent for using friction as an ignition source in high-pressure oxygen. After his work with LEMSCO, in 1985, he designed concrete-lined, irrigation conveyance canals and appurtenances with Franzoy Corey Engineers and Architects in Phoenix, Arizona. From 1989 to 2003, Randy worked with the Bureau of Indian Affairs to manage various projects, working with a wide range of agencies, including Federal, state, and municipal agencies to coordinate water deliveries from the Rio Grande to the Pueblos. This work required extensive interaction with lawyers and engineers dealing with highly complex water issues.

Randy is a licensed Civil Engineer, and graduated from New Mexico State University in Las Cruces, New Mexico, in 1977 with a Bachelors of Science in Agriculture Engineering.

Frank Leitz, Chemical Engineer

Frank Leitz has been a leading figure in the desalination field for over half a century. His career in Advanced Water Treatment technology began with research on membranes for electrodialysis in the 1950s and 1960s and continued with process selection, design, and, ultimately, construction of the world's largest reverse osmosis (RO) membrane desalination plant in the 1970s and 1980s.

In the early 1960s, Frank joined Ionics, Inc., to help develop electrodialysis (ED), the first commercial desalting membrane process. He holds a number of patents in the early science of electro-chemical membrane processes. Though electrodialysis opened the path toward affordable desalination, it was RO membranes that eventually paved the way to large-scale desalination, and Frank led the way. In 1975, Reclamation recruited Frank to lead the technical development of the Yuma Desalting Plant (YDP) in Yuma, Arizona (built to treat water entering the Colorado River to meet water quality requirements for Mexican deliveries under Minute 242 of the International Boundary and Water Commission). YDP—which would become the world's largest desalination plant—was initially planned for 100 million gallons of water per day (gpd) at a time when the largest desalination plant was only 3 million gpd.

Frank created a demonstration facility at YDP, which later became the Water Quality Improvement Center (see page 18). He led the engineering development aspect of YDP, which helped launch a private industry for membrane, pressure vessel, pump, and—eventually—energy recovery suppliers, and he contributed to the later development of microfiltration, ultrafiltration, and nanofiltration membranes.

While still at Reclamation, Frank then spent 3 years in Saudi Arabia (working for the U.S.-Saudi Joint Commission) as a member and later team leader of the Hydros Team. This small group provided technical assistance to the Governor of the Saline Water Conversion Corporation, who reported to the Minister of Agriculture and Water. Frank helped develop the Research Development and Training Center in Al Jubail.

Currently, Frank is the lead technical expert for Reclamation's Desalination and Water Purification Research (DWPR) Program. For many years, he has provided significant technical mentoring for Reclamation employees and grant recipients through this program. Frank's understanding of a wide range of science is fundamental in properly evaluating the DWPR research proposals.

Frank holds 5 patents, and has authored and co-authored over 75 articles, reports, and publications (spanning academic, military, governmental, and professional publications worldwide). He holds advanced degrees in chemical engineering from the Massachusetts Institute of Technology.

"Frank realized the vital importance of desalination and of membrane processes at a very early time . . . In the following years, Frank had the chance to direct research and development so essential to progress. Generations of engineers and scientists are grateful for his leadership."

Ora Kedeem
Professor Emeritus, Ben Gurion University of the Negev and Weizmann Institute of Science Department of Biological Chemistry, Israel

Frank Leitz completing a membrane autopsy.

Membranes and Concentrate

"Membrane and other nanotechnology applications that dominate the current desalination and water-purification industries are likely to account for the biggest advances and effects on fresh water availability."

Global Water Security Intelligence Community Assessment, February 2012.

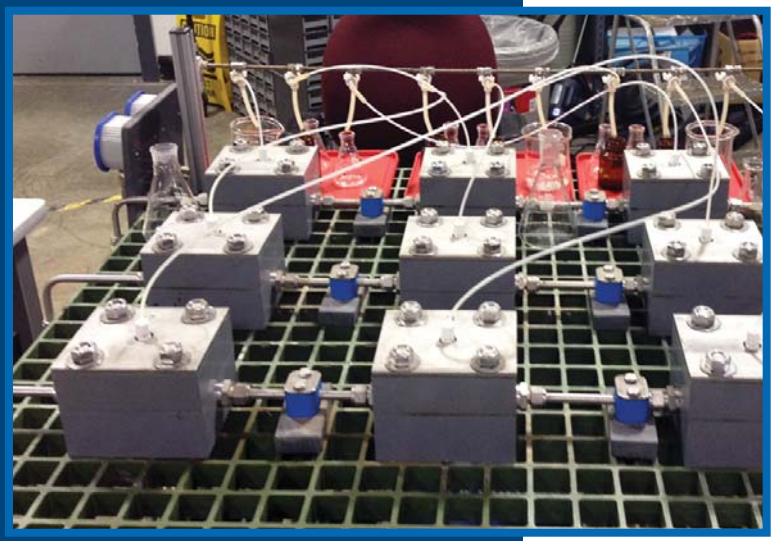
Patenting Chlorine Resistant Polyamide Membranes

Desalination by present commercial systems (electrodialysis, reverse osmosis [RO], multistage flash distillation, and vapor compression) is both capital and energy intensive. RO using polyamide (PA) membranes has proven an effective technology to desalinate brackish and seawater sources. Most RO desalination plants use PA spiral-wound thin-film composite membranes, because PA membranes operate with less energy (lower pressure) and higher salt rejection than the original cellulose acetate RO membranes.

Chlorine is added to feed water sources that typically contain microbial compounds or natural organic matter that can lead to microbial growth. Operating RO membrane with residual chlorine may reduce biological fouling, result in more efficient operation, and reduce operating cost. Unfortunately, chlorine causes chemical degradation of the commercially available PA membranes.

Reclamation partnered with Separation Systems Technologies to develop new materials which could lead to successful chlorine-tolerant PA membranes. Reclamation has filed three patent applications, and one has already been issued by the United States Patent Trademark Office. A divisional patent from this first patent is still pending.

The Denver Water Treatment Engineering and Research Laboratory's (WaTER Lab) high level research and accomplishments led to Reclamation entering into a Material Transfer Agreement (MTA) with Dow Water & Process Solutions (Dow) to manufacture pilot-scale spiral wound elements with our new monomer formulation to test for chlorine-tolerance in 2011.



Flat sheet membrane testing system designed by Separation Systems Technologies, Inc.

We are conducting long-term testing at the Water Quality Improvement Center in Yuma, Arizona, to operate the PA membranes for 6 months to a year. We will also conduct short-term operation tests (for up to a week) in the Denver WaTER Lab. This short-term testing will test for chlorine resistance using the flat sheet unit system designed by our partner, Separation Systems Technologies, Inc. See www.usbr.gov/research/docs/updates/pre-2012/Chlorine_Resistant.pdf.
Contact Yuliana Porras-Mendoza, Chemical Engineer, yporrasmendoza@usbr.gov.

Improving Membrane Performance and Cleaning Efficiency

At the Denver WaTER Lab, we conducted experiments to describe membrane performance over a wide range of conditions (such as differences in membrane size, operating conditions, or source water). Membrane material properties, the physical pore size of the membranes, source water characteristics, and the operational conditions of the membrane process affect the rejection and rate of production of product water for the membrane process. Evaluating materials with a controlled set of experiments can be applied to any ultrafiltration (UF), nanofiltration (NF), and RO membrane to characterize the water productivity and contaminant rejection compared to commercially available materials. Additionally, these experiments can be used to predict the optimum system configuration and operating parameters using any type of source water.

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Typically, membrane specifications are presented for one set of operating conditions, and these results cannot be extrapolated to another set of operating conditions. To develop results that can be extrapolated to any conditions, we examined a range of hydrodynamic conditions (i.e., the flow rates through the channel and pressure, which are the mass transfer parameters that describe the convective and diffusive forces in the membrane channel).

To highlight the effectiveness of these techniques, we compared the performance and cleaning efficiency of ceramic and polymeric UF membranes. Experiments used the Denver WaTER Lab's laboratory-scale system with various synthetic water sources that simulate real-world water types (see page 18). Performance results revealed that operating at higher flows (pushing more water through the membrane) does not mean a higher fouling rate if the cross-flow velocity increases accordingly to balance out forces that would cause particles to settle on the membrane. While operating at higher flows requires less membrane area, these operations require more energy; thus, illustrating the need to combine performance data with a cost model to quantify these trade-offs.

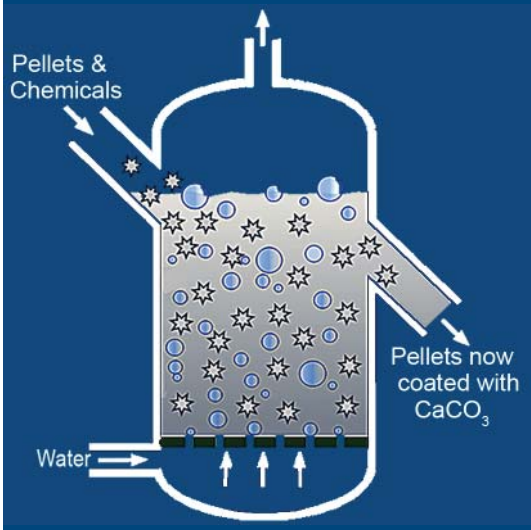
We have also identified novel cleaning protocols that can reduce the time and chemical requirements associated with typical membrane cleaning approaches. Typically, membranes are cleaned by recirculating cleaning chemicals and flushing the membranes with clean water. The amount of time for recirculating is usually based on a "rule of thumb." This research monitored membrane permeance during cleaning for ten cleaning cycles to determine the least amount of cleaning time needed for effective membrane flux recovery. We found that the time needed to recirculate cleaning solutions can be drastically reduced, for example, from 140 minutes to 15 minutes. Using these data and research methods, we developed a protocol for determining the optimum length of cleaning. We worked with a membrane development company to refine their product using our protocols in the Denver WaTER Lab. See www.usbr.gov/research/projects/detail.cfm?id=4141.
Contact Katie Guerra, Chemical Engineer, kguerra@usbr.gov.

Ultrafiltration skid with cleaning chemical tanks.

Using Pellet Softening to Precipitate Calcium Carbonate

Pellet softening is a concentrate management technique that reduces the volume of concentrate generated from RO processes using a fluidized bed reactor. Sand and/or calcium carbonate seed pellets help formulate calcite precipitation. As the concentrate flows up through this fluidized bed, chemicals can be added to adjust the pH to change the rate of crystallization in the column. The calcium carbonate precipitates on the surface of the pellets. When the pellets reach a critical size, they are separated from the bulk (based on diameter or density sorting) and replaced with new seed pellets.

We conducted bench-scale tests to study the effect of water quality, pH, retention time, bed expansion, chemical dose, and pellet size on calcium carbonate precipitation at the Denver WaTER Lab. Modeling source water with pH adjustments has been completed to gain a theoretical understanding of the system. Jar tests are being conducted for reaction rates and mechanisms for model validation, and bench testing has successfully fluidized a bed. The next steps will be testing various water compositions with different seed pellet material to optimize removal. See www.usbr.gov/research/projects/detail.cfm?id=2444.
Contact Saied Delagah, Chemical Engineer, sdelagah@usbr.gov.



Fluidized bed reactor schematic.

Wetlands for Treatment & Habitat

Using Wetlands for Natural Treatments

Constructed wetlands act as biological filters to remove a variety of contaminants from water and can be a cost-effective and technically feasible approach to treating wastewater. Wetlands are often less expensive to build than traditional wastewater treatment options and have low operating and maintenance expenses. While not all constructed wetlands replicate natural ones, they can also support wildlife habitat while improving water quality.

In many parts of the United States (U.S.), publicly owned treatment works rely on direct or indirect reuse or reclaimed wastewater to meet increasing water demands. Indirect potable reuse uses environmental buffers, such as wetlands or ground water aquifers, to further enhance the quality of reclaimed wastewater. Treatment wetlands have been widely used as the environmental buffer to polish reclaimed wastewater and are now being applied as a concentrate management tool for Advanced Water Treatment (AWT).

"Wetlands have a wide range of applications from treating impaired surface water to membrane concentrate. The use of wetlands in conjunction with conventional processes offers a natural, low-cost solution to obstacles encountered in Advanced Water Treatment, such as concentrate management."

Katharine Dahm
Civil Engineer,
Reclamation's Technical Service Center

Improving Water Quality in Brazos River Demonstration Wetland

A concern with using indirect potable reuse as a water supply is the potential for endocrine disrupting chemicals (EDC) in reclaimed wastewater to adversely affect ecological or human health. The Texas Water Development Board's (TWDB) 2011 Water Reuse Research Agenda identified this issue as the second highest research priority for Texas. It is important to address EDCs in reclaimed wastewater and to evaluate the potential for using environmental buffers as a resource management tool to further attenuate their concentrations. Although wetland processes naturally attenuate EDCs, the rate of removal has not been verified or optimized at the demonstration scale.

The proposed Brazos River Demonstration Wetland would investigate an innovative constructed wetland system's ability to attenuate EDCs from reclaimed wastewater.

A collaborative, Federal-state-local partnership has been formed to design, construct, study, and monitor the demonstration wetland among Reclamation's Technical Service Center and Oklahoma-Texas Area Office, U.S. Geological Survey, TWDB, Waco Water Utilities Services Department, and Baylor University. Reclamation's Science and Technology Program provided funds to investigate potential sites, develop a monitoring plan, and prepare the final design for construction. Funds to construct the Brazos River Demonstration Wetland at the Waco Metropolitan Area Regional Sewerage System will be provided through the city of Waco, Texas, and additional sources.

See www.usbr.gov/research/projects/detail.cfm?id=9589.
Contact Anna Hoag, Civil Engineer, ahoag@usbr.gov or Katharine Dahm, Civil Engineer, kdahm@usbr.gov.

Investigating the Future Uses of Reverse Osmosis Concentrate for Wetlands Restoration

The City of Oxnard Department of Public Works held an Applied Wetlands Research Workshop, "Investigating the Future Uses of Reverse Osmosis Concentrate for Wetlands Restoration," with Reclamation and CH2MHill on April 30, 2013. The research workshop was held at the Advanced Water Purification Facility (AWPF) in Oxnard, California. The conference objectives included:

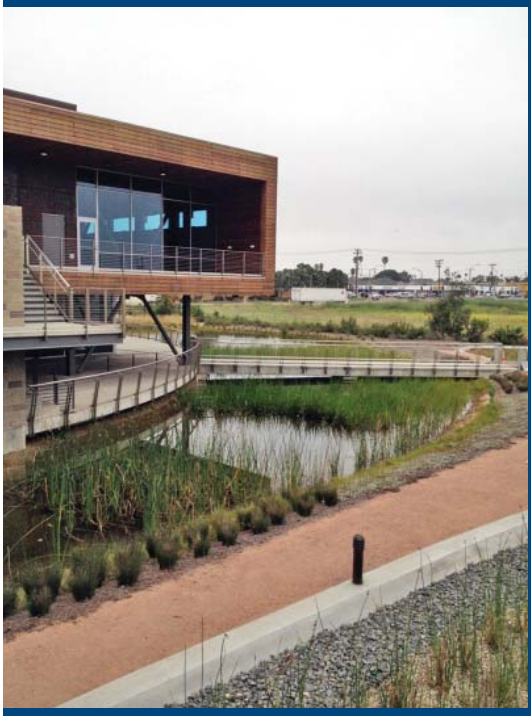
- Exploring the effectiveness of the research and study opportunities available at the AWPF to study the AWT indirect potable reuse facility and the concentrate treatment wetland.
- Engaging the local research community in studies that will provide mutual benefits with the city of Oxnard, California.
- Identifying areas of collaboration, including grant opportunities between Federal, state, local, private, and academic partners.

Consultants, environmental stewards, and researchers from California universities attended to discuss research collaboration at the facility. The overarching goal is to create a research center to explore the use of wetlands to manage reverse osmosis (RO) concentrate from wastewater treatment and reuse facilities.

Highlights of the workshop included tours of the AWPF and treatment wetlands and presentations:

- Presentations by CH2MHill on the design of the AWPF treatment wetlands by Mary Vorissis and Jim Bays. The presentations included design components, operational alternatives, and CH2MHill pilot studies.
- Presentation by the California Coastal Conservancy on the future restoration of Ormond Beach Wetlands by Peter Brand. The presentation focused on the expanded conservation of coastal marshes around the facility.
- Presentations by Reclamation on the significance of the Oxnard Brackish Treatment Wetland for Managing Water in Southern California, and current research at the AWPF Treatment Wetlands, by Doug McPherson and Katharine Dahm. The presentations highlighted the opportunity for research collaboration and outlined four objectives of Reclamation research at the facility:
    1. Demonstrate the use of wetlands as a natural treatment technology for RO concentrate.
    2. Determine optimized performance of the wetland for concentrate treatment and scale up.
    3. Establish points of comparison with other engineered wetland treatment systems in the Western U.S.
    4. Evaluate potential for creating and/or restoring coastal saline wetlands habitat.

See www.usbr.gov/research/docs/updates/2013-04-coastal-wetlands.pdf.
Contact Doug McPherson, Environmental Protection Specialist, dmcpherson@usbr.gov or Katharine Dahm, Civil Engineer, kdahm@usbr.gov.



Open water marsh around the AWPF educational facility and laboratory building. Photograph courtesy of Katharine Dahm.

Bullrushes growing in the horizontal subsurface flow wetland cells in front of the AWPF. Photograph courtesy of Katharine Dahm.

Treatment for Rural Communities

"The coupling of renewable energy sources with desalination has the potential of providing a sustainable source of potable water, initially for end-users in arid areas with limited alternative solutions."

Michael Papapetrou, Marcel Wieghaus, Charlotte Biercamp, eds. 2010. "Roadmap for the Development of Desalination Powered by Renewable Energy." Fraunhofer Verlag.

Brackish Groundwater National Desalination Research Facility Testbed for Renewable Energy

The performance of systems that use renewable energy and Advanced Water Treatment (AWT) depends heavily on factors such as source water quality, geographic location, and environmental conditions. Brackish Groundwater National Desalination Research Facility (BGNDRF) is an ideal testbed for this research because different types of technologies can be compared under similar test conditions (see page 19). As part of this effort, we are identifying infrastructure needs, testing protocols, and data monitoring procedures that can be used by researchers to evaluate their technology's performance compared to those previously tested at BGNDRF. These efforts are aimed at increasing renewable energy research at BGNDRF. Those interested in testing integrated renewable energy-AWT technologies at BGNDRF, please contact Randy Shaw, Facility Manager, rshaw@usbr.gov.

Using Solar Panels as an Energy Source for Desalinating Water

Solar panels, or photovoltaic (PV) technology, convert solar energy into electricity. To evaluate a hybrid photovoltaic-reverse osmosis (PVRO) system, Reclamation is partnering with New Mexico State University (NMSU), Institute for Energy and the Environment, on testing at BGNDRF. This project will serve to benchmark the current performance of a PVRO system and advance the state-of-the art for this technology through an economic analysis of operational improvements.

To increase the efficiency of the system, we are investigating operational strategies to meet the challenges imposed by the intermittent power availability inherent with solar powered resources. Additionally, we are quantifying the costs and benefits for water production, capital costs, and operation and maintenance costs. Operational data for the PVRO unit (shown) will be used to compare PVRO to other renewable energy powered desalination processes currently being investigated by Reclamation, such as solar stills, wind-powered reverse osmosis, and solar powered membrane distillation.

Contact Katie Guerra, Chemical Engineer, kguerra@usbr.gov.

This project is using a PVRO system developed by ITN Energy Systems, Inc. Photograph courtesy of ITN Energy Systems, Inc.

Coupling Solar Power With Novel Advanced Water Treatment Technologies

Many Native American reservations in the southwest lack access to running water, sanitary facilities, or even line-connected electricity. Reclamation partnered with the Navajo Nation and the University of Arizona (UA) to test off-grid, AWT technologies using renewable energy. Researchers initially focused on sustainability factors in designing a solar energy and membrane distillation system to supply water for livestock.

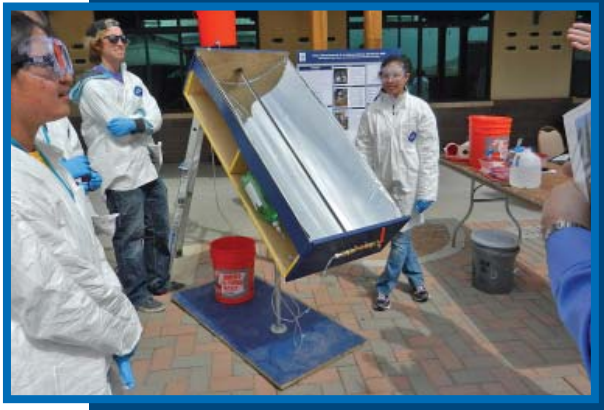
Navajo Well 5T-529, test facility. Photograph courtesy of Mitch Haws.

In January 2012, UA completed the Navajo Nation Solar Desalination Research Pilot Demonstration Project report for Reclamation. The applied research and design project combines a Concentrating Photovoltaic Thermal Hybrid System as the heat and electrical energy source, with a membrane distillation system for the off-grid AWT system. By using "off-the-shelf" products that are simply designed to minimize the operation, maintenance, and replacement costs, researchers envision a stand-alone system producing distilled water to be blended with the lesser quality water. This will serve as livestock water and is a prerequisite step in developing a potable water system for human consumption. The test well, Navajo Well 5T-529, is on a mesa higher in elevation than much of the area and, thus, could be a main distribution point for water without requiring energy for distribution. See http://www.usbr.gov/research/projects/detail.cfm?id=4850.

Contact Mitch Haws, Water Resources Planner, mhaws@usbr.gov.

Designing Better Solar Stills With Students

Each year, the Institute for Energy and the Environment at NMSU hosts the International Environmental Design Competition. The contest draws hundreds of college students from throughout the United States and around the world to develop solutions to challenging environmental issues. For the past 4 years, Reclamation has helped sponsor the event and submitted a challenge for the students to address. The 2013 task was to develop a solar still and document its performance. The goal was to design a unit with the highest possible water production and demonstrate an improvement over commercially available stills.



NMSU students displaying solar stills at BGNDRF.

Seven teams participated in the task and three of the solar stills were chosen as candidates for further evaluation. The solar stills constructed by these three teams are currently on display at BGNDRF. Two students from the winning teams will be awarded internships through NMSU and will continue work demonstrating and improving their solar still design at BGNDRF this summer.

Contact Katie Guerra, Chemical Engineer, kguerra@usbr.gov.

AWT Applications

"AWT research advancements have reduced the cost, improved the reliability, and increased the lifespan of desalination and water treatment technologies. Further improvement in desalting process technology will continue; further reductions in cost will lead to even more growth in desalting as a solution to water supply and quality problems."

Yuliana Porras-Mendoza
Advanced Water Treatment Research Coordinator

Using the Right Technology to Save Costs

High capital and operating costs for reverse osmosis (RO) is a critical challenge for membrane based desalination technology. Nanofiltration (NF) removes fewer monovalent ions and rejects less salt than RO. However, as NF operates at a lower pressure, using NF rather than RO can save life-cycle costs.

Reclamation's Oklahoma Texas Area Office partnered with the Texas Water Development Board to develop a new methodology and planning guidance to estimate the costs of membrane desalination, and select the most suitable membrane for a given application. This research uses membrane manufacturer supplied software programs and a simplified cost model. For example, NF is a potential treatment method for brackish ground water wells in the Texas Groundwater Database. Ongoing efforts will quantify the range of cost savings realized by using NF rather than RO membranes where water quality is suitable.
Contact Collins Balcombe, Program Coordinator, cbalcombe@usbr.gov.

Choosing Effective Technologies for Navajo-Gallup

The Navajo-Gallup Water Supply Project would convey a reliable municipal and industrial water supply to a quarter of a million people by the year 2040. Treatment technologies are based upon the water quality at the two water treatment sites (San Juan River and Cutter Reservoir). Raw river water would be treated and made safe by advanced treatment processes to remove microbiological, organic, and inorganic contaminants.

The proposed San Juan Water Treatment Plant would treat the San Juan River, which experiences spikes in turbidity and organic matter during spring snowmelt and summer monsoons. The San Juan River Water Treatment Plant would use pre-sedimentation for solids, enhanced coagulation for natural organic matter (NOM), microfiltration/ultrafiltration membranes for microbiological and solids, ultraviolet light for primary disinfection, and granular-activated carbon for further organic matter removal.

The proposed Cutter Water Treatment Plant would treat water that has flowed though both Navajo and Cutter Reservoirs. As this is better quality water, the Cutter Water Treatment Plant would use enhanced coagulation, ozone and biologically active filtration for NOM removal, and ultraviolet light for primary disinfection. While these treatment processes are not new, fewer treatment plants use biologically active filters than rapid sand filtration. As biological filters use micro-organisms to decompose the organic matter, this would be a more efficient treatment for the particular water qualities at the Cutter Water Treatment Plant.

Top:
Sediment handling basic pond.

Bottom:
Pilot Water Treatment Plant shows the pilot treatment filtration trains and instrumentation. Photographs courtesy of David Gates.

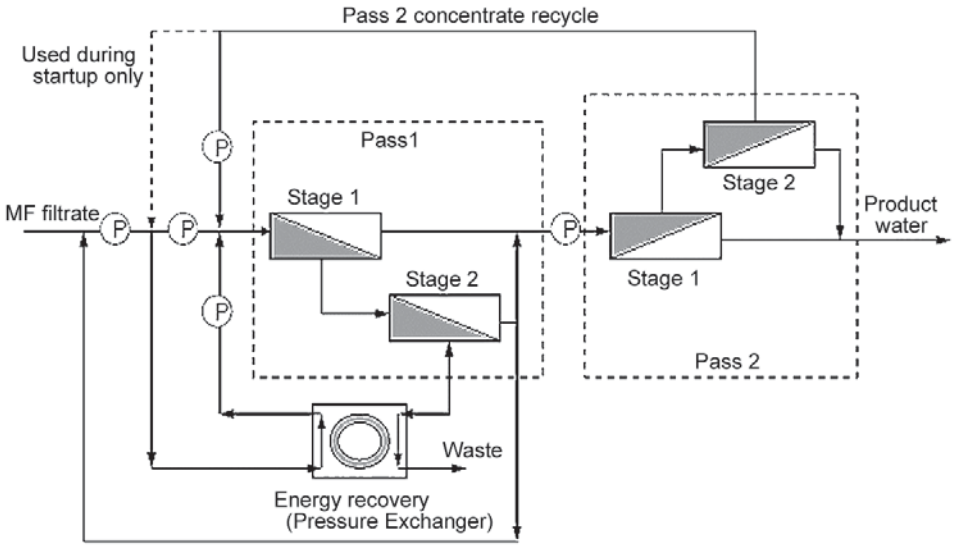
Municipalities, research organizations, and others in water treatment design and research could use the operating data from these treatment plants to consider similar applications to treat water with similar compositions.
Contact Barry Longwell, Supervisory Civil Engineer, blongwell@usbr.gov.

Demonstrating Two-Pass Nanofiltration Seawater Desalination

Seawater desalination by RO is widely practiced; however, the energy costs are higher than surface or ground water treatment and conveyance. The Long Beach Water Department, California, developed and patented a two-pass NF process to reduce the energy requirement for desalting. The goal is to minimize desalination cost, while producing permeate with water quality equal to or better than the Long Beach Water Department's current distribution system. The two-pass process provides an additional physical barrier for contaminant removal. The second pass concentrate recycle dilutes the source water, which allows lower feed pressures to be used (see schematic). This technology has been successfully bench- and pilot-scale tested.

To further this research, the Long Beach Water Department collaborated with Reclamation and the Los Angeles Department of Water and Power in constructing and operating a 300,000-gallon-per-day seawater desalination prototype facility. This facility consists of two parallel membrane trains designed to test the NF and RO processes side-by-side. This prototype was operated from October 2006 to January 2010. See www.usbr.gov/research/AWT/reportpdfs/report158.pdf.

Contact Saied Delagah, Chemical Engineer, sdelagah@usbr.gov.



Schematic of two-pass nanofiltration process.

Testing Yuma Desalting Plant Operating Scenarios

Reclamation in cooperation with Metropolitan Water District of Southern California, Southern Nevada Water Authority, and the Central Arizona Project are evaluating possible alternative Yuma Desalting Plant (YDP) operating scenarios which might potentially reduce costs. Reclamation's Water Quality Improvement Center performed multiple tests with two feed supply sources involving screening to evaluate pretreatment processes on polyamide (PA) membranes and full array to determine the cost-effectiveness and reliability of the treatment alternatives under circumstances similar to normal operating conditions. Findings include:

- Microfiltration (MF) experienced cleaning challenges. However, even if these issues are solved, MF appears to offer no cost savings compared to the existing YDP lime-softening pretreatment.
- PA membranes exhibited significantly higher water transport coefficients than those reported for cellulose acetate membranes in all cases.
- Results obtained during testing indicate that PA membranes may be feasible to implement at full scale.
- The lowest-cost alternative is the existing YDP lime-softening pretreatment and new PA RO membranes with estimated costs about 22 to 25 percent lower than existing YDP design.

Contact Chuck Moody, Research Chemical Engineer, cmoody@usbr.gov.

Photograph of two-pass nanofiltration at YDP.

Labs and Facilities

For more information, see www.usbr.gov/research/AWT/Denver_WaTER_lab.pdf and www.usbr.gov/pmts/water.

Parallel train flat sheet membrane testing system at the Denver WaTER Lab.

Denver Water Treatment Engineering and Research Laboratory

The Water Treatment Engineering and Research Team in Reclamation's Technical Service Center uses and maintains the Denver Water Treatment Engineering and Research Laboratory (WaTER Lab), which has a bench-scale chemistry laboratory and a laboratory-scale testing facility. The Denver WaTER Lab equipment is continually updated, based on Reclamation and its stakeholders' research needs. This laboratory provides research and development facilities/services to:

- Design, install, and evaluate bench-scale, laboratory-scale, and pilot-scale systems
- Evaluate processes for treating various source waters
- Develop and execute experimental proof-of-concept tests
- Troubleshoot processes and equipment
- Measure membrane properties and fouling tendencies
- Perform membrane autopsies
- Provide Advanced Water Treatment (AWT) workshops

See www.usbr.gov/research/AWT/Denver_WaTER_lab.pdf and www.usbr.gov/pmts/water.

Contact Chris Holdren, Group Manager, gholdren@usbr.gov.

WQIC mobile laboratory.

Water Quality Improvement Center

The Water Quality Improvement Center (WQIC) is one of six National Centers for Water Treatment Technologies and the only center focused on inland brackish water: both surface and ground water. WQIC is located in Yuma, Arizona, at the southern end of the Colorado River and is a 12,000-square-foot research facility with a mobile laboratory (see photograph). This research facility offers laboratory space, equipment, and experienced engineers and technicians knowledgeable in water treatment processes and operations. Collaborators interested in using this facility can also conduct their research or testing on a variety of source waters, including surface and brackish agricultural and ground waters.

Reclamation partners with academia, state and local governments, and the private sector to conduct research. Since its inception in 1997, WQIC has worked with 24 partnered projects and leveraged more than $1.5 million in external research funds. See www.usbr.gov/lc/yuma/facilities/wqic/yao_facilities_wqic.html.

Contact Chuck Moody, Research Chemical Engineer, cmoody@usbr.gov.

Brackish Groundwater National Desalination Research Facility

Reclamation's Brackish Groundwater National Desalination Research Facility (BGNDRF) in Alamogordo, New Mexico, helps government agencies, universities and private companies develop and test AWT technologies. This research facility focuses on developing:

- Desalination technologies and concentrate management solutions to reduce costs and address technical challenges
- Renewable energy/desalination hybrids
- Economically viable small-scale desalination systems
- Treatments for produced waters from oil and gas
- Effective ways to irrigate agricultural waters with concentrate

This 40-acre research facility is designed to conduct research on cost-effective advancements on desalination and alternative energy technologies. It offers resources including laboratory space; spacious conference rooms; equipment; and experienced scientists and chemical and environmental engineers in process development, design, construction, and testing. There are indoor and outdoor test pads and large-scale test areas, and various qualities of source water. Three evaporation ponds are available for concentrate disposal and research (such as enhanced evaporation studies and algal growth in concentrate).

BGNDRF works with many university, industry, and other partners. For example, Reclamation is collaborating with New Mexico State University (NMSU) on a cooperative agreement to conduct research to and enhance education and outreach related to AWT technologies. To serve the AWT program objectives, this program funds graduate and undergraduate students as well as NMSU faculty to conduct research at BGNDRF and NMSU. Outreach and educational activities, such as the BGNDRF testbed (see page 14) and the contest for solar stills (see page 15) are designed to increase knowledge and understanding of AWT for students and the general public. See www.usbr.gov/research/AWT/BGNDRF.

Contact Randy Shaw, Facility Manager, rshaw@usbr.gov (see page 8).

Water tanks at BGNDRF.

Dr. Neil Moe, visiting scientist from General Electric Water & Process Technologies at BGNDRF.

Panorama of testbays at BGNDRF.

Water for the Future Video

See the video at www.usbr.gov/research/awt/bgndrf.

Brackish Groundwater National Desalination Research Facility's New Video

At the Brackish Groundwater National Desalination Research Facility (BGNDRF) in Alamogordo, New Mexico, researchers are finding new technologies for treating water that cost less and are more environmentally friendly.

Reclamation recently produced a 5-minute video with interviewers from these researchers, providing an inside look at BGNDRF's cutting-edge research and facilities. This video explores the need for desalination; provides efficient means to test new ideas; and educates researchers, water management agencies, stakeholders, and the public on putting new ideas into reality. Highlights include:

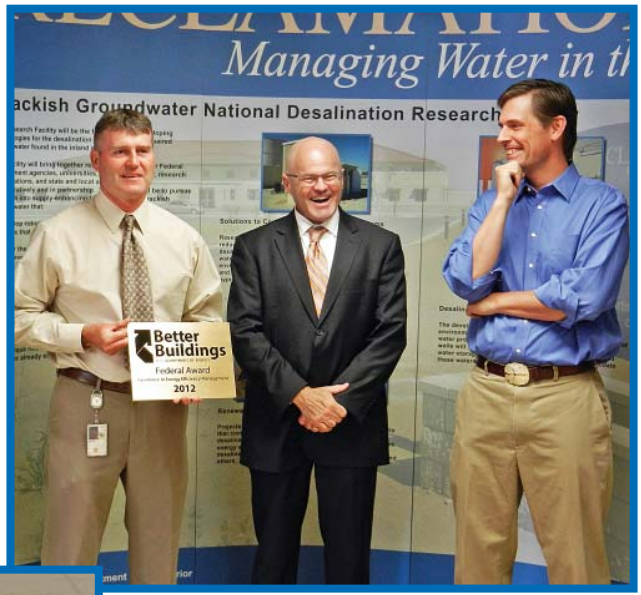
- Randy Shaw, Facility Manager, BGNDRF, discusses the need for new water supplies and the opportunities at BGNDRF to streamline research and move from the laboratory to larger scales to determine what technology works.
- Dr. Ali Shabat, New Mexico State University (NMSU), explains how NMSU's research breaks the boundaries and pushes the limits to lower energy use through electrodialysis reversal (EDR).
- Dr. Jim Loya, NMSU, talks about the ease of using BGNDRF as a research facilitiy to focus on research rather than paperwork, as his research finds better ways to manage and reduce concentrates from desalination.
- Chris Martin, Water Standard Management, lauds the ease of working with 3,000 gallons of artificial seawater in BGNDRF's indoor testbay for preliminary tests before going to the ocean.

Better Buildings Award

Brackish Groundwater National Desalination Research Facility Receives the Better Buildings Federal Award

BGNDRF was recently selected for the U.S. Department of Energy's first annual Better Buildings Federal Award for its extreme energy savings—reducing energy use by 53.6 percent over a year. As part of a comprehensive effort launched in 2011 to reduce energy use and save money, BGNDRF facility operators altered the building's air conditioning control settings and adjusted lighting (for landscapes, 24-hour lighting, and indoor nighttime) to minimize energy use during unoccupied hours. Steve Holland, BGNDRF's electronic technician, coordinated this work across the facility to achieve these high savings.

On July 12, 2013, New Mexico Senator Martin Heinrich joined Dr. Timothy Unruh from U.S. Department of Energy to present the facility with the 2012 Better Buildings Federal Award. They also participated in a private tour of the facility.



Steve Holland holding the 2012 Better Buildings Federal Award with Dr. Unruh and Senator Heinrich.

Randy Shaw and Senator Heinrich with Dr. Unruh in the background.

Senator Heinrich touring the facility.

"The operations and maintenance staff won the Energy Department's 2012 Better Building Federal Award by reducing the lab's energy use by 53.6 percent from the previous year's baseline—all while spending less than $800."

Randy Shaw
Facility Manager, BGNDRF

"I congratulate the Brackish Groundwater National Desalination Research Facility on winning the 2012 Better Buildings Federal Award. What the team at the facility has accomplished is impressive and serves as a model for not only the rest of the Federal Government but for all of us. I commend the entire Bureau of Reclamation team for beating their initial goal of a 10 percent reduction by five times, and for supporting a culture of excellence and shared responsibility. In a time of fiscal challenges, not only are we increasing our energy independence and reducing the impacts of our energy needs, but we are cutting our costs and saving taxpayer dollars. Getting the most out of each unit of energy we use should be a goal for every American. These are examples of pragmatic and incremental progress. Energy efficiency is within reach, and New Mexico is leading the charge."

U.S. Senator Martin Heinrich (D-N.M.)

RECLAMATION Managing Water in the West

July 2013
Research and
Development Office
Bulletin 2013-15

The Knowledge Stream
Research Update

Ceramic and Polymeric Membranes

Comparing performance and cleaning of ceramic and polymeric membranes

Bottom Line

This research identified how and why ceramic membrane performance differs from polymeric membrane performance and used a techno-economic model to compare the life-cycle cost differences between membranes made from the two materials.

Better, Faster, Cheaper

Ceramic membranes, due to their numerous benefits, including longer operational life and cleaning efficiency, may be a more cost-effective approach—even though they have a higher capital cost.

Principal Investigator

Katie Guerra
Chemical Engineer
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kguerra@usbr.gov

Collaborators

University of Colorado

Potential future researcher explores the Denver Water Treatment Engineering and Research Laboratory where we compare ceramic and polymeric membranes.

Problem

Improved water treatment technologies help to increase the water supply to areas of the West where demands may soon exceed supplies. Effectively using treatment technologies like microfiltration (MF) and ultrafiltration (UF) are easier to operate, take up less space, and require less maintenance than conventional water treatment technologies like media filtration and coagulation/flocculation/sedimentation. MF and UF are best used to remove suspended solids, *Giardia* and *Cryptosporidium,* and to reduce turbidity. They are also used as a pretreatment to desalination technologies such as nanofiltration and reverse osmosis. MF and UF processes use membranes that can be made of polymeric or ceramic materials. Membrane material properties, the characteristics of the source waters to be treated, and the operational conditions of the membrane process affect the degree to which contaminants are removed and the product water recovery.

As there are no standard sizes and configurations for low-pressure membranes, each manufacturer has adapted their technology to meet customer needs. However, there is little guidance in the industry to help membrane users select the most efficient low-pressure membranes for various applications. Polymeric membranes have dominated the market for low pressure membrane systems for the past 20 years. Yet, ceramic membranes have many benefits, including longer operational life and cleaning efficiency, and may be a more cost-effective approach—even though they have a higher capital cost.

Solution

This Reclamation Science and Technology Program research project compared two types of MF and UF membranes: ceramic and polymeric. We conducted laboratory experiments to quantify differences in the fouling propensity for an alumina ceramic and a polyethersulfone (PES) polymeric UF membrane. To increase the certainty that observed differences in flux behavior, rejection, and cleaning efficiency resulted from the materials and not various uses, we tested both types of membranes under comparable conditions. These tests used the Peclet number (Pe) to compare the same mass of foulant per unit area under the same hydrodynamic conditions.

This research project also developed and demonstrated a data-driven, techno-economic model to describe the life-cycle costs for a hypothetical membrane plant using these ceramic or polymeric membranes. The data-driven cost model is a novel tool that can be used to compare the performance and cost differences and to identify the technical and economic lever points that dictate which membrane system is more cost effective. Additionally, this model allows for the comparison of different materials based on a number of other important factors such as labor, operations and maintenance, replacement costs, energy input, power consumption, chemical usage, and source water recovery.

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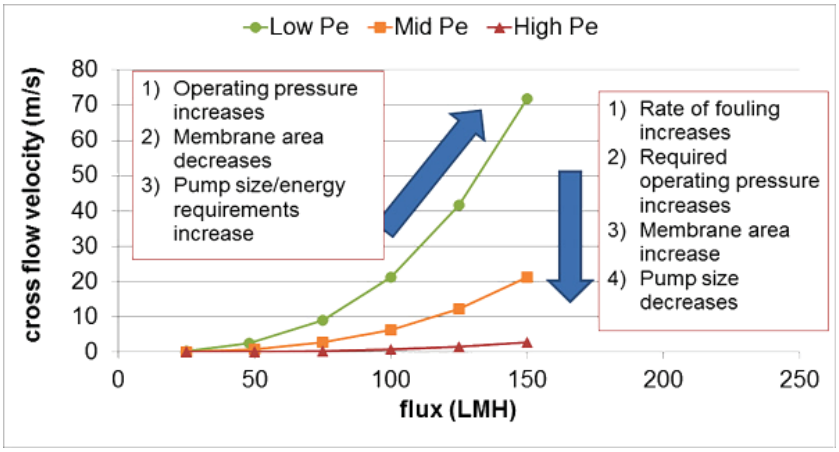
For the analysis conducted, the alumina membrane is cost competitive with the PES membrane:

- When harsh operating conditions or feed quality limit polymeric membrane life to less than 3 years,
- If the ceramic membrane is operated with a fouling rate >2.5 times that of the polymeric membrane, and
- The ceramic membrane material cost is ≤ $250 per square meter.



Graph illustrating the value of considering performance and operational factors in cost calculations.

Future Plans

This work will help identify areas where future research efforts should be focused. Future steps include:

1. Experimental

- Describe performance in terms of membrane material properties, solute properties, and hydrodynamics.
- Compare ceramic to polymeric membranes in a pilot test.
- Use Pe to scale laboratory results to full-size modules and to investigate economic impact of varying different operating conditions.

2. Cost Modeling

- Update cost correlations based on most recent MF and UF knowledgebase from the American Water Works Association.
- Incorporate long-term cleaning and backwash inefficiencies into cost model.
- Use optimization algorithm to determine optimal operating conditions to minimize total plant cost.

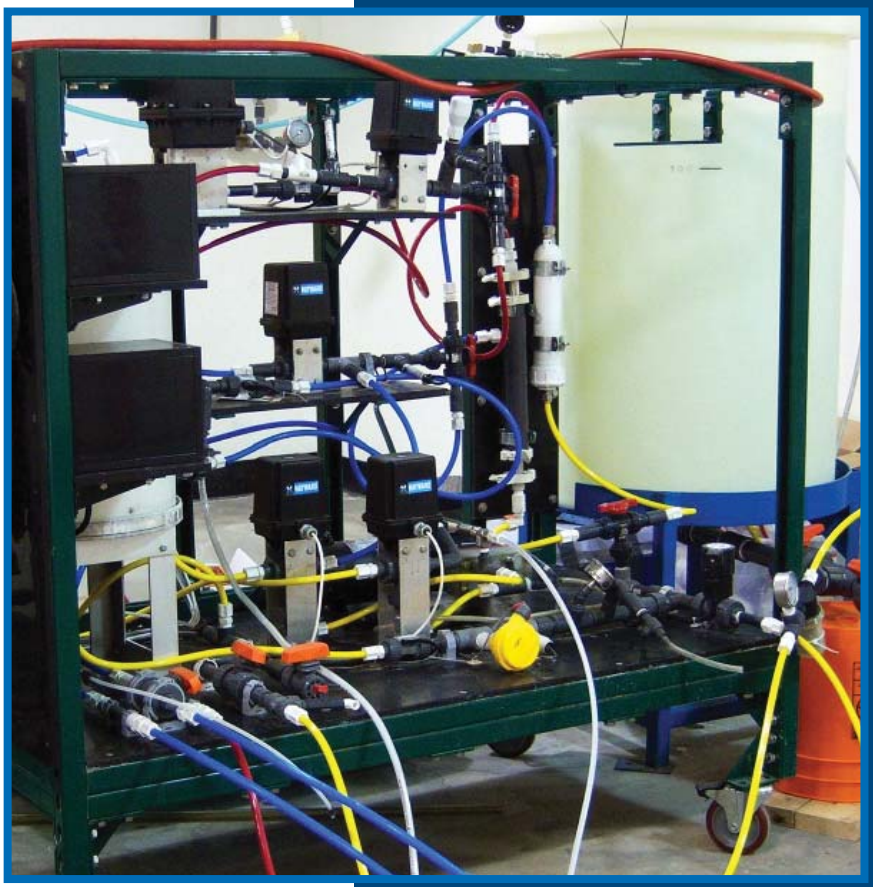
"More research is needed to minimize the cost [of low-pressure membrane systems] by reducing membrane fouling and optimizing membrane design and operation"

National Research Council, 2008

More Information

Science and Technology Program research project:

www.usbr.gov/research/projects/detail.cfm?id=4141



Laboratory-scale testing facility for polymeric and ceramic membranes.

RECLAMATION Managing Water in the West

July 2013
Research and
Development Office
Bulletin 2013-16

The Knowledge Stream
Research Update

High Recovery Nanofiltration/Reverse Osmosis Integrated Treatment System

Using both systems to recover more than 90 percent of an impaired water source

Bottom Line

This system can provide/recover more water to help restore/maintain existing ground water aquifers.

Better, Faster, Cheaper

This treatment system:

- **Saves energy by using a high flux, low-pressure system**
- **Reduces chemical use**
- **Lowers capital and operating costs**
- **Reduces waste discharge and associated disposal costs**
- **Increases local water supplies.**

Principal Investigator

Greg Krzys
Water Resources Planner
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Collaborators

- **Sanitation Districts of Los Angeles County**
- **Water Replenishment District of Southern California**

Problem

The Los Angeles County's Groundwater Reliability Improvement Program (GRIP) is designed to improve reliability and reduce dependency on imported water to replenish the ground water in this area. To achieve this goal, a significant portion of the imported replenishment water needs to be replaced with locally produced, high-quality recycled water.

Reverse osmosis (RO) treats impaired waters by forcing a concentrated solution of salts through a semipermeable membrane to a region of low solute concentration. The membrane is designed to allow only water to pass through this dense layer, while preventing the passage of solutes (such as salt ions). However, one of the main drawbacks of using RO membranes is that these systems are typically limited to recovering approximately 85 percent of the impaired waters, leaving 15 percent as a concentrated waste. This limitation stems from the potential for soluble salts to precipitate, or stick to, the membrane surface (known as membrane scaling).

Solution

Nanofiltration (NF) membranes, unlike RO membranes, are designed to selectively remove compounds such as salts or organic contaminants that can cause scaling, while allowing other compounds to pass. By using an NF system to first treat impaired water and then using an RO system, a dual system can recover much more water.

Overall NF/RO integrated system feed pressure requirements are lower than typical high-pressure RO membrane systems, thus saving energy as well. Moreover, the integrated system's product water has higher total dissolved solids concentration than RO systems, and is thus less corrosive, reducing costs for post treatment stabilization.

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Rio Hondo spreading basins.

San Gabriel River spreading basins.

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Application

This Reclamation Science and Technology Program research project worked with the Sanitation Districts of Los Angeles County (Sanitation Districts) and the Water Replenishment District of Southern California to provide a pilot-scale test for this NF/RO integrated system. Eventually, these results may be used in an advanced water treatment plant to produce 10,000 acre-feet of water per year (about 9 million gallons per day).

Pilot-scale testing was conducted from August 2011 to March 2012, at the Sanitation Districts' San Jose Creek Water Reclamation Plant using effluent from an ultrafiltration system as source water to evaluate the:

- Operational performance of the NF/RO integrated system for feed pressure, fouling, and related cleaning requirements.
- Rejection performance of the NF/RO integrated system for relevant constituents for indirect potable reuse projects including nitrogen, total organic carbon, and chemicals of emerging concern (e.g., N-Nitrosodimethylamine [NDMA], 1,4-dioxane, hormones, pharmaceuticals, and personal care products).

The NF/RO integrated system was operated for over 3,000 hours in two distinct phases, with different anti-scalant products for membrane scale control. Phase one used SpectraGuard (Professional Water Technologies), which was not effective for scale control and resulted in relatively significant membrane fouling in both the primary NF and secondary RO systems. Phase two used Y2K (King Lee Technologies), which was effective for controlling membrane scale formation. In phase two, the pilot system was operated for approximately 3 months (~ 2,000 hours), with significantly less fouling compared to phase one. Over the 3-month operating period, the normalized specific flux for the primary NF and secondary RO systems decreased by 16 and 28 percent, respectively.

Future Plans

The results from this study demonstrated that the NF/RO integrated treatment system concept is a viable alternative to a standard RO system and can potentially be employed for the GRIP project. The next steps would involve a demonstration project if funding becomes available.

"NF/RO integrated treatment system concept is a viable alternative to a standard RO system and could be employed for the GRIP project. The main advantages of this system include the ability to operate at an overall recovery of approximately 93 percent and to achieve a high degree of rejection for many of the constituents that are relevant for indirect potable reuse projects, including total organic carbon and select chemicals of emerging concerns."

Bruce Mansell
Engineer, Los Angeles County Sanitation Districts

More Information

Science and Technology Program research project:

www.usbr.gov/research/projects/detail.cfm?id=7251

Mansell, Bruce, 2012. *GRIP--Evaluation of a High Recovery NF-RO Integrated Treatment System*. Prepared by Sanitation Districts of Los Angeles County.

www.usbr.gov/research/projects/download_product.cfm?id=7251

RECLAMATION Managing Water in the West

February 2013
Research and
Development Office
Bulletin 2013-05

The Knowledge Stream
Research Update

Variable Salinity Source Water Desalination

Developing flexible desalination systems design for both brackish and seawater desalination

Bottom Line

Re-configuring a one-stage seawater reverse osmosis system with energy recovery to a two-stage system for brackish water enabled higher recovery (75 percent rather than 50 percent), used no more power than the one-stage configuration, and produced water with comparable quality.

Better, Faster, Cheaper

Flexible advanced water treatment design enables adapting the system to changing inlet water quality. Flexible systems can be adjusted to optimize water or energy efficiency.

Principal Investigator

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R&D Office Contact

Miguel Rocha
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Collaborators

- **Reclamation's Oklahoma-Texas Area Office**
- **Texas Water Development Board**
- **Southmost Regional Water Authority, Brownsville, Texas**

Problem

Many potential sources of water go unused because they have widely varying levels of salinity. It is difficult for a water treatment system designed for one level of salinity to use these varying supplies.

Solution

A desalination system designed with flexibility to handle various sources of water can address many challenges:

- Coastal areas with seawater could use one plant to treat both seawater and impaired waters from storm water, tidal influenced surface water, and/or brackish ground water.
- Rural water districts could treat irrigation return flow where salinity varies with precipitation level.
- Well fields could have one location to treat water from wells with a range of water qualities.
- Military operations and emergency personnel could immediately treat water until the site and source waters are evaluated.

Cities could use more effective seawater desalination systems, which typically require higher pressure and higher quality materials. The Long Beach, California Nano-Nano pilot study, for example, demonstrated that even low pressure systems can be adapted to treat seawater as long as corrosion resistant materials are incorporated into the feed and concentrate piping.

To pursue this idea, Reclamation's Science and Technology Program funded an evaluation of the practicality and power consumption of converting a seawater system capable of 50 to 60 percent recovery to a brackish ground water system capable of 75 to 80 percent recovery. The Reclamation Expeditionary Unit Water Purification (EUWP) system was converted from a one-stage configuration with three parallel trains using energy recovery to pressurize one train, to a two-stage configuration by diverting the concentrate from two trains from the energy recovery device to feed the third train.

Anna Hoag measures EUWP concentrate.

Reclamation has evaluated the EUWP's performance with seawater, highly brackish delta water, brackish waste water, brackish ground water and fresh water over the last 7 years. Previous operations used one stage, which recovered about 40 to 60 percent of the source water. During the summer of 2011 the re-configured EUWP was evaluated on brackish ground water at the Southmost Regional Desalination Plant in Brownsville, Texas.

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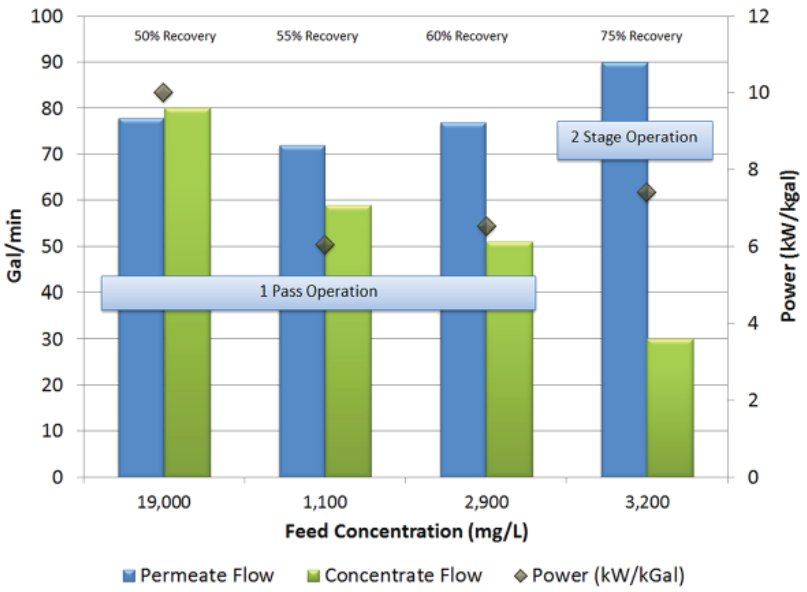
Application

Results of the comparison show that power usage for the EUWP as a two-stage configuration without energy recovery was no different than the previous testing as a one-stage configuration with energy recovery. This was to be expected since we used the same pumps. However, the configuration produced the same amount of product water from one-third less feed water. Recovering more usable water is important for desalination systems with significant infrastructure and energy costs.

Brownsville, Texas, for example, has a wide array of wells that are pumped from several miles to the treatment facility. The Southmost Regional Desalination Plant uses a two-stage brackish water configuration. It is 24 miles from the coast, but only 1.3 miles from a shipping channel that could be used to access seawater with an appropriate intake system. The Laguna Madre Water District on South Padre Island is also planning a new desalination plant that will have access to brackish tidal water and seawater. The Gulf often has high turbidity storm events and algal blooms that would be challenging to handle with a static treatment system. A flexible system could be re-configured to a two-stage brackish configuration by incorporating one or two valves.

Future Plans

Pending funding decisions in the state of Texas, a workshop highlighting the importance of desalination system design flexibility will be held in late summer 2013 to explore other methods for building flexibility in treatment process design. This is timely in that, due to the extreme drought in Texas over the past 2 years, the Texas Commission on Environmental Quality (TCEQ) has received several applications for desalination systems. Current regulations categorize membrane filtration for suspended solids, softening, or for desalination as "Innovative and Alternative" treatment processes that require a pilot study and or evaluation reports on the exact system tested with a similar feed water quality. With the drought, many communities are finding that their source water is changing, ground water becoming more brackish, and surface water having higher turbidity and total organic carbon from algae blooms. Existing systems are not able to maintain performance with deteriorating water conditions. TCEQ has been meeting with membrane system suppliers to formulate new regulations for membrane systems. It is important that flexible designs are considered in the new regulations.



Recovery, product water quality, and energy use in single stage and two-stage configuration at various locations: Biloxi, Texas; Gallup, New Mexico; Reclamation's Brackish Groundwater National Desalination Research Facility in Almagordo, New Mexico; and Brownsville, Texas, respectively.

"This project exemplifies the practical value of partnering to advance desalination research. This project was made possible through the creative leveraging of efforts and resources of at least six different organizations."

Jorge Arroyo,
Director, Texas Water Development Board,
Innovative Water Technologies

The EUWP generates and stores purified drinking water.

More Information

Papers on variable source projects are at:

www.twdb.state.tx.us/innovativewater/desal/projects/burec/index.asp

RECLAMATION Managing Water in the West

February 2013
Research and
Development Office
Bulletin 2013-02

The Knowledge Stream
Research Update

Treating Concentrate in Desert Wetlands

An innovative, environmentally sustainable, cost-effective method to treat concentrate in inland areas

Bottom Line

Treating the saline concentrate from water treatment plants with a wetlands system and then blending it with wastewater effluent for surface water discharge will benefit the city of Goodyear's reclaimed water quality, as well as provide a source of water appropriate to restore riparian habitats in the Gila and Salt Rivers.

Better, Faster, Cheaper

Vertical flow wetlands can treat concentrate to meet applicable water criteria for most metals while creating and restoring wetland habitat. Regulating wetlands can be used in a variety of concentrate management scenarios.

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Collaborators

- **CH2M Hill**
- **City of Goodyear, Arizona**
- **City of Phoenix, Arizona**

Problem

Managing concentrate produced by reverse osmosis (RO) membrane treatment is a significant challenge. The concentrate can include salts, metals, and nutrients at levels that exceed water quality standards and must be removed or diluted before being discharged to surface waters. In an inland area such as central Arizona, few pragmatic alternatives exist to handle this concentrate. Thermal driven evaporation processes are commonly used at industrial facilities, but have high energy and carbon footprints. While deep well injection has been used in some states such as Florida, this has never been successfully permitted in Arizona. Solar evaporation ponds, though proven, have large land requirements and are not always practical when dealing with large concentrate volumes.

In the future, RO facilities in the greater Phoenix, Arizona, metro area may produce up to 80 million gallons per day (mgd) of potable water, producing 12 mgd of saline concentrate as a byproduct. Currently, the city of Goodyear, a nearby suburb, discharges their concentrate to the 157th Avenue Water Reclamation Facility (WRF), and they plan to increase their RO treatment capacity in coming years. However, the RO concentrate degrades the effluent quality (with total dissolved solids of about 2,000 milligrams per liter [mg/L]), which is too high to use this reclaimed water for irrigation at parks, schools, and local baseball fields.

Solution

Wetlands have a proven capacity to remove pollutants such as nutrients and metals while creating and restoring wetland habitat. Using wetlands is a way to re-use this concentrate in an inland area, and to treat water for irrigation. Reclamation's Science and Technology Program funded a pilot system using vertical flow wetlands, where untreated concentrate is piped into the bottom of the wetland.

Bins held wetlands in the pilot-scale project.

The concentrate diffuses up through a gravel and rock bed. Peat moss or green waste (compost) serves as the media for the wetland plants and micro-organisms to grow. These microbes consume the oxygen, creating an anaerobic zone. The microbes then reduce the sulfates to sulfides, which link to the heavy metals (i.e., arsenic and selenium), forming metal sulfide compounds that precipitate out of the water. Other methods of removal are through plant uptake, sorption, and physical settling. The treated water then travels up through the wetland to a manifold where it exits.

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Application

To test this approach, we constructed a pilot-scale facility at the city of Goodyear's Bullard Water Campus. If successful, the regulating wetlands will provide riparian habitat along the Gila River and also allow the city to use the reclaimed water from the 157th Avenue WRF for local irrigation.

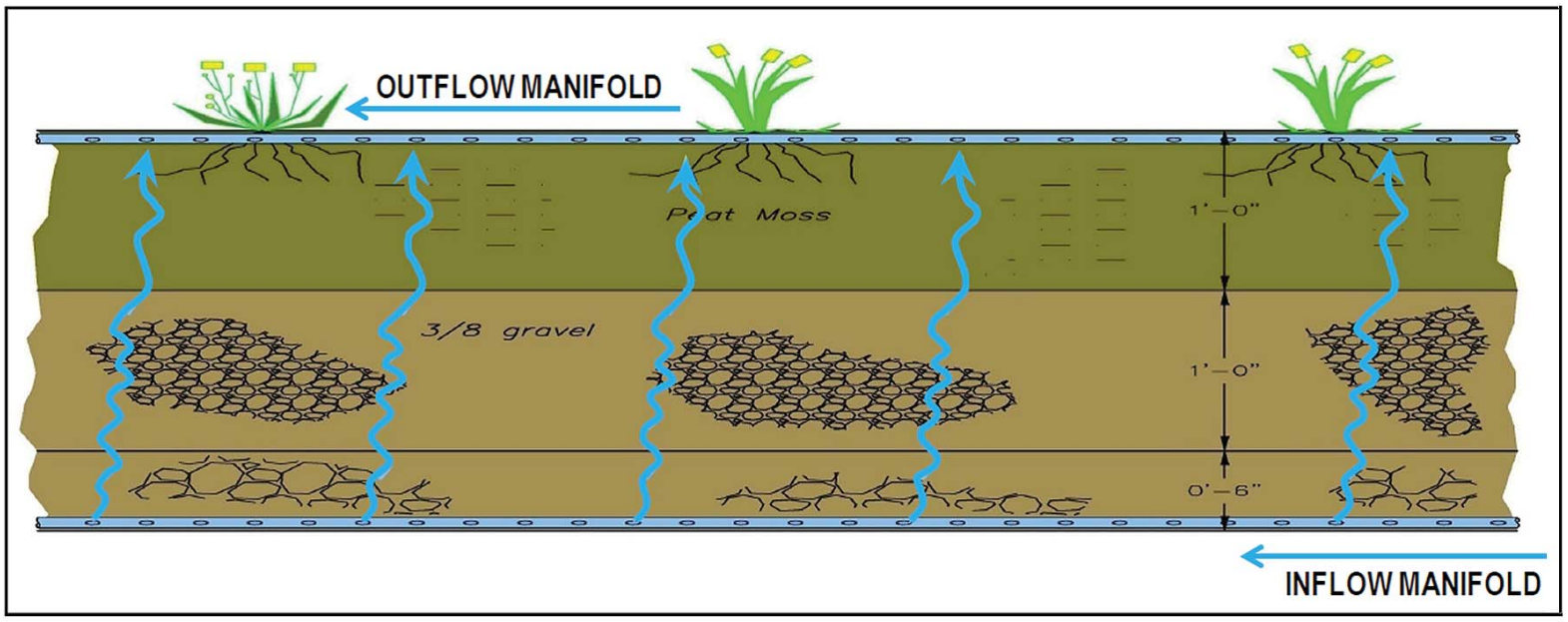
In this pilot system, the wetlands were grown in bins. Each bin was 8 feet wide and 24 feet long (192 square feet of surface area) and contained various media, plant types, and hydraulic configurations. All bins were planted with a variety of wetland plant species native to central Arizona and the southwestern United States.

The pilot system helped determine how hydraulic and mass loading rates, type of media beds, and plant species affected performance, thereby establishing preliminary engineering criteria for a full-scale system.

These vertical flow wetlands can reduce heavy metal contaminants in the concentrate to non-detectable levels. Results from this pilot system indicated that the wetlands could reduce concentrations of arsenic from greater than 30 to less than 10 micrograms per liter (µg/L), selenium from greater than 20 to less than 1 µg/L, and chromium from greater than 45 to less than 5 µg/L—all well within water quality standards. Nitrate-nitrogen concentrations were also reduced from approximately 55 mg/L to less than 1 mg/L. Preliminary estimates and monitoring of contaminants accumulation indicate that the green waste (compost) would need to be replaced every 20 years and the media removed to a landfill.

"This idea of managing concentrate through natural means is a complete shift in thinking from conventional concentrate management. Instead of using lots of energy and highly engineered systems, we can use natural means to process the concentrate, removing the harmful constituents and returning the benign salts back to nature, with the added bonus of water for the desert environment."

Tom Poulson,
Civil Engineer/Planner, Reclamation



Schematic of vertical flow wetlands.

Future Plans

This research paved the way for a full-scale concentrate management system using wetlands in an inland desert area. The city of Goodyear plans to develop a full-scale system.

More Information

Comparative Analysis of Innovative Concentrate Management Systems

www.usbr.gov/research/projects/detail.cfm?id=3699

RECLAMATION Managing Water in the West

February 2013
Research and
Development Office
Bulletin 2013-01

The Knowledge Stream
Research Update

Tool for Planning Temporary Water Supplies for Drought Emergencies

Compendium of information and guidance to assist communities challenged by drought

Bottom Line

The tool is an interactive compilation of information for water utilities and city planners to help plan for an emergency water supply during droughts or other shortage situations.

Better, Faster, Cheaper

City planners and others can access one location to find the information they need to plan for water sources in a drought emergency.

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Collaborators

Reclamation:

- **Oklahoma-Texas Area Office**
- **Nebraska-Kansas Area Office**
- **Office of Policy's Drought Program**

Texas Water Development Board

Texas Division of Emergency Management

Texas Commission on Environmental Quality

Problem

Droughts are common in the arid west, and planning for emergency water supplies during droughts is critical. However, every situation is unique, involving different potential water sources and water issues. Cities and smaller municipalities often do not have access to the expertise needed to plan for droughts or to develop emergency water supplies. Nearly 1,000 Texas communities were directly impacted by drought in 2011-2012. These small towns are being challenged to expand their concept of "usable" water. However, there are institutional and financial barriers to implementing temporary water supplies for drought responses. Local utilities may not know about advanced water treatment methods that can salvage good water from sources with high salt content, high turbidity, or organic carbon contamination from high temperatures and low precipitation.

Solution

We developed a tool to help local governments (both in cities and rural areas) to plan for water shortages. This tool is an interactive cd/powerpoint guide with links to websites, documents, and worksheets. In this guide, users can find information on alternative sources, treatment processes, distribution options, short-term equipment solutions for treatment, and the regulatory process for emergency situations.

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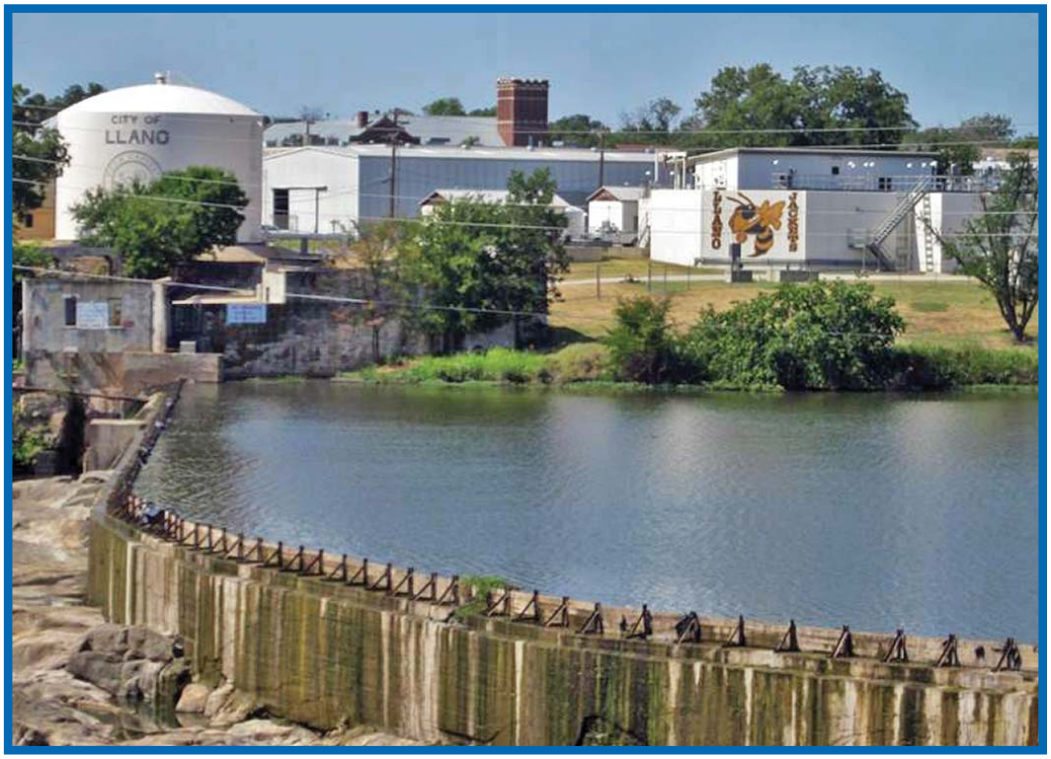

Temporary flashboards help expand water storage in Llano, Texas, 2012. This impounded supply would last for 186 days.

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Reclamation's Science and Technology Program provided the seed money for this program for a short guide in 2012. Other Reclamation offices (the Oklahoma-Texas Area Office and the Office of Policy's Drought Program) saw the value in this work and took on the challenge of expanding the guide and tools. To test the usefulness of the Drought Tool, we conducted case study interviews in four Texas towns: Llano, Florence, Haskell, and Hale Center.

Through interviews and analyses in these case studies, we found that:

- The city managers are very knowledgeable about their potential backup sources of water, but were not always certain how to secure the backup supply, how to treat it, or how it would be permitted.
- The city managers are interested in investing in permanent solutions rather than temporary solutions; however, much of the drought relief funding available was for temporary measures.
- Regulatory personnel are passionate about protecting public health and community resources. Lack of information can lead them to advise small rural communities to haul water from approved water utilities in an emergency, which can be the most expensive alternative.

The tool covers key topics for planners, such as:

- Drought contingency planning resources
- Determining emergency water capacity needs
- Evaluating alternative water sources
- Regulated contaminants
- Treatment processes
- Waste management
- Water system regulations—who to call for what
- Temporary treatment equipment resources
- Public relations ideas

Each section provides information on a decision that planners must make to prepare a practical plan for emergency water supplies.

The tool provides:

- Links and explanations of Texas' drought planning resources
- A worksheet to estimate emergency water supply requirements
- Links for guidance and worksheets to determine potential sources of emergency water
- Guidance and links for treating those sources and managing the waste that will be generated
- Ideas for distribution of emergency water
- A clear plan for navigating the regulatory process

"This work is an impressive effort. I see this tool as a foundational contribution that will evolve with use and time—which will in itself be a good measure of success."

Jorge Arroyo,
Director, Texas Water Development Board,
Innovative Water Technologies

Water rationing in Florence, Texas, helped stretch water supplies after the city's main well was out of commission.

More Information

The Drought Tool is available on request.

Future Plans

This year, we will provide a similar tool for Oklahoma and Kansas, with funding from the Office of Policy's Drought Program and the Nebraska-Kansas Area Office.

RECLAMATION Managing Water in the West

July 2013
Research and Development Office
Bulletin 2013-17

The Knowledge Stream
Research Update

Produced Water Treatment and Management for Oil and Gas Production in the Western United States

Researching water quality and providing guidance for treating water from oil and gas extraction

Bottom Line

If treated to appropriate standards or managed properly, produced water could serve as a "new" water supply.

Better, Faster, Cheaper

Treating produced water could reduce the cost and environmental impact of energy production on existing water supplies.

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Collaborators

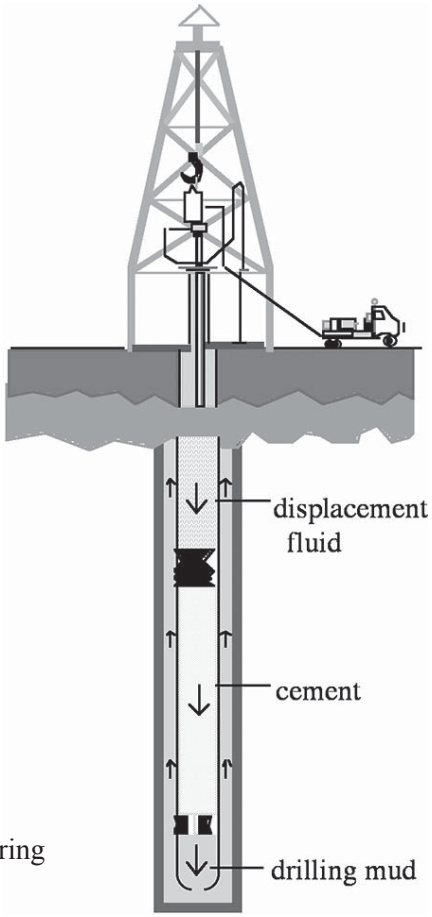
- **U.S. Geological Survey (USGS)**
- **Department of Energy (DOE)**
- **Environmental Protection Agency (EPA)**
- **State Oil and Gas Commissions**
- **Oil and Gas Industry Energy Producers**

Problem

The oil and gas industry is both a consumer and a producer of water. Oil and gas recovery techniques require large amounts of water to be used for hydraulic fracturing, while water that naturally exists in subsurface formations with oil and gas resources is brought to the surface during extraction.

Produced water coexists naturally with oil and gas deposits underground and is the largest waste stream associated with oil and gas production. Produced water is extracted at an average rate of 2.4 billion gallons per day in the United States (U.S.). Over 80 percent of production occurs in the Western U.S. Produced water is commonly re-injected for disposal due to its salinity, but in water stressed areas this water can be treated and managed for use as:

- Livestock water
- Irrigation water
- Surface water augmentation
- Drinking water applications
- Onsite reuse for well drilling or hydraulic fracturing
- Emergency drought supply



Most produced water requires treatment to make it suitable for beneficial use. Many different types of technologies can be used to treat produced water; however, produced water varies widely in quantity and quality depending on the method of extraction, type of oil and gas reservoir, geographical location, and the geochemistry of the producing formation. Thus, choosing the best technology for a particular site must consider the types of constituents removed by each technology and the degree of removal.

Solutions

To increase the likelihood of using produced water to help meet the growing demand for water in the Western U.S. in an environmentally friendly, cost-effective manner, we need to evaluate commercially available treatment systems and explain the benefits, limitations, and most appropriate applications for these technologies to water managers. Reclamation is working on several products to evaluate and guide water managers and others in using produced water.

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Oil and Gas Produced Water Management and Beneficial Use in the Western United States

This report was created in 2011 as a comprehensive background document on the treatment and management of produced water from beneficial use in the Western U.S. The report includes information on produced water quality, water treatment technologies, and suitability for beneficial use opportunities.

Produced Water Treatment Primer for Oil and Gas Operations

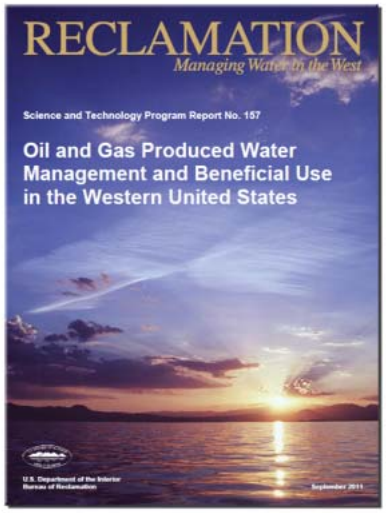
This primer document will be available in September 2013. This document catalogs available technologies, categorizes water treatment capabilities and performance, lists applicable contaminants removed, describes technologies based on classification of mechanisms, references technology applications in produced water treatment, and provides operational experience and performance data where available.

Guidance for the Evaluation of Produced Water as an Alternative Water Supply

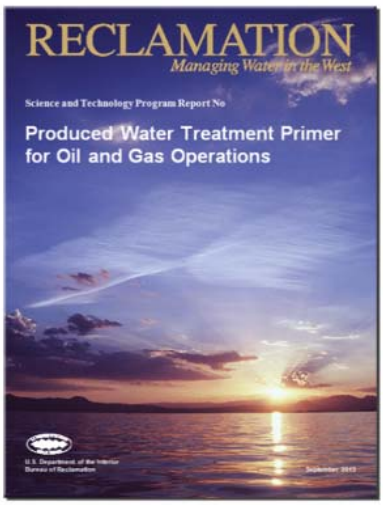
This guidance document is a companion document to the *Produced Water Treatment Primer for Oil and Gas Operations* and will also be available in September 2013. This document highlights locations of opportunity for the beneficial use of produced water using geographic information system (GIS) mapping and water supply estimations. It also advises water managers on the potential supply and demand balance associated with energy production. Alternative water resources for fracturing and industry reuse projects are also highlighted, with information on existing produced water treatment facilities.

Future Plans

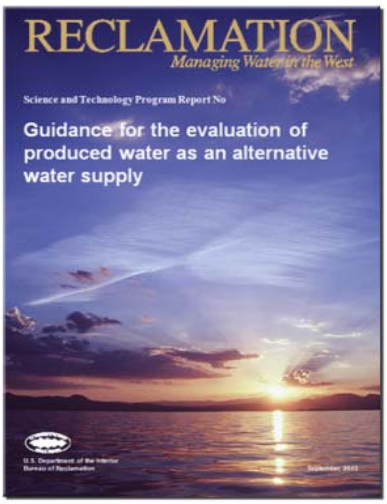
Using the solutions highlighted in this update, researchers are applying these concepts to the evaluation of water supplies on a watershed scale. Results of these studies will be used in cooperation with Reclamation's Basin Study Program to evaluate the potential supply and demand planning related to oil and gas operations within study basins.



Reclamation background report on the beneficial use of produced water in the West.



Reclamation report catalogs available treatment, technologies, capabilities, and performance.



Reclamation report highlights locations of opportunity for produced water beneficial use.

"In arid and rural areas, water for hydraulic fracturing and oil and gas development poses challenges to regional water supply allocations. It is important to consider water requirements for energy production and the potential supply available if produced water is treated for use in the region. The goal of this research is to assess the value of produced water in the Western U.S. to manage water resources effectively for all water users."

Katharine Dahm
Civil Engineer,
Reclamation's Technical Service Center

More information

Science and Technology Program research projects:

www.usbr.gov/research/AWT/reportpdfs/report157.pdf

www.usbr.gov/research/projects/detail.cfm?id=1617

www.usbr.gov/research/projects/detail.cfm?id=3259

Recent AWT 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.

Membrane Treatment

Chapman, M. 2013. *Is There a Role for Membrane Technology in Planning for Drought in Texas?* Proceedings of the AMTA/AWWA Membrane Technology Conference, February 2013, San Antonio, Texas.

Chapman, M. 2013. *The Challenge for Membrane Materials in Water Separations.* Proceedings of the American Chemical Society Conference: Advances in Materials and Processes for Polymeric Membrane Mediated Water Purification. February 24, 2013, Pacific Grove, California.

Chapman, M. 2012. *Evaluation of High Productivity Brackish Desalination Membrane.* Desalination Journal, December 2012.

Cheng, R.C, T.J. Tseng, and K.L. Wattier. 2013. *Two-Pass Nanofiltration Seawater Desalination Prototype Testing and Evaluation*. For Long Beach Water Department. Reclamation, Desalination and Water Purification Research and Development Program. www.usbr.gov/research/AWT/reportpdfs/report158.pdf

Guerra, K. 2012. *Techno-Economic Model for Evaluation of Ceramic Membranes for Surface Water Treatment* (ID 4141).

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Guerra, K. and J. Pellegrino. 2013. *Investigation of Low Pressure Membrane Performance, Cleaning, and Economics Using a Techno-Economic Model* (ID 4141).

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MacHarg, J. 2012. *Optimizing Seawater Reverse Osmosis for Affordable Desalination.* Proposition 50 6a Desalination Final Report (ID 9081).

Wetlands

Dahm, K., J. Daniels, A. Witherall, and D. McPherson. 2012 *Oxnard Saline Treatment Wetlands: Monitoring Plan, Baseline Monitoring Results, and Supplemental Research Topics* (ID 9424).

Daniels, J., K. Dahm, S. Keefe, B. Brooks, and L. Barber. 2012. *Hydrological, Chemical, and Biological Monitoring Plan* (ID 9589).

Hoag, A., C. Balcombe, and M. Chapman. 2012. *Demonstration Project Alternatives Analysis* (ID 104).

Poulson, T., J. Bays, and R. Rhoades. 2012. *Concentrate Management Wetlands* (ID 3699).

Produced Water

Dahm, K., C.M. Van Straaten, J. Munakata-Marr, J.E. Drewes. 2013. *Identifying Well Contamination Through the Use of 3-D Fluorescence Spectroscopy to Classify Coalbed Methane Produced Water*. Environmental Science and Technology, 47, 649-656 (ID 3259).

Dahm, K., K. Guerra, P. Xu, and J.E. Drewes. 2011. *Composite Geochemical Database for Coalbed Methane Produced Water Quality in the Rocky Mountain Region*. Environmental Science and Technology, July 2011, Volume 45, Pages 7655-7663 (ID 3259).

Guerra, K., K. Dahm, and S. Dundorf. 2011. *Oil and Gas Produced Water Management and Beneficial Use in the Western United States* (ID 1617). www.usbr.gov/research/AWT/reportpdfs/report157.pdf

Recent Research Products

Contact the authors for information about these documents or research projects. To access documents having a Science and Technology Program research project ID number, see www.usbr.gov/research/projects/search.cfm.

Andersen, Doug. *Vulnerability of Riparian Ecosystems to Elevated CO_2 and Climate Change in Arid and Semiarid Western North America* (ID 310).
dandersen@usbr.gov

Andersen, Doug. *Floral Ecology and Insect Visitation in Riparian* Tamarix Sp. *(Saltcedar)* (ID 310).
dandersen@usbr.gov

Contor, Bryce. *Policy Issues Associated With Groundwater Debit and Credit Accounting, Managed Aquifer Recharge, and Trading of Mitigation Credits* (ID 901).
jmjohnson@usbr.gov

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jmjohnson@usbr.gov

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dhosler@usbr.gov

Lai, Yong and David A. Gaeuman. *Bedload Adaptation Length for Modeling Bed Evolution in Gravel-Bed Rivers* (ID 3054).
ylai@usbr.gov

Mortensen, Joshua. *Resistance of Protective Coatings to High Pressure Water Jets for Invasive Mussel Removal* (ID 1740).
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Nelson, Mark. *Construction and Testing of a Soil Temperature Modification Unit for Climate Change Studies in Remote Areas* (ID 310).
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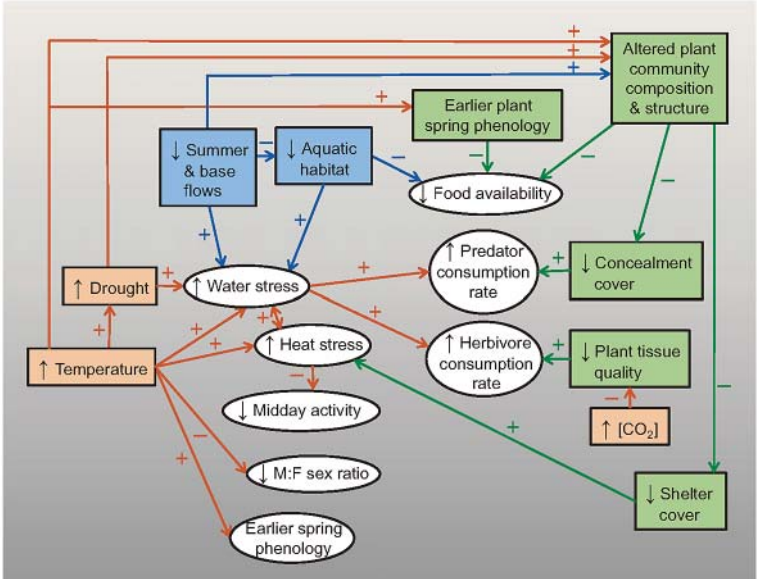
Nibling, Fred. *Monitoring Invasive Quagga Mussels,* Dreissena Rostriformis Bugensis (Bivalvia:Dreissenidae), *and Other Benthic Organisms in a Western U.S. Aqueduct* (ID 4442).
snelson@usbr.gov

Siegle, Rebecca. *Effects of the Biological Control Agent* Diorhabda Elongata Deserticola *on Resprouted Saltcedar* (ID 6397).
dhosler@usbr.gov

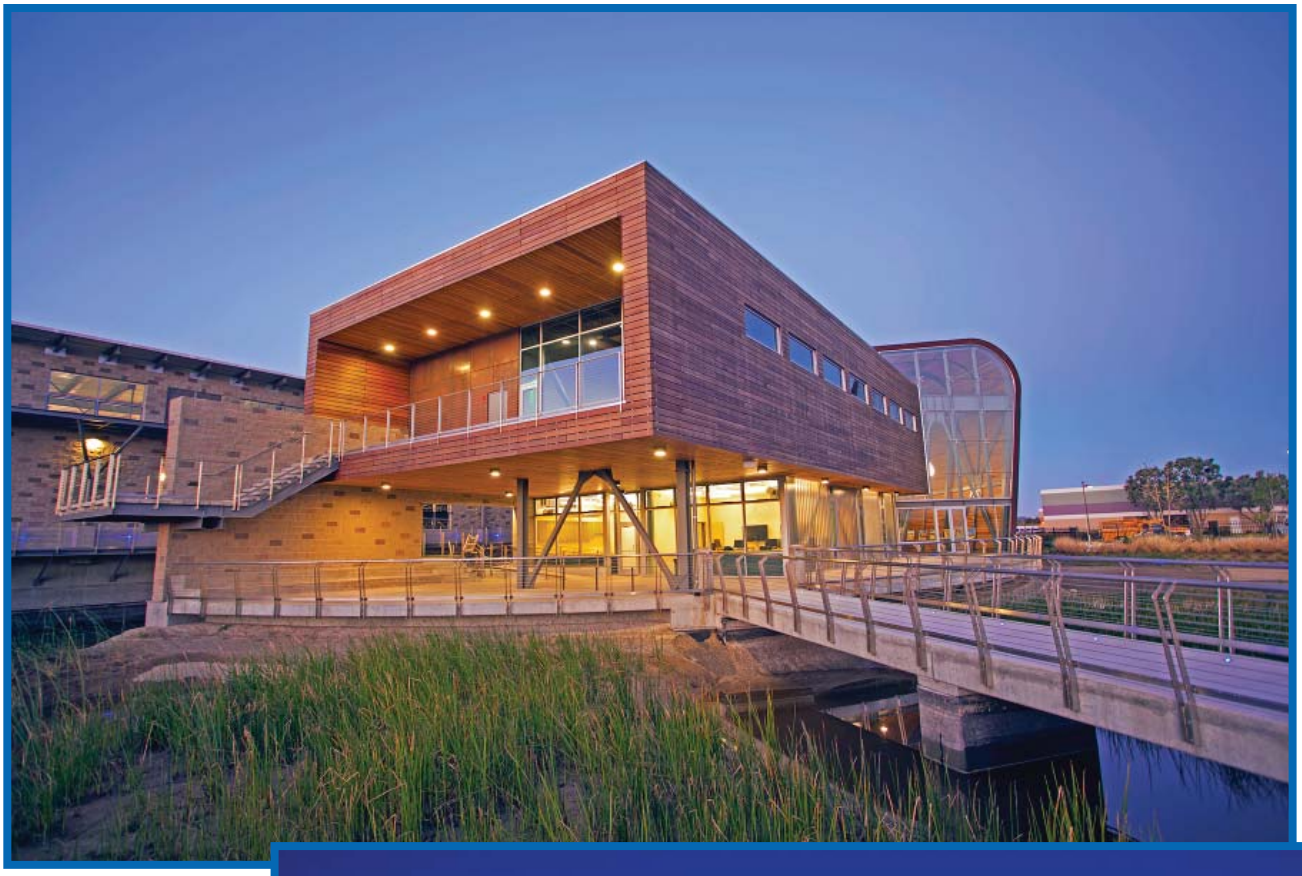
Soddell, Jade. *Potential Reclamation Applications of the T-Hawk – A Gasoline Micro Air Vehicle: A Guide for Potential Reclamation UAS Users* (ID 5063).
jsoddell@usbr.gov



Potential effects of elevated CO_2, climate change, and climate-driven streamflow and plant community changes (rectangles) on riparian animals (ovals).

Measuring bedload when the Upper Junction City project was under construction in August 2012.

Saltcedar, an invasive species in the Western United States, and Diorhabda beetle.



City of Oxnard's Advanced Water Purification Facility and Treatment Wetland. Photographs courtesy of the city of Oxnard, California *(see page 13).*