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Congress on Sustaining Western Water

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About RNRF

Purposes

The Renewable Natural Resources Foundation (RNRF) is an I.R.C. §501(c)(3) nonprofit, public policy research organization, founded in 1972. It is a consortium of scientific, professional, educational, design and engineering organizations whose primary purpose is to advance science, the application of science, and public education in managing and conserving renewable natural resources. RNRF's member organizations recognize that sustaining the Earth's renewable resource base will require a collaborative approach to problem solving by their disciplines and other disciplines representing the biological, physical and social sciences. The foundation fosters interdisciplinary assessments of our renewable resources requirements and advances public policies informed by science.

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RNRF's members are membership-based nonprofit organizations with member-elected leaders. The foundation is governed by a board of directors comprised of a representative from each of its member organizations. Directors also may elect "public interest members" of the board. Individuals may become Associates.

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American Water Resources Association

Geological Society of America

Society of Environmental Toxicology and Chemistry

Society of Wood Science and Technology

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The quarterly journal, first published in 1982, features articles on public policy related to renewable natural resources. It also includes news from member organizations, general announcements, meeting notices, and international conservation news. The journal is provided as a program service to the governing bodies of RNRF member organizations, members of the U.S. Congress and staff of its natural resources- and science-oriented committees.

Congress on Sustaining Western Water

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The **American Geophysical Union** agreed once again to host the congress at its modern conference facility at its headquarters in Washington, D.C. Another way that AGU advances interdisciplinary science!

Congress Program Committee Chair **Richard Engberg** and members of the committee provided essential leadership and guidance. Committee members and additional contributors to the congress's planning and success are listed on page 3.

RNRF Program Director **Melissa Goodwin** made a significant contribution by working with our committee, speakers and delegates. She also contributed to the production of this report as the writer and as an editor. RNRF Research Associate **Jennee Kuang** assisted with meeting planning and logistics and contributed editorially to this report.

Finally, sincere appreciation goes to the speakers and delegates who made such an excellent meeting possible. Speakers and registered delegates are listed in the appendices.

Robert D. Day
Executive Director

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Editorial Policy: The editors seek general interest articles concerning public policy issues related to natural resources management. Recommended maximum length of manuscripts is 4,000 words. All manuscripts will be reviewed by the editors and, where appropriate, by experts in the subject matter. (A "Guide for Contributors" is posted at RNRF's website.) ***Editorial Staff:*** Robert D. Day, editor; Melissa M. Goodwin, associate editor; Jennee Kuang, assistant editor.

Executive Summary

Introduction

The past four years have seen extreme drought in the western United States with no relief in sight. While precipitation patterns in this region are highly variable, the National Climate Assessment predicts that drought trends will likely intensify over this century and beyond, with longer-term droughts anticipated. Nevertheless, population in the western states has increased rapidly, and the region continues to support significant agricultural production. Strategies for coping with drought have a long history in the region, but it will be a challenge to adapt and apply these strategies to severe projected droughts.

This report is a summary of the presentations, findings and recommendations of expert speakers and delegates present at the Renewable Natural Resources Foundation's 2015 Congress on Sustaining Western Water. Professionals from RNRF member organizations, and leaders from government, industry, academia and nonprofit organizations attended the meeting.

Summary of Presentations

Drought and Water Use in the Western United States (The Western Water Landscape)

Doug Parker, director of the California Institute for Water Resources, provided an overview of historical water management and development in the West. Limited water availability defined settlement of the West, with regional growth reliant on the development of water infrastructure. Imbalances between water allocations determined by a system of historic rights and actual water availability are managed with storage and conveyance systems. Drought and increasing water demands inhibit the ability of this highly engineered system to meet the needs of water rights holders and ecosystem needs. Projected climate change impacts will diminish water supplies throughout the region and undermine the ameliorative potential of storage reservoirs.

Legal Issues and Constraints on Western Water Resilience

Barton H. "Buzz" Thompson, Jr., Robert E. Paradise Professor of Natural Resources Law and Perry L. McCarthy Director of the Woods Institute for the Environment at Stanford University, presented legal influences and constraints on western water supplies and implications for resilience. Central tenets of water law are the doctrines of *prior appropriation* and *beneficial use*, which lend both security and inefficiency to the management of scarce water resources. While water law is ultimately state law, its regulation in the West is complicated by the proliferation of interstate rivers and the ensuing need to resolve interstate water disputes. Thompson argues that although there are many problems and inefficiencies in western water law, as applied, it has proven to be surprisingly flexible, adaptive to new problems, and frequently effective in facilitating solutions to water challenges. Statutory adjustments and negotiated agreements will continue to provide the paths forward in this evolving environment.

Pathways to Sustaining Western Water

Sustainable Water Use in the Arid Southwest

Sharon Megdal, director of the Water Resources Research Center at the University of Arizona, discussed the legal, institutional, and governance context of assessing potential solutions to water issues in the Southwest. The extent of monitoring, data and regulatory mechanisms needed for sustainable water management and governance is variable and uncertain. Legal recognition of the connection between surface water and groundwater is necessary to manage water in a holistic and sustainable manner. Many challenges are technical, such as the failure or inability to measure or monitor groundwater storage and use. Financing, research and dialogue among water stakeholders are essential for continued progress toward sustainable water use. This region is a leader in the adoption of technological and management solutions, such as water reclamation, restrictions on water use, state-financed water infrastructure, and conditioning the approval of new development on the availability of water.

Sustainable Water Use in the Rocky Mountains

Reagan Waskom, director of the Colorado Water Institute at Colorado State University, discussed pathways to ensuring a sustainable water supply for people and the environment in the Rocky Mountain region. Rocky Mountain hydrology is highly dependent on snowmelt. Decreasing snowpack and shifts in melt season have implications for how the Colorado River Basin states manage water, particularly for meeting late-summer demand. Looking forward, storage will be an important part of how western states cope with climate change and precipitation changes.

The constrained hydrologic system of the Rocky Mountain states is further challenged by rapid population growth. States will face increasing pressure to shift water away from agriculture and/or increase supply with new diversions from nearby water sources.

Policy and institutional changes at all levels are necessary to promote the resilience of water systems in the Rocky Mountains. Waskom highlighted several key elements of an integrated response including water management practices, regulatory protections, data and information needs, planning and infrastructure. Managing expectations is important, as sustainability is out of reach in many areas. For example, although there are efforts to construct and implement institutional mechanisms to prolong the life of the Ogallala Aquifer, a sustainable solution to overdraft remains out of grasp. As long at it remains profitable to pump groundwater, there is no economic incentive to transition back to dry-land farming in the High Plains.

Satisfying the full combination of human demands, historic levels of agricultural water use, and requirements for healthy ecosystems into the future is probably impossible. Although society requires a robust and resilient food system, agriculture will not be able to compete with energy, industry, and municipalities for water in this region

California: Managing Groundwater for Drought, Clean Water, Food Security and Ecosystems

Thomas Harter, Robert M. Hagan Endowed Chair in Water Management and Policy and Cooperative Extension Specialist (Professor) in Groundwater Hydrology in the Department of Land, Air and Water Resources at the University of California, Davis, discussed pathways to sustaining water in California. Harter's presentation focused on groundwater depletion and management issues in the state, where over 2,000 wells have run dry.

During the past four years of drought, massive amounts of groundwater have been pumped from California's aquifers (particularly in the Central Valley) to make up for lack of surface water. Aquifer levels are significantly lower than they have ever been during the 20th Century. Unsustainable pumping has permitted California farmers to sustain production without large price spikes. Consequences of this groundwater overdraft include saltwater intrusion, increased cost of obtaining water, land subsidence, water quality degradation, and ecosystem impacts. Approximately eight miles of saltwater intrusion has occurred in the Salinas Valley aquifer north of Monterey, California. Land subsidence has in many instances permanently impaired future aquifer capacity.

In response to these and other impacts, California enacted the Sustainable Groundwater Management Act in 2014 to promote local and long-term sustainable management of groundwater resources. This legislation is comprehensive and aims to achieve sustainable groundwater management by the 2040s—relatively quickly from an administrative perspective. Future groundwater management in agricultural regions presents a unique opportunity to advance creative solutions that simultaneously address groundwater supply management, groundwater quality improvement, drinking water protection, and the economic viability of agriculture.

Water Transfers

Adam Schempp, senior attorney and director of the Western Water Program at the Environmental Law Institute, discussed how water transfer mechanisms can be made more effective and useful for maximizing the utility of water resources. In determining how to facilitate water transfers in a given region, it is essential to tailor the process to best suit the circumstances in which they will be administered. Recognizing the role of influential factors such as law, administrative capacity, social and political dynamics, economics, infrastructure, and the proximity of buyers and sellers is essential. State-to-state variability in water law and the influence of prior appropriation make transfers extremely complex.

Land-Use Policy and Water in the West

Ellen Hanak, senior fellow and center director of the Public Policy Institute of California, discussed the importance of linking water and land use, and their connection to water quality and quantity. The integration of water and land-use planning, if applied more frequently, can minimize damage to investments from water scarcity, protect people and infrastructure from water deluges, and sustain healthy watersheds.

Conditioning new development on the adequacy of water supply limits the pressures of population growth on worsening water supply issues. State policies can help shift development from unincorporated areas to municipal areas, alleviating concerns about unmanaged development and use of groundwater. However, domestic well loopholes that encourage some development off the water grid limit success in these state policies.

Forward-thinking planning in agricultural areas that integrates tools such as water conservation, resilience of permanent crops, and land retirement can improve long-term land use. Hanak also highlighted the importance of land-use policies for environmental purposes, including the provision of pop-up wetlands for migratory bird habitat. Additionally, regions of high permeability soils that provide significant groundwater recharge should be preserved.

Forested Watersheds in a Hotter, Drier West: Meeting Adaptation Challenges

David Cleaves, former climate change advisor for the U.S. Forest Service, described the status and future of forested watersheds in the context of challenges posed by a hotter and drier West. His presentation included the major challenges for adaptation to climate-driven, compound risks; examples of initiatives to address those challenges; and next steps for program delivery and policy support.

Drought and high temperatures are pushing forest systems beyond their mortality threshold—the point at which trees die and the ability of the ecosystem to regenerate diminishes. Under a climate change regime, these impacts are intensified. Climate change will contribute to insect infestation, disease and large-scale die-offs. Wildfires are becoming an increasingly prevalent feature of the western landscape; climate change impacts will increase the length of the fire season, size of individual fires, and their intensity.

The primary goal for watershed restoration is to restore functionality for the watershed, thereby building resilience. This can be achieved by protecting headwaters, managing disturbance patterns, connecting fragmented parcels, discouraging development in floodplains, directing grazing away from riparian areas, limiting urban and agricultural pollution, and keeping rivers shaded by trees. Public-private partnerships, adequate financing, and science-based management are central to this objective.

Managing Western Fish, Wildlife and Plants in an Era of Changing Climate and Increasing Drought

Kurt Johnson, national climate change scientist with the U.S. Fish and Wildlife Service Science Application Program, discussed the impacts of the current drought on western fish and wildlife resources, and how managers are addressing those impacts.

As a result of prolonged drought, fish and wildlife resources face a survival emergency in the West. Current drought and temperature forecasts portend a future that falls outside of the experience of natural and human systems in the western United States. These conditions will present substantial challenges to the adaptive capacity of the region and to the resources and ingenuity of natural resources agencies and partners.

Short-term interventions adopted by the U.S. Fish and Wildlife Service and partners to protect fish and wildlife resources include: increased groundwater pumping; strategic drying; strategic prioritization and provision of high-value habitats (e.g. wetlands); and capture, translocation and captive maintenance of fish species.

Johnson stressed that the need to address significant impacts in the short term must be balanced with planning for long-term solutions to climate change. Longer-term solutions take the form of collaboration between federal and state natural resources agencies and non-governmental organizations to safeguard fish, wildlife, and plants, as well as the natural systems on which they depend. Such initiatives include water supply and demand studies, drought response and planning activities, and review of land and water management practices.

Landscape Conservation Cooperatives (LCCs) are self-directed partnerships created to define science needs and jointly address broad-scale conservation issues. LCCs addressing drought conditions in the West seek to increase the predictability of water supplies for decision-makers, conduct vulnerability assessments and scenario planning, predict habitat changes and their impacts on species migrations and survival, foster collaboration to design future landscapes, and increase capacity for general drought and climate management.

An Approach to Scenario Planning in the Colorado River Basin: The Colorado River Basin Water Supply and Demand Study

Carly Jerla, Lower Colorado region operations research analyst at the U.S. Bureau of Reclamation, discussed how scenario planning can be used as a tool for promoting the sustainable use of freshwater resources. In this context, Jerla examined the 2010-2012 Colorado River Basin Water Supply and Demand Study.

For the Colorado River Basin, scenario planning provided a medium for broad thinking about the future of water resources and set the stage for robust decision-making about the future of the basin. The integration of tens of thousands of supply and demand scenarios enabled a comprehensive assessment of resource vulnerability, the evaluation of different options and strategies to respond to those vulnerabilities, and a method of assessing their relative effectiveness and trade-offs.

Median supply-demand imbalances of approximately 3.2 million acre-feet of water by 2060 necessitate a range of adaptation and management responses. Depending on the severity of these imbalances and the response strategy pursued, the study estimated an annual implementation cost of approximately $2 billion to as much as $7 billion annually.

Conclusion

The presence of water, or lack thereof, has shaped the development of the West in profound ways and will continue to do so in the years ahead. The resilience of historical development and water law will be put to the test over the next century and beyond as the region faces more intense and longer-term droughts.

Water scarcity and changing precipitation patterns, along with environmental needs and water quality issues, pose new challenges to the adaptive capacity of an already constrained and over-allocated water system. RNRF congress speakers and delegates highlighted an array of technological, policy and management responses available to promote short-term solutions to drought and long-term resilience to climate change impacts on the region's water system. These responses are discussed throughout this report. Highlights include:

- ***Recognizing connected surface and groundwater hydrology.*** Surface water and groundwater are historically managed under separate bodies of law despite their connected hydrology. Recognition of their interconnected hydrology is essential for sustainable and holistic management of the hydrologic system.
- ***Water storage.*** The western states rely on storage in reservoirs, snowpack, and underground aquifers to balance water supply and demand, as well as seasonal variation in precipitation. As snowpack storage declines, increased reliance on aquifer storage requires a regulatory framework for ownership and a scientific and engineering assessment of the water's fate once pumped underground. Aquifer recharge introduces water quality challenges, which must be addressed as well.
- ***Conservation and efficiency.*** Water conservation and efficiency improvements can enable consumptive water users to maximize benefits from a given water allocation. However, these initiatives can affect the distribution and availability of water in the system by limiting return flows.
- ***Water transfers and marketing.*** Water transfer and marketing mechanisms have been successfully implemented throughout the West to move water from low- to high-value uses. Long-term success of these mechanisms is dependent on the sustained goodwill of involved parties. Individual water transfer regimes and markets must be tailored to best suit the regulatory circumstances of a given region.
- ***Land-use planning***. Development must be conditioned on water availability in the West. Coupling decisions about land use with water planning can prevent damage to investments from water scarcity, protect people and infrastructure, and sustain healthy watersheds.
- ***Watershed restoration***. Restoring functionality to degraded and stressed watersheds promotes resilience via enhanced water quality and ecosystem function. Successful watershed restoration efforts require partnerships and the involvement of all water stakeholders. The best available science should be applied to solve problems on a watershed-by-watershed basis.
- ***Long-term collaborative solutions***. Water users and decision-makers must work collaboratively to enhance the predictability of water supplies and increase the capacity for drought and climate resilience in the years ahead.
- ***Scenario planning***. The integration of many possible supply and demand scenarios in the long-term planning process of a watershed enables a comprehensive assessment of resource vulnerability, preparing the state for robust decision-making about future management options.

These and other technological and management responses must be considered and applied within the context of existing water law. Despite its challenges, water law will continue to offer the flexibility needed to facilitate solutions to the water challenges faced by western states in the years ahead.

The need for interstate cooperation and compromise regarding water resources will increase as water supply and demand imbalances become greater. Collaboration is critical for establishing pathways to sustainable water use, as is the recognition that all water users are water stakeholders.

Meanwhile, environmental flows must be protected. Ongoing drought conditions pose a serious challenge to the adaptive capacity of fish, wildlife and plants. Natural resources agencies and partners are implementing short- and long-term strategies to promote ecosystem health and save threatened species. However, financial constraints and the severity of this challenge are limiting success.

Ultimately, forward-thinking investments in resilience will enable continued economic prosperity in the western states, but many water users—particularly agriculture and ecosystems—will face extreme and daunting obstacles.

Appendices

Delegates to the congress are listed in **Appendix A**.

A copy of the congress program is included in **Appendix C**.

Introduction

Water is scarce throughout much of the western United States. West of the 100th meridian, evaporation exceeds precipitation rates, and average annual rainfall is less than 20 inches annually. Regardless, population in western states has increased rapidly, and the region continues to support significant amounts of agricultural production. From 2000 to 2010, the population of the West grew by 13.8%, or 8.7 million people. California's $2.2 trillion economy is the seventh largest in the world; population in this state increased from 15.7 million people in 1960 to 38.8 million today. California's agricultural industry generates roughly $37.5 billion annually, more than that of any other state.

The population growth and shaping of the West during the later half of the 20th century occurred during an anomalously wet period in the region's history. Analysis of tree rings indicates that western states have experienced many droughts lasting two decades or longer, including two megadroughts that lasted over a century.

According to the U.S. Drought Monitor, 11 of the past 14 years have seen drought in much of the American West, from California to Texas and Oklahoma. The past four years in particular have seen extreme drought in this region with no relief in sight. Sierra Nevada snowpack, critical to California's water supply, reached a historic low in April 2015—just 5% of the long-term average. The water level in Lake Mead dropped 4 feet between May and June in 2015; at 1,075 feet and 37% of capacity, the reservoir had not seen these levels since it was created in the 1930s.

The 2014 National Climate Assessment predicts that drought trends will likely intensify in most U.S. Regions over this century and beyond, with longer-term droughts expected in large areas of the Southwest, southern Great Plains and Southeast.

In the American West, cities account for approximately 20% of total water withdrawals; agriculture consumes the remaining 80%. Strategies for coping with drought—including irrigation and water conservation—have a long history in this region. However, it will be a challenge to adapt these strategies and apply them to the severe droughts projected for the future.

Recognizing an opportunity to contribute to the dialogue on the management of water resources in the western United States, directors of the Renewable Natural Resources Foundation (RNRF) called a national *Congress on Sustaining Western Water*.[1] The congress brought together a select group of professionals from RNRF member organizations, and leaders from government, industry, academia and nonprofit organizations.[2] Over 60 delegates met on December 1-2, 2015 at the American Geophysical Union conference center in Washington, D.C.[3]

RNRF congress delegates assessed the challenges of managing scarce water resources within the economic and regulatory framework of the western states. The congress featured discussion of methods and opportunities to sustain water resources including water transfers, land-use policy tools and future scenario planning. Finally, it addressed the importance of conserving water for forests, wildlife and ecosystems.

This report features a synthesis of information and commentary presented by speakers over the course of the two-day congress. Their presentations are supplemented by insights offered by delegates during each subsequent question-and-answer session.

1 Videos of speaker presentations, PowerPoint slides, and materials for further reading are available at www.rnrf.org/2015cong.
2 See Appendix A for a list of registered delegates.
3 See Appendix B for the complete congress program.

Summary of Presentations

Drought and Water Use in the Western United States (The Western Water Landscape)

The availability and use of water and water resources are distinctive features separating the eastern and western United States. Compared to the East Coast, where precipitation is relatively uniform year-round, the western states receive most of their precipitation in the winter months. This fundamental difference has impacted development of the West in profound ways and will affect this region's continued growth and prosperity in the years ahead. **Doug Parker**, director of the California Institute for Water Resources, opened the congress with an overview of historical water management and development in the West and explored why water availability is an issue today.

Supply and Demand Imbalances

Limited water availability defined settlement of the West, with regional growth reliant on the development of water resources. Of particular importance was the Colorado River, which today supplies water to over 40 million people, only 12.7 million of whom live within the watershed. Its water irrigates 4 million acres of cropland and generates 12 billion kilowatt hours (kwh) of hydropower annually.

The Colorado River is managed and operated under several compacts, federal laws, court decisions, contracts and regulatory guidelines, collectively known as the "Law of the River." The cornerstone of its management is the 1922 Colorado River Compact, which divided the river between upper basin states (Colorado, New Mexico, Utah and Wyoming) and lower basin states (Arizona, California, and Nevada). The upper and lower basins are each allocated 7.5 million acre-feet (MAF) annually. The Mexican Water Treaty of 1944 committed 1.5 MAF of the river's annual flow to Mexico. While the flow of the Colorado River is variable year-to-year, average annual flow is approximately 15 MAF, 1.5 MAF less than total allocations.

The Colorado River supplies water to over 40 million people, only 12.7 of whom live within the watershed.

Due to such imbalances between water allocation and supply, as well as intra-annual variation in precipitation, western states are subject to water shortages. Over 29 major dams provide storage capacity to regulate inter- and intra-seasonal water flow, while hundreds of miles of canals move water to where it needs to be. Major projects include the Hoover Dam, constructed in 1935 to hold 28.5 MAF in Lake Mead, and the Glen Canyon Dam, constructed in 1966 to hold 26.2 MAF in Lake Powell.

Drought and increasing demands on water supplies inhibit the ability of this highly engineered system to meet ecosystem needs and the needs of water rights holders. Projected climate change impacts will diminish water supplies throughout the region and overburden storage reservoirs.

The Importance of Storage

While all states in this region have been in extreme drought for the past 5-10 years, some of the worst effects have been in California. To meet demand, water is transferred south from the northern portion of the state and diverted from the Colorado River. Resilience in the state's water supply stems from this diversification in supply, as well as an expansive system of reservoirs and canals that store water and transport it where needed.

These storage and conveyance functions are essential in California. While the majority of water use occurs in the southern two-thirds of the state, the majority of water supply originates in the northern third. Within any given year, precipitation is also subject to seasonal imbalance: most precipitation falls in the months of December-March, while the remaining portion of the year is much drier. Meanwhile, interannual precipitation is highly variable: Parker remarked that there is no such thing as an average water year in California—it is either too wet or too dry.

The state's water storage capacity includes 43 MAF of surface storage, over 150 MAF of groundwater storage, and 15 MAF in snowpack. The dams that comprise surface storage are necessary to control runoff from heavy precipitation in the winter and to provide a steady supply of water throughout the year.

While the snowpack provides winter storage, meltwater is collected in the spring and used to refill reservoirs that had been drained in preparation for winter flooding. California's water infrastructure was designed around its snowpack. However, current climate change models predict that average snowpack storage will decrease by one-third, averaging 10-11 MAF in the coming years. A reduction in precipitation that falls as snow will stress the existing water system.

These impacts are occurring today. The 2014-2015 water year was the worst on record for snowpack in California, with less than 5% of normal snowpack in the state. As of September 30, 2015, the last day of the water year, many reservoirs were operating at approximately 50% capacity.

"The Fallacy of the Solutions Mindset"

While there have been longer droughts in the region's geological history, few droughts have approached the severity of recent years; 2011 to 2015 were the worst four consecutive years of drought for the region in 1,200 years. Snowpack levels in 2015 were the lowest in the past 500 years on record.

To compensate for diminished surface water supplies, water users are increasingly relying on groundwater resources. More than 2,000 wells have gone dry in California, and there are regions of severe subsidence; groundwater extraction is causing land to sink rapidly in some areas, causing structural damage to transportation and water infrastructure. Meanwhile, the future storage capacity of aquifers is being seriously and permanently reduced.

This transformative, long-term drying trend necessitates an array of technological and policy responses. As we are unable to predict future water supply with certainty, the adoption of a menu of responses will maximize resilience in the system. These responses include desalination, waste water reuse, improved surface storage, improved utilization of groundwater storage, adjustments to water allocation and marketing, water use efficiency,[4] and conservation.

Meanwhile, state and federal planners and officials must address both short-term drought and long-term water supply issues in the region. The volume of water in western river basins that has been allocated to users exceeds average annual flow. This overallocated system has been exacerbated by drought. Parker asserted that due to physical and political limitations, short- and longer-term challenges are unlikely to be fully resolved. Rather, residents of the West will learn to live with a drier climate and build an economy that is resilient to wide fluctuations in water supply. Westerners must become increasingly creative and embrace diverse approaches to improving water resilience.

Water supply will never equal water demand in the western states.

Doug Parker concluded his presentation with the assertion that water supply will never equal water demand in the western states. This stems from an inability to achieve a steady state in water demand or use. For example, the West is rich in land but poor in water. In California, 26 million acres of agricultural land, 13 million acres of pasture and rangeland, and 9.5 million acres of irrigated cropland comprise an industry generating more than $46 billion of gross revenue annually. Any effort to increase water storage, and thus supply, will bring more land into production. In times of drought, water availability would again become an issue.

This principle necessitates a change in the dialogue surrounding western water. We must think about how to design systems to be resilient given drought and long-term water supply issues. How can the western states continue to grow and be robust without undermining their sustainability?

Legal Issues and Constraints on Western Water Resilience

Although each state has its own set of water laws, water rights in the United States can be classified according to two major doctrines: riparian and prior appropriation. Riparian rights, where the owner of land adjacent to a source of water has the right to reasonable use of that water, are most common in the East. Since water supplies are limited in the western states, water rights are awarded under prior appropriation, wherein the first individual to take a quantity of water from a water source for "beneficial use" has the right to continue to use that quantity of water for that purpose. The remaining water is available for beneficial use by subsequent users, provided that they do not impinge on the rights of senior water rights holders.

While western water law is extremely complex, conflict-ridden, and fragmented, it is a driving force behind development and the economy in the west. **Barton H. "Buzz" Thompson, Jr.**, Robert E. Paradise Professor of Natural Resources Law and Perry L. McCarthy Director of the Woods Institute for the

4 Agriculture is the largest user of water in the western states, comprising 80% of consumptive water use in California. While output per unit of water has increased dramatically, increasing efficiency introduces a range of administrative complications and can negatively impact rates of groundwater recharge.

Environment at Stanford University, discussed legal influences and constraints on western water supplies and implications for resilience. He emphasized that while there are many problems and inefficiencies in western water law, it has ultimately proven to be surprisingly flexible, adaptive to new problems, and frequently effective in facilitating solutions to the water challenges we face.

The development of water law in the West echoed gold mining in California, where mining rights were awarded on a "first-come, first-served" basis. While senior water rights are unambiguous under prior appropriation, it is nevertheless a highly inefficient and inequitable system. First, there is no reason to believe, Thompson asserted, that a senior water right holder can place the water to a higher economic or social value than a junior rights holder. Secondly, the inefficiencies inherent in prior appropriation are particularly apparent during times of drought. If you assume a declining marginal benefit for water use, it is highly inefficient to deny some users all of their water, while ensuring full allocation for others.[5]

While water law is ultimately state law, its regulation in the West is complicated by the proliferation of interstate rivers in the region (a consequence of using straight lines to define state borders, ignoring watershed boundaries) and the ensuing need to resolve interstate water disputes.[6]

Interstate Water Allocation Methods

Although western water law is administered at the state level, interstate water disputes must be resolved at the federal level. The three tools available to resolve interstate water allocation are interstate compacts, equitable apportionment by the Supreme Court, and legislation by Congress. None of these tools, however, have proven to be an efficient means of allocating water between states.

According to the Colorado Foundation for Water Education, a compact is an agreement between two or more states, approved by state legislatures and Congress under the authority of the U.S. Constitution. A *water compact* sets the terms for sharing the waters of an interstate stream between states. States typically favor compacts because they allow each state to retain control over the negotiation process and create more certainty for the parties involved.[7] However, relevant parties frequently continue to dispute water rights even after an agreement has been made, leading to litigation.

Alternatively, states can settle water rights disputes through *equitable apportionment* by the Supreme Court of the United States (SCOTUS). New interstate apportionment cases are being filed regularly. Although states typically prefer to settle between themselves rather than allowing SCOTUS to control water allocations, it can be politically difficult for two or more states to come to an agreement. In these situations, settling through the SCOTUS may be the only option. SCOTUS cases, however, are often both time- and cost-intensive. Even after SCOTUS reaches a decision, the relevant parties may disagree in the future over how the rulings apply to a new situation.

Finally, Congress has the power to allocate state water rights through *legislation*. However, there are no instances in which Congress has clearly exercised this power. Congress is sensitive to state sovereignty over water, and the issue is highly politicized for members of Congress who represent states that have a current or future stake in the outcomes of water allocations.

Conservation

Built into western water law is the regulatory requirement that all use of water be "reasonable and beneficial." Such uses include municipal and industrial uses, irrigation, hydroelectricity generation, and livestock watering, as well as recreational use and fish and wildlife protection. A violation of this mandate may result in the loss of a water right. However, there are few examples of regulators or the courts determining that a user has committed such a violation. Thompson indicated that the reason for this lack of enforcement is reluctance on the part of the court system to decide whether a user is wasting water or to require that users invest capital to upgrade systems that may be inefficient compared to newer technologies.

The reasonable and beneficial use doctrine can prevent farmers, the largest consumptive water users, from engag-

5 A marginal benefit is the additional utility a person receives from consumption of an additional unit of a good or service. It defines the maximum amount they are willing to pay to consume that additional unit. Generally, the marginal benefit decreases as consumption increases.

6 The Yellowstone River Compact between Montana, Wyoming, and North Dakota is one of 26 interstate water compacts that have been negotiated between states. It was ratified in 1950 following three failed negotiations. Since the 1970s, relevant parties have been litigating on the Compact, often disputing water allocations even after Supreme Court rulings have been made.

7 Colorado Foundation for Water Education. Citizen's Guide to Colorado's Interstate Compacts. 2010.

ing in voluntary conservation initiatives.[8] For example:

1. If a farmer were to take some action to conserve water, e.g. adopting an efficient irrigation system, they could open themselves to the accusation that prior use of the resource was wasteful and the potential loss of that water right.
2. There is ambiguity concerning the use of conserved water—can the farmer redirect it to alternative uses or is the right to that water forfeited? (One of the basic elements of prior appropriation and western water law is "use it or lose it.")

Meanwhile, conservation can affect the distribution and availability of water. Absent conservation initiatives, "wasted" water may be flowing back into a river or recharging groundwater aquifers. This recovered water may constitute some or all of the allocation of a junior water right holder. Put another way, the use of conserved water by a senior water right holder may make water unavailable for a junior water right holder. Thompson noted that a basic principal of western water law is that not only are the rights of senior appropriators protected, but junior rights holders as well. Therefore, no change in a water right may injure a junior appropriator.

Steps have been taken to alleviate these concerns. Conservation is considered a reasonable use, thus eliminating the threat of forfeiture under the reasonable and beneficial use doctrine. A variety of courts have ruled that users can save and use conserved water, even if it may injure a junior appropriator downstream.

Water Marketing

Water marketing[9] has long been an element of western water law. However, only recently has its value for encouraging conservation and the movement of water from low- to high-value uses been fully appreciated. Its use has grown significantly since the early 1980s, but plateaued in recent years because of the need to provide proof that the water rights of junior appropriators are not injured.

Water marketing between states introduces additional complications. While states are not typically permitted to hold on to their respective resources to the detriment of the welfare of other states, such protectionism is permitted in water law. For example, the Red River Compact, an agreement between Oklahoma, Texas, Arkansas and Louisiana ratified by Congress in 1980, ensures that each state is entitled to an "equitable apportionment of water" from the Red River and its tributaries. Under pressure from a growing population and drought, a Texas state agency, the Tarrant Regional Water District, unsuccessfully sought permits to purchase water from Oklahoma. Ultimately, in a 2013 U.S. Supreme Court case, *Tarrant Regional Water District v. Herrmann*, the justices sided unanimously with Oklahoma, upholding that the Red River Compact does not pre-empt state regulations prohibiting out-of-state applicants from taking or diverting water from within Oklahoma's borders.[10]

Groundwater

One of the inefficiencies inherent in western water law is the existence of separate bodies of law for surface water and groundwater, despite the fact that they share a connected hydrology. Notwithstanding a decade of pervasive drought, many states allow users to pump an unlimited amount of groundwater, regardless of impacts. As a result, a tremendous amount of groundwater overdraft has occurred in the central and western United States, particularly in regions dominated by irrigated agriculture, impacting groundwater users and groundwater dependent ecosystems.[11]

The creation and enforcement of effective groundwater management regimes is essential for sustainable water management. One approach is via the creation of Groundwater Management Districts, which can regulate how much groundwater is pumped in a region. A fair and reasonable approach to implement new regulations may be to allocate all users their historical groundwater use and ratchet down over time. However, Thompson noted that water is a protected property right in state and federal law, and this approach may constitute an unconstitutional taking.[12]

An important component of the solution to groundwater depletion is aquifer storage and recovery, wherein available surface water is pumped into underground aquifers for storage. However, several legal considerations must be addressed before this can be pursued at scale. While regulators must address the question of ownership, scientists and engineers must assess what happens to

8 Consumptive water use is defined as water use that permanently withdraws water from its source. Consumptive uses of water include water used in manufacturing, agriculture, and food preparation that is not returned to a stream, river, or water treatment plant.

9 For more information on water transfers, see page 21.

10 Supreme Court of the United States. Syllabus: *Tarrant Regional Water District v. Herrmann et al.* http://www.supremecourt.gov/opinions/12pdf/11-889_5ie6.pdf

11 The implications of groundwater overdraft were discussed in more detail by University of Davis groundwater expert, Thomas Harter. See page 19.

12 The Takings Clause of the U.S. Constitution's Fifth Amendment states that private property may not be taken for a public use without just compensation. In U.S. law, takings include physical occupation and a complete regulatory restriction on the use of property.

the water after storage. The potential for wrongful extraction of stored water by a downstream well must be addressed and mitigated. Thompson described these as curable problems, but stressed that this is an evolving challenge.

Water quality issues associated with groundwater recharge must be addressed as well. According to a 2015 report by the U.S. Geological Survey, high rates of artificial recharge and well pumping enhance the movement of some contaminants from human-related sources to deeper parts of basin-fill aquifers. The report indicates that water from 42% of domestic wells and 26% of public supply wells in the Southwest United States contain at least one contaminant at a concentration greater than its human-health benchmark, including arsenic, nitrate and uranium.[13]

Environmental Flows

Due to a variety of stresses including drought and development, native fish and wildlife species are in decline throughout much of the western United States. Historically, water law has not provided instream protections for species—statutes such as the Endangered Species Act, which prohibits the taking of an endangered species, have played a more prominent role in species conservation efforts.

The 1983 California Supreme Court case*, National Audubon Society v. Superior Court*, established that the Public Trust Doctrine and appropriative water rights are "part of an integrated system of water law," and so both must be considered when determining appropriate use of water in California. Thus, the state owns navigable rivers, streams and lakes in trust for the public and, when managing this water, must take the public trust's interests—including environmental protection—into account as practicable. This interpretation of the law is not universal in the United States. Several states, including Nevada, have not followed this example.

Another tool available for ecosystem protection is the use of environmental transactions, wherein an entity purchases water in a water market and puts it "back" into rivers and streams. This approach has been adopted by several organizations. For example, the Delta Water Trust has used environmental transactions to restore riparian forest along the Colorado River in Mexico.

The failure of political boundaries to conform to watersheds necessitates cooperation and compromise for effective management.

Other Legal Challenges

Thompson highlighted several legal challenges that must be addressed as governments, organizations, and water rights holders apply water law to improve the resilience of water in the West:

- *Monitoring and enforcement* of water use must be improved.
- Our ability to sustain *water quality* is hindered by regulatory fragmentation. While water quantity is regulated by states, water quality standards are set by the federal government. Nonpoint sources of pollution remain an ongoing problem.
- While *dams* provide benefits such as water storage, flood control and hydropower, they come with high maintenance and environmental costs including habitat destruction, degradation and fragmentation. There is currently no comprehensive system for deciding which dams should be maintained or retired.
- *Innovation* in water management and policy is needed. Thompson bemoaned a deficit in water innovation and the lack of investment in the field.

Despite the limitations of western water law, it has proven to be flexible and adaptable, and remains a valuable tool to resolve supply and demand issues in the western United States. Every state and water district faces unique challenges and must apply law and ingenuity in new ways to resolve their respective issues.

Pathways to Sustaining Western Water

The western states must plan for future population growth, water-related infrastructure investments and environmental needs amidst climate change and the threat of increasingly severe and unpredictable drought. In light of these stresses, both surface water and groundwater resources must be used in a sustainable and holistic way. The path to resilience in western watersheds will be determined by each state's respective resource base and political environment. During the congress, speakers described the regional differences and challenges for sustaining western water in the arid Southwest, Rocky Mountain states, and California.

13 Thiros, Susan A. et al. The Quality of our Nation's Waters – Water Quality in Basin-Fill Aquifers of the Southwestern United States: Arizona, California, Colorado, Nevada, New Mexico, and Utah, 1993-2009. U.S. Geological Survey Circular 1358. 2014.

Sustainable Water Use in the Arid Southwest

Sharon Megdal, director of the Water Resources Research Center at the University of Arizona, discussed the importance of legal, institutional, and governance[14] context when assessing potential solutions to water issues in the Southwest. She cited the importance of the geographic context of water resources as well, particularly given interstate and international flow of rivers in the Southwest.

The failure of political boundaries to conform to watersheds necessitates cooperation and compromise for effective management. The United States and Mexico have a history of collaborating through the International Boundary and Water Commission (IBWC), established in 1889 to govern and manage shared water. The IBWC is charged with implementing the 1944 Treaty relating to the Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande. Recent examples of collaboration facilitated by the Commission include the US-Mexico Transboundary Aquifer Assessment Program, of which Arizona, New Mexico, Texas, Sonora and Chihuahua are participants, and a five-year historic agreement signed in November 2012 to share Colorado River shortage and surplus and cooperate in restoring the Colorado River Delta ecosystem.

Collaboration on evaluating and fostering pathways to sustainable water use and management is necessary, as is the recognition that all water users are water stakeholders.

Demonstrating the flexibility of western water laws and regulations, states frequently develop creative intrastate solutions to avoid disruptive changes to water law or litigation. For example, recognizing vulnerabilities in its water supply, Arizona established the Arizona Water Banking Authority (AWBA) in 1996 to increase utilization of its Colorado River entitlement and secure water supplies for the state in times of shortage. Annually, the AWBA brings Colorado River water into central and southern Arizona through the Central Arizona Project canal. The water is stored underground in existing aquifers (via direct recharge) or used by irrigation districts in lieu of pumping groundwater. The AWBA accrues credit that can be redeemed during time of drought. This is made possible in part by the presence of a robust statutory framework for storage of groundwater in Arizona.

States also work flexibly and collectively with existing laws and regulations to solve interstate challenges. For example, the Colorado River Basin is currently in its 16th year of drought. As a result, reservoir storage has declined over time, threatening the continued delivery of water to users within the Basin. To limit interstate and inter-basin tensions, the Department of the Interior joined these states in 2007 to develop interim shortage sharing guidelines to coordinate regulation of Lake Powell and Lake Mead water supplies, establish criteria for declaration of a shortage, and provide greater certainty regarding the cutback of lower basin Colorado River water deliveries during times of drought. This cooperation has facilitated enhanced coordination, resilience and flexibility among the basin states.

Opportunities for Sustainable Water Use

The extent of monitoring, data and regulatory mechanisms needed for sustainable water management and governance is variable and uncertain. In some states, the failure of legal frameworks to recognize the connection between surface water and groundwater can make it difficult to manage water in a holistic and sustainable manner. Other challenges are technical, such as the failure or inability to measure or monitor groundwater storage and use. Financing, research and dialogue among water stakeholders are essential for continued progress toward sustainable water use in the Southwest.

Megdal concluded her presentation with a discussion of additional options and opportunities for fostering sustainable water use:

- On the demand side, there is a need to increase conservation and water use efficiency. This has revenue implications for utilities and their customers, however. The cost structure for utilities is dependent on fixed costs and not directly affected by the quantity of water delivered. Thus, cutbacks on water demand may result in increased rates.
- Regular and sustained dialogue between land use planners and water utilities is needed because land use decisions can affect future water demand.[15]
- The use of reclaimed water, including for potable purposes, can be increased.
- Desalination is an available technology for brackish water, seawater, and reclaimed water.
- Augmentation of water supplies is possible through importation and/or storage.
- Water transactions and marketing can facilitate the movement of water resources, mitigating the risk of water shortages.

Financing these options will require commitment from all sectors and must include public-private partnerships.

14 For example, a large percentage of the land in Arizona is owned by Tribal nations. These nations have sovereignty when it comes to water management.

15 This is discussed in more detail by Ellen Hanak. See page 23.

In assessing these options, it is crucial that the water rights framework of western states be upheld. For example, Arizona has a constitutional provision prohibiting takings. Property, including water rights, cannot be taken from individuals without compensation. Education and engagement of water stakeholders will be instrumental for facilitating informed decisions for dealing with these issues in the long term.

Sustainable Water Use in the Rocky Mountains

Positioned at the headwaters of the Colorado River, Missouri River, Rio Grande River, Snake River, and Platte River, among others, the Rocky Mountain states face both similar and unique issues regarding water use, drought, population growth and energy production. **Reagan Waskom**, director of the Colorado River Institute at Colorado State University, discussed pathways to ensuring a sustainable water supply for people and the environment in this region.

He opened his presentation by acknowledging that management of many water supplies, particularly groundwater systems, will not sustainably provide water over the next century. If only human needs are considered, long-term sustainability in western water use is achievable. However, satisfying the mix of human demands, historic levels of agricultural water use, and requirements for healthy ecosystems into the future may be impossible.

The eight interior western states, including Nevada and Arizona, are the most arid in the U.S. and have the highest percentage of federally owned land.[16] They comprise one of the fastest growing regions in the country, with six of the ten most rapidly growing states located within the Colorado River Basin. Drought and aridity are characteristic of this region, and its water allocation system has developed with water scarcity and limits as a central, driving factor. The strength of prior appropriation is its certainty in how water is allocated during times of scarcity. However, population growth, changing environmental needs, water quality issues, and hydrologic uncertainty pose new challenges for an already constrained system. These challenges are further amplified by environmental degradation of rivers and streams after nearly two centuries of water use by miners, loggers, agriculture, and urban users.

Storage will be an important part of how western states cope with climate change and precipitation changes.

Agriculture

Agriculture is central to water use and supply in the West. Food production is water intensive and accounts for over 80% of water use, 73% of which supports irrigated agriculture. While fundamental to the U.S. economy and food supply, the value of water in irrigated agriculture is an order of magnitude lower than the value of water applied for municipal and industrial uses. Thus, Waskom noted, water is moving out of the agricultural sector and will continue to do so in the years ahead as water scarcity persists. This trend is reflected in decreasing acres of irrigated land in the West as water levels in aquifers decline and urban and industrial activity increases in the region.

Rocky Mountain Hydrology

The Colorado River Basin states are characterized by a snowmelt-driven hydrograph, where two-thirds of the region's water flows occur over two months (June–July).[17] Variation from high flows to low flows within an average year due to the snowpack and melt results in both flooding and water scarcity, complicating water management for human use.

Surface water reservoirs in the Rocky Mountains are renewed annually by early summer melt of winter snowpack. Rising temperatures projected by climate change models will result in a higher percentage of precipitation as rainfall in the winter, thus dramatically altering runoff dynamics. Resulting declines in snowpack and streamflow will affect the reliability of surface water supply for cities, agriculture and ecosystems.

While severe runoff changes will manifest in the next 30-50 years, Waskom noted that impacts are already being observed. For example, snowmelt has occurred 1-3 weeks earlier than average during the last decade in Colorado.[18] This has implications for how the Colorado River Basin states manage water, particularly for meeting late-summer demand. Looking forward, storage will be an important part of how western states cope with climate change and precipitation changes.

16 Nevada is 84% federally owned.
17 A hydrograph is a graph showing the rate of flow of water (discharge) vs. time.
18 Mote, Philip W., et al. Declining mountain snowpack in western North America. *Bulletin of the American Meteorological Society*. Volume 86, pp. 39–49. 2005.

Case Study: South Platte Basin in Northeast Colorado

Waskom discussed the impacts of population growth and land use change in the South Platte Basin in Northeast Colorado. The basin is home to 85% of Colorado's population and 830,000 acres of irrigated agriculture. Surface water supplies are dependent on annual snowpack, as well as significant transmountain diversions from the Colorado River: approximately 0.4 MAF of Colorado River water is diverted annually to supplement 1.4 MAF average river flow and 0.5 MAF of pumped groundwater.

Urban growth and sprawl are the dominant drivers of growth in this region. Looking ahead to 2040 and beyond, this trend will continue to strain the South Platte. By 2050, the population in the basin is projected to increase from approximately 3.5 million people today to 6 million. This will coincide with an increase in municipal and industrial water demand from 650,000 AF in 2000 to 1.25 MAF by 2030. It is in this context that sustainability—including management for variability and drought—must be addressed.

Responding to increasing water demand during drought and irregular precipitation will require creative management and action by all users. Interventions are needed. Waskom noted that the basin could expect to dry up to 250,000 acres of irrigated farmland over the next few decades. He identified three possible responses for the South Platte Basin: 1) constrain population growth to water supply, 2) shift increasing amounts of water away from agriculture, or 3) increase supply by creating infrastructure to divert more water from the Colorado River.

These are not the only solutions available to increase the sustainability of the basin near-term. Demand management through water use efficiency improvements, conservation, and water reuse systems can increase the utility of current supplies substantially. The development of new and enlarged storage and modernized conveyance systems can augment existing supplies. Agricultural water efficiency and conservation are key elements as well, though as discussed previously, hydrological and legal ramifications must be addressed. Finally, water quantity concerns must be addressed in conjunction with watershed health and water quality management.

Groundwater governance must be integrated with surface water, and over-allocated river and groundwater basins must be rebalanced.

Case Study: High Plains (Ogallala) Aquifer

Water in the Ogallala Aquifer is not a story of population growth, but rather the use of a nonrenewable water supply for irrigated agriculture. The aquifer underlies 174,000 square miles across eight states. Approximately 165,000 irrigation wells pump water for over 14 million irrigated acres of farmland, representing approximately 25% of irrigated land in the United States. The aquifer is subject to substantial overdraft; it contained an estimated 3.2 billion acre feet of water in 1990, down to 2.9 billion acre feet in 2013.

In this aquifer, maintaining existing groundwater levels is not a realistic goal. Rather, Waskom stated, a more reasonable goal is to prolong the life of the aquifer by developing solutions to sustain the communities and ecosystems that rely on it, e.g. water efficient farming techniques and technological innovations. As long at it remains profitable to pump groundwater, there is no economic incentive to transition back to dry-land farming. A sustainable solution to overdraft in the Ogallala Aquifer remains out of grasp, although there are efforts to construct and implement institutional mechanisms to prolong the life of the aquifer.

Pathways to Sustainability

Achieving sustainability in the Rocky Mountain region will require policy and institutional changes at all levels. Policies to manage supply and use of water must take into account water quality, as well as ecosystem needs. Waskom identified several key elements of an integrated response:

- *Basin-wide management that integrates surface and groundwater governance with science and data*. Groundwater governance must be integrated with surface water, and over-allocated river and groundwater basins must be rebalanced. Quantification of water supplies and time lags for replenishment are challenges that must be addressed.
- *Sustainable groundwater utilization*. Over-pumping of groundwater can cause subsidence that results in a loss of porosity[19] and diminishment of storage capacity.

19 Porosity determines how much water rock, sediment, or soil can retain. It refers to the total volume of open space in which groundwater can reside.

- *Robust interstate markets with manageable transaction costs, transparency and oversight*. Water banks, interruptible supply and forbearance agreements, split season irrigation, and temporary fallowing are tools that can be used to conserve irrigation water and transfer it to other, potentially more valuable uses. Doing so requires metered diversion structures and wells, modernized diversion and delivery systems, remote verification methods, quantified consumptive use value of water rights, the removal of institutional barriers (e.g. "use it or lose it" provisions), and incentives for efficiency.
- *Reasonable protections for agriculture*. Although society requires a robust and resilient food system, agriculture ultimately will not be able to compete with energy, industry and municipalities for water. Incentives for water conservation and efficiency in agriculture are needed.
- *Real time water data and information systems.* The ability to measure and monitor water use in all sectors will facilitate better management and enforcement.
- *Market signals and social norming for urban water conservation and efficiency.* Despite continued population growth, gross water use in the larger western cities remained relatively steady, largely due to a combination of outdoor water conservation policies, pricing signals and water efficient appliances. This pattern must continue and expand to smaller cities and towns.
- *Infrastructure modernization and financing.* Efficiency improvements to infrastructure are needed across all sectors in the United States. Aging infrastructure provides a unique opportunity to redevelop water infrastructure to be more efficient and resilient.
- *Integrate water planning with growth management and land use planning*. State and local leaders must consider the broader consequences of growth, particularly regarding the reliability of projected water supplies. This requires that decisions about land use and growth be coupled with water planning, such as through statutory requirements, comprehensive land-use plans that integrate water availability, and the coordination of local land-use priorities with state water plans.
- *Climate resilience*. The western states must prepare better for drought and shortage, as well as floods and wet periods. Waskom questioned calls for removing dams and reservoirs in the name of sustainability, citing their utility for retiming flows for the environment, flood control, and drought mitigation. The capacity to store water and provide flood protection during wet periods is essential.

Although society requires a robust and resilient food system, agriculture ultimately will not be able to compete with energy, industry and municipalities for water.

California: Managing Groundwater for Drought, Clean Water, Food Security and Ecosystems

Pathways to sustaining water in California were discussed by **Thomas Harter**, Robert M. Hagan Endowed Chair in Water Management and Policy and Cooperative Extension Specialist (Professor) in Groundwater Hydrology in the Department of Land, Air and Water Resources at the University of California, Davis. Harter's presentation focused on groundwater depletion and management issues in the state, where over 2,000 wells have run dry.

While groundwater storage is a critically important component of California's water system, its use is normally relatively small compared to overall storage capacity: it represents approximately one-third of total water use (15-16 MAF). Each of the last four years, however, has seen an additional 6 MAF of groundwater extraction. Drought and enhanced reliance on groundwater have resulted in less recharge than normal.

In a typical year, the groundwater system is balanced between winter months, when most precipitation falls, thereby recharging the aquifers, and consumptive use in the summer months, which are far drier and characterized by depletion. Inefficiencies in the system and irrigation return flow can alter the balance and provide significant aquifer recharge in the summer months. Efficient irrigation alters the balance in the opposite direction—shifting water resources toward consumptive use and limiting water available for groundwater recharge.

Between years, groundwater budgets are balanced by wet and dry years. For example, during wet years, ample surface water enables groundwater to be recharged for use during times of shortage. Long-term droughts, such as the current western drought, result in significant drawdowns of groundwater. Groundwater levels in many areas of

California are significantly lower than they have ever been in the 20th century.

Groundwater storage in California's Central Valley declined by approximately 130 MAF from 1922 to 2009. The past four years of drought have increased this deficit to approximately 150 MAF. Moving forward, some of this unused storage capacity may be actively used and managed for storage of excess or conserved water but there will be complications (see below).

Groundwater overdraft has consequences beyond reduced supply:

- *Saltwater intrusion* occurs when the level of water in a coastal aquifer dips below sea level.[20] Approximately eight miles of saltwater intrusion has occurred in the Salinas Valley aquifer north of Monterey, California.
- *Increased pumping cost and the cost of drilling new wells to supply water.*
- *Land subsidence* ranging from 6-12 inches has occurred across large swaths of land, causing structural damage to building and water conveyance infrastructure. Subsidence also diminishes recharge capacity.
- *Water quality degradation* results from overdraft, as well as aquifer recharge.
- *Surface water depletion* as water tables are drawn down.
- *Impacts to groundwater-dependent ecosystems.*

Sustainable Groundwater Management Act of 2014

Sustainable groundwater management requires adaptive supply management, adaptive demand management, stakeholder engagement, and monitoring and assessment.

In September 2014, California's legislature enacted the Sustainable Groundwater Management Act (SGMA), which provides a framework for the sustainable management of groundwater supplies by local authorities. Two principles of the SGMA are that 1) groundwater is managed sustainably for the long term and 2) groundwater is managed locally. According to Section 2.113 of the Act, "It is the policy of the state that groundwater resources be managed sustainably for long-term reliability and multiple economic, social, and environmental benefits for current and future beneficial uses. Sustainable groundwater management is best achieved locally through the development, implementation, and updating of plans and programs based on the best available science."[21]

The SGMA defines sustainable groundwater management as "the management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results," i.e. chronic lowering of groundwater levels, reduction of groundwater storage, saltwater intrusion, degraded water quality, land subsidence and surface water depletions. This effectively integrates surface and groundwater resources, as well as groundwater quantity and quality, in water management policy and practice.

Implementation of the SGMA will occur quickly from an administrative perspective and will consist of four phases:

- *Phase I (2015-2017):* Phase I will be characterized by the formation of local Groundwater Sustainability Agencies (GSAs) by June 30, 2017. GSAs must assess the conditions in their respective water basins, assess what policies and practices are needed for sustainable groundwater management, and study methods applied elsewhere. The process will be characterized by extensive stakeholder engagement and transparency.
- *Phase II (2017-2020/22)*: Within five years of formation of a GSA (three years for critically overdrafted basins), a Groundwater Sustainability Plan (GSP) must be developed and adopted by the GSA. These plans must integrate the context of the particular basin, public and agency involvement, basin supply and demand management objectives, monitoring, and accountability and review. GSAs have discretionary authority on a wide range of monitoring and assessment activities including well registration and monitoring, reporting requirements, and fees, with some exceptions for private owners. Metrics for the six undesirable results (chronic lowering of groundwater levels, reduction of groundwater storage, saltwater intrusion, degraded water quality, land subsidence and surface water depletions) must be monitored with trigger points established for management action. While trigger points and thresholds for emergency response are to be developed by individual GSAs, the State Department of Water Resources will define minimum guidelines. A locality's GSP is not required to address undesirable results that occurred before January 1, 2015.
- *Phase III (2020/22 – 2040/42):* Initial management through water budgets and implementation of the Groundwater Sustainability Plan.

20 Harter cited a 2014 CDM Smith study exploring saltwater intrusion in the Central Valley Aquifer. They found that the amount of saltwater that must be desalinized in the aquifer on an annual basis to prevent current levels from increasing is on the order of 1.5 MAF and would come at a cost of approximately $1.5 billion annually.

21 Sustainable Groundwater Management Act. State of California. 2014.

Sustainable groundwater management must be achieved by no later than 2040.

- *Phase IV (2040/42 – Future):* Sustainable groundwater management.

Beyond the SGMA, little work has been done so far in California to manage surface water-groundwater interactions. Harter noted that much effort will be needed going forward to manage that interface.[22]

Groundwater Quality

In California, the most widespread contaminants in public supply wells are naturally occurring, arsenic being the most prominent. The principal anthropogenic contaminant is nitrate, which is found mostly in rural, agricultural areas where it leaches into the groundwater following the application of synthetic fertilizer and manure.[23]

Managing pollution from nonpoint source contaminants like nitrate is difficult. While point sources of pollution are regulated by National Pollutant Discharge Elimination System (NPDES) permits under the Clean Water Act, nonpoint sources of pollution to surface water are regulated under total maximum daily loads (TMDLs), the maximum amount of a pollutant that a body of water can receive while still meeting water quality standards.[24] Notably, the Clean Water Act was enacted specifically to regulate surface water contamination and does not address groundwater. California has enacted its own legislation to regulate groundwater pollution. The Porter-Cologne Water Quality and Control Act, for example, specifically identifies groundwater as a water body, thus requiring a permit for discharge.

Regulating nonpoint sources of discharge to groundwater remains a challenge. The solution advocated by Harter is enforcement monitoring. A triplet of actions can enable regulators to monitor and regulate nitrate discharges to groundwater: 1) monitoring nitrogen budgets on a farm and field scale (a proxy for nitrogen discharge), 2) coalitions of farms to implement technologies and best practices to limit groundwater contamination, and 3) regional monitoring programs.

State-to-state variability in water law and the influence of prior appropriation make [water] transfers extremely complex.

Future groundwater management in agricultural regions presents a unique opportunity to advance creative solutions that simultaneously address groundwater supply management, groundwater quality improvement, drinking water protection, and the economic viability of agriculture.

Harter concluded his presentation by noting that while poor irrigation efficiency is the largest driver of nitrate pollution in groundwater, improvement of groundwater quality by reducing irrigation inefficiency will result in a loss of groundwater recharge. Thus, groundwater quality management may mean the loss of some groundwater supplies. Moving forward, these trade-offs must be addressed and mitigated to the extent practicable.

Water Transfers

Adam Schempp, senior attorney and director of the Western Water Program at the Environmental Law Institute, discussed how water transfer mechanisms, can be made more effective and useful.[25] His presentation focused on surface water, as there is more consistency in the underlying legal regime.

Water transfer mechanisms can be made more effective and useful by changing the characteristics of the systems and recognizing the role of influential factors, e.g. law, administrative capacity, social and political dynamics, economics, infrastructure, and the proximity of buyers and sellers. However, state-to-state variability in water law and the influence of prior appropriation make transfers extremely complex.

Under prior appropriation, the first to use the water, or acquire a permit, is always the first in line to receive all of the water necessary to meet the original purpose of use in the original place of use. Water is distributed to each subsequent right holder until all rights are fulfilled or there is no water remaining in the source.

Two key tenets of prior appropriation —protection of water rights and the avoidance of forfeiture—have implications for water transfers. The need to protect the rights of other water rights holders results in high scrutiny of proposed transfers , thus slowing the process. Meanwhile, regardless of whether it is an actual or perceived legal impediment, the threat of forfeiture can dis-

22 More information about the Sustainable Groundwater Management Act and progress toward sustainable groundwater management in California is available online at http://www.water.ca.gov/cagroundwater.
23 Harter noted that less than 50% of the total nitrate applied as fertilizer is taken up by crops. The remaining total nitrogen added to the landscape is free to leach into groundwater.
24 Clean Water Act Sec. 303(d)
25 For consistency, Schempp used the term water transfer. However, water transactions and water sharing are other commonly used terms.

suade both sides of a deal from pursuing a transfer. Most states have administrative or judicial procedures for reviewing transfers to enforce these tenets.

Inherent in this process is the need to quantify consumptive use—a difficult, time consuming and expensive process. Consumption includes water used, as well as evaporation, transpiration, surface runoff and groundwater recharge. It calls to attention the connection between surface water and groundwater, as well as the conundrum of efficiency in agriculture and its effects on groundwater recharge. The time and expense of determining historic consumptive use encourages long-term transfers over short ones and reduces the responsiveness of transfers by introducing a large time lag.

Schempp provided several examples of successful transfer mechanisms and regimes in different parts of the West and examined what worked well and why.

Washington: Expediting Transfers via a Community-Assisted Process

In 2001, the Washington Department of Ecology and U.S. Bureau of Reclamation established the Yakima Emergency Water Bank to facilitate short-term water transfers to address the 2001 drought. They established the Yakima Water Transfer Working Group to provide technical review of proposed water right transfers in the Yakima River Basin.

The group is comprised of representatives of the Washington Department of Ecology, U.S. Bureau of Reclamation, hydrologists, water users, and water rights experts from the basin, informally representing a wide range of interests. These members serve voluntarily and do not formally represent their respective organizations.

If the group finds a proposed transfer to be consistent with its guidelines, it tags the proposal as recommended for the Yakima County Superior Court or Department of Ecology. Support is provided for non-recommended proposals to identify needed improvements. Given the members' knowledge and diversity of interests represented, unanimous approval is a positive indication to the approving agency that a transfer would not adversely affect streamflow. Indeed, nearly all recommended proposals are approved by the Department of Ecology.

The strength of this process is its turn-around time. From application to approval, this effort has accomplished a 15-day turn-around period in dry years and 45-day turn-around in wet years. This speed is instrumental for meeting demand in dry periods.

In addition to the pre-approval process, Schempp attributed much of this expedited review to the full adjudication of the Yakima River Basin, which resulted in clarity of water rights and a history of collaboration between involved parties. Due to its successes, the program has continued in both wet and dry years.

California: Long-Term Agreement

In 2004, the Palo Verde Irrigation District and the Metropolitan Water District of Southern California signed a 35-year water supply agreement for year-to-year variable water quality leasing. The agreement requires Palo Verde farmers to fallow 7-28% of land in any given year to make water available for urban users in Southern California. Participating farms received a one-time payment of $3,170 per acre enrolled and annually receive $602 per acre fallowed, adjusted for inflation.

This agreement follows a 1992-1994 pilot project during which the Metropolitan Water District paid Palo Verde farmers a total of $25 million to set aside 115,000 acre feet of water per year. The program resulted in the temporary loss of 52 full-time agricultural jobs and farm-related losses of roughly $4 million.

To offset economic effects from the long-term agreement, the Metropolitan Water District established a $6 million Palo Verde Valley Community Improvement Fund to supplement lease payments. The fund is managed by a local board and invests in workforce training, local business loans, and other community resources.

The key to the success of this agreement is its adaptability to year-to-year variation in water availability. The amount of water transferred to the Metropolitan Water District annually depends on demands, but lies within set limits: 6,000–26,500 acres of land (roughly 29,500-118,000 AF of water).

Notably, one of the challenges associated with agricultural to urban water transfers is the need to maintain underlying relationships. Maintaining goodwill between parties over time is central to the success of a long-term water transfer agreement.

Delegates discussed how agricultural water transfer—more commonly known as "buy and dry"—the practice of permanently transferring agricultural water rights to cities, threatens this goodwill. Farmers struggling to make ends meet sell their water rights to cities and, unable to irrigate it any longer, allow their land to dry. While this is a relatively inexpensive way for cities to acquire needed water, long-term impacts on farming communities and the agricultural industry are of great concern.

Water Banking: Idaho State Water Bank

Water banking is complementary to water transfers and has been tried in some form in most western states with mixed results. One of the most successful examples is the Idaho State Water Supply Bank.

In 2002, the Idaho State Legislature added depositing a water right in the water supply bank to its list of exceptions and defenses to forfeiture. To receive this protection, the water need not be rented, merely deposited in the bank. The success of the water bank has been attributed to this forfeiture exemption.

One of the most common challenges for water banks is financial support. If a water right deposited in the Idaho State Water Supply Bank is leased, 10% of the lease price is paid as administrative fees to the bank. This was found to be insufficient to cover operating costs, so the Idaho Legislature approved a $250 lease application fee in 2011.

As the use of the bank has risen, demands on record-keeping and staffing resources have increased. In response, the bank implemented a GIS-based data management system in 2012. This has facilitated easier analysis and rental data access, and streamlined payments to lessors.

The Colorado-Big Thompson Project

The Colorado-Big Thompson Project stores and diverts water from the Colorado River on the western slope of the Continental Divide to the eastern slope of the Rocky Mountains. It consists of 95 miles of canals, 35 miles of tunnels, and 12 reservoirs, spanning 65 miles north to south and 150 miles east to west. It delivers supplemental water for 30 towns and cities and the irrigation of approximately 270,000 acres of farmland.

Since water delivered by the Colorado-Big Thompson Project comes from outside of the water basin, Colorado water law allows it to be used to extinction, thus removing concerns about return flows. At its inception, water users acquired "units," each representing a *pro rata* share of the available project water in a given year. The 310,000 units can be leased or sold within the project's service area.

The Northern Colorado Water Conservancy District, the sole authority for allocation of Colorado-Big Thompson water, sets and implements transfer rules. Since the District works independently, it was able to create a water transactions program that operates with few administrative requirements at relatively low cost.

Concluding Points

Schempp concluded his presentation by noting that *why* a system exists and operates the way it does is as important as *what* the current system is and what changes might be made. While simplifying the transfer process is important, potential consequences and third-party interests must be considered and addressed. In determining how to go about facilitating water transfers in a given state, it is essential to find and tailor the process to best suit the circumstances in which they will be administered.

Arizona has responded with rigorous laws designed to assure that water is available for new development before it receives approval.

Land-Use Policy and Water in the West

Ellen Hanak, senior fellow and center director of the Public Policy Institute of California, discussed the importance of linking water and land use and their connection to water quality and quantity. The integration of water and land-use planning can diminish damage to investments from water scarcity, protect people and infrastructure from water deluges, and sustain healthy watersheds.

However, this linkage does not occur by default. Divisions in land use and water planning responsibilities do not readily facilitate cooperation. In California, for example, cities and counties approve development while separate districts or utilities are responsible for the provision of water. This can lead to counties approving new development, assuming that neighboring water agencies can satisfy new demand.

Short time horizons for public and private decision makers also contribute to this problem. Those buying housing may not have full information about whether or not water is available. Preventing dry-lot development is a significant concern.

The most difficult challenges are in regions where oversight is limited, such as rural communities and open access groundwater basins. Arizona has responded with rigorous laws designed to assure that water is available for new development before it receives approval. Similarly, in the Colorado Front Range, the state's most populous region, requirements were put in place conditioning new development on the availability of water or the capital to acquire it.

Water Supply Adequacy for New Development

Facing rapid population growth and increasing water supply issues, most states have passed legislation conditioning some new development (e.g. housing or development in unincorporated areas) on the availability of water. To comply with state and local water supply rules, developers have a variety of options.

In municipal service areas, developers can purchase water rights, retrofit new houses (water neutral development), and/or use less water in landscaping. The most common solution is to pay for water system development: homebuyers are charged a fee that covers the cost of adding their property to the system. Rates range from $2,000 – $10,000 and are increasing. Meter caps to limit water use can also be applied, although this is rare and only used in small communities facing extreme water supply constraints.

Remote areas dependent on well water have fewer options. Compliance with state and local rules entails housing limits in the form of minimum lot sizes, and water rationing or pumping limits on groundwater. Prohibitions on outdoor landscaping are common.

Hanak observed that, according to statistical analysis and interviews, these regulations are working well. Water supply adequacy laws rarely block development, but do result in the downsizing of some projects. Colorado and New Mexico restrictions have shifted development from unincorporated areas to municipal areas, alleviating concerns about unmanaged development and use of groundwater. Notably, domestic well loopholes that encourage some development off the water grid limit success in these states.

Agricultural Land Use

While the population in western states is growing, total urban water demand has remained fairly static in some areas due to conservation initiatives. Agriculture remains the predominant user of water in the West. Agricultural water use ranges from 68% in Washington and 72% in Nevada to 97% in Montana, Idaho and Wyoming. It accounts for 77% of water use in California, 79% in Arizona and 91% in Colorado.

Forward-thinking planning that integrates tools such as water conservation, resilience of permanent crops, and land retirement can improve long-term agricultural land use. Examples follow:

- Permanent retirement ("buy and dry") or rotational fallowing are agricultural land-use tools to address with water scarcity. Rotational fallowing is the preferred method in agricultural communities for economic and policy reasons. It also increases water storage in the soil profile for subsequent crops.
- Long-term water trading deals support the management of permanent crops like orchards and vineyards. Confidence in future water availability assists farmers in collectively managing their crops. Water use can be managed across farms through coordination and planning.
- Absent intervention or incentive, farmers will not normally retire land until it fails to produce crops. The resulting saline soils do not permit regrowth of wildland vegetation for habitat development and connectivity. Incentives to facilitate early retirement would have large ecosystem benefits.

As more funds and personnel are dedicated to response efforts, the Forest Service has been forced to cut back on risk mitigation and preparation for future events.

Land Use for Environmental Purposes

Pop-up wetlands help provide water bird habitat in California during periods of drought. In wet years, rice farmers who flood their fields to break down rice straw in the fall provide this service. The Nature Conservancy and USDA Natural Resources Conservation Service collaborated to form a "Migratory Bird Conservation Partnership" to pay farmers to flood their fields, thereby providing wetland habitat for migratory birds. Over 10,000 acres of pop-up wetlands were created in 2013 through this initiative.[26]

Groundwater recharge potential is an urban and agricultural land use concern. As different soils have different recharge potential, regions of higher permeability should be used for active recharge. Historical failure to take advantage of this characteristic has resulted in the paving over of high-quality recharge land.

Forested Watersheds in a Hotter, Drier West: Meeting Adaptation Challenges

David Cleaves, former climate change advisor for the U.S. Forest Service, described the status and future of forested watersheds in the context of challenges posed by a hotter and drier West. His presentation included the major challenges for adaptation to climate-driven, compound risks; examples of initiatives to address those challenges; and next steps for program delivery and policy support.

Forest Vulnerability to a Changing Climate

Approximately 23-30% of western land is forested. These same forested lands account for 58-75% of the water supply, making them disproportionally important for safeguarding water quality. Forested land is owned by both the federal government (51%, 62% of water

26 The Migratory Bird Conservation Partnership is now managed by the Nature Conservancy, Audubon California, and Point Blue Conservation Science.

supply) and states and private interests (49%, 37% of water supply). Forested watershed management is dependent on federal, state and private programs and financing.

Drought and high temperatures are pushing forest systems beyond their mortality threshold—the point at which trees die and the ability of the ecosystem to regenerate diminishes. Under a climate change regime, these impacts are intensified.

Climate change impacts on forested watersheds manifest primarily as changes in precipitation, long-term moisture stress, and wildfires. Changes in snowfall (quantity and persistence) and rainfall (timing and intensity) are already being observed. Long-term moisture stress will impact regeneration conditions and ecosystem transitions in watersheds, as well as the competitive advantage of invasive species. It will contribute to insect infestation, disease and large-scale die-offs. Wildfires are becoming an increasingly prevalent feature of the western landscape; climate change impacts will increase the length of the fire season, size of individual fires, and their intensity.

Cleaves noted that there are not more fires today than in previous decades. Rather, the proportion that burn longer and more severely is increasing. Climate change has contributed to fire seasons that are now on average 78 days longer than in 1970. Twice as many acres burn today as three decades ago.[27] Fire prevention programs of past decades also have contributed to the flammable condition of forests today.[28]

There are significant opportunity costs to responding to fire events. As more funds and personnel are dedicated to response efforts, the Forest Service has been forced to cut back on risk mitigation and preparation for future events. Response efforts pose a social dilemma: the better managers become at managing risk, be it flood or fire risk, the more individuals are encouraged to engage in risky behavior such as living in firesheds and flood plains. This poses a significant tax burden in the form of costly flood insurance and fire management programs.

Fire management has risen from 15% of the Forest Service agency budget in 1995 to 52% in 2014. It is projected to increase to 67% of the budget by 2030.

The primary goal for watershed restoration is to restore functionality for the watershed, thereby building resilience.

The opportunity costs are reductions in non-fire capacity, including cuts in staff, vegetation management, road maintenance, deferred maintenance, wildlife and fish habitat management, land management planning, inventory and monitoring. These services have been cut 24-95% in recent years.

In response to rising physical and institutional liabilities, the federal government is advancing initiatives to facilitate adaptation to climate change. Much of this effort has been advanced under the directive of President Obama's Climate Action Plan, as well as climate-related executive orders (EOs) including EO 13514 (Federal Leadership in Environmental, Energy & Economic Performance), EO 13653 (Preparing the United Sates for the Impacts of Climate Change), and EO 13693 (Planning for Federal Sustainability in the Next Decade). Federal natural resource agency actions include:

- Vulnerability assessments and adaptation plans
- Employee education
- Science and management collaboration
  - The National Integrated Drought Information System (NIDIS)
  - Federal Climate Change and Water Working Group
  - Forest Service Planning Rule
  - Regional science and management partnerships
- Establishment of new institutional mechanisms
  - Landscape Conservation Cooperatives (U.S. Department of the Interior)
  - Climate Science Centers (U.S. Geological Survey)
  - Regional Climate Hubs (U.S. Department of Agriculture)
  - Regional Integrated Sciences and Assessments Program (National Oceanic and Atmospheric Administration)
- Public-private partnerships

Watershed Restoration

Watersheds, an integral part of the western water landscape, are impacted by climate change in many ways, resulting in related impacts on wildlife, water,

27 U.S. Forest Service. The Rising Cost of Wildfire Operations: Effects on the Forest Service's Non-Fire Work. August 4, 2015.
28 When the national fire policy was first established, fire exclusion was believed to promote ecological stability. As a result, decades of fire policy largely called for fire suppression, even as federal agencies began recognizing the natural role of fires in regulating the lifecycles of trees and plant communities. Vegetation accumulation from historic fire management continues to contribute to more frequent and intense fires that are expected to become even larger and more severe in the future.

and fire cycles. Enhancing the resilience of watersheds necessitates both adaptation and conservation. Such efforts will shape downstream water quality and quantity, and alleviate ecosystem stressors. State and federal policies can enable these goals to be achieved more efficiently and effectively.

Notably, the Forest Service does not aspire to restore watersheds to historical conditions, but rather to restore the system to a system of functionality and resiliency. "Restoring for the future" requires the establishment of risk-based priorities and a risk-management strategy to approach those priorities, as well as social and political ownership of the watershed and the capacity and will to implement needed policies.

The Forest Service and other agencies are performing risk-based assessments of watersheds. For example, to prioritize watersheds for restoration treatments, the Forest Service has developed a Watershed Condition Framework, a multi-stress and value index which is used to define and determine the severity of watershed degradation and prioritize response efforts for resilience.

The primary goal for watershed restoration is to restore functionality for the watershed, thereby building resilience. Goals include protecting headwaters, managing disturbance patterns, connecting fragmented parcels, discouraging development in floodplains, directing grazing away from riparian areas, limiting urban and agricultural pollution, and keeping rivers shaded by trees.

The Forest Service is making progress toward watershed restoration, though much work remains. Efforts from 2011-2014 identified 300 priority watersheds at risk, 34 of which have been restored. Thirty-nine watersheds are scheduled for restoration in 2015-2016. Improved capacity for implementation, coordination and financing is necessary for continued progress.

There are several barriers to proactive adaptation. These include the need to manage connected risks and build collaborative capacity for adaptive action. Cutting-edge science must be built into mainstream response operations.

Looking Ahead

Cleaves cited the importance of public-private partnerships for implementing watershed restoration. Several are currently operating in the western states, including the Denver Water Board (Colorado), Flagstaff Watershed Protection Project (Arizona), Santa Fe Municipal Watershed Program (New Mexico), Sierra Nevada Restoration Project (California), Ashland Forest Resiliency Stewardship Project (Oregon), Rio Grande Water Fund (Arizona and New Mexico), North Cascades Adaptation Partners (Washington), and others.

It is essential that resource managers and scientists work together to adapt the best available science for the specific problems of a particular watershed.

Facilitated in part through these public-private partnerships, research management partnerships will also be critical for adaptation. It is essential that resource managers and scientists work together to adapt the best available science for the specific problems of a particular watershed.

Cleaves concluded with a discussion of policies and program changes needed to enable adaptive actions. He cited the need to mainstream risk-based priority setting via the use of common terms to define risk, and common expectations for its management. Behavioral incentives for mitigating climate-driven risks are needed, as is a shift from reactive, emergency responses to forward-thinking investment in resilience. Adequate financing for collaborative ventures and innovative, science-based watershed management is necessary to achieve these goals.

Managing Western Fish, Wildlife and Plants in an Era of Changing Climate and Increasing Drought

Kurt Johnson, national climate change scientist in the U.S. Fish and Wildlife Service (USFWS) Science Application Program, discussed the impacts of the current drought on western fish and wildlife resources, and how managers are addressing those impacts.

Current drought and temperature forecasts portend a future that falls outside of the experience of natural and human systems in the western United States. These conditions will present substantial challenges to adaptive capacity in the region. In a drier climate with less predictable water, fish, wildlife and plants will suffer.

Western National Wildlife Refuges are largely water-focused. Many have wetlands that are dependent on the diversion of surface water or groundwater to maintain water levels, while others are associated with reservoirs, rivers or spring systems. Drought and changes in water availability pose significant management challenges such as wetland drying, reduced river and stream flows, lower reservoir levels and increased incidences of wildfire. Over two dozen refuges in the West are facing these challenges. More than 15 federally threatened and endangered species in the West are at risk.

Drought impacts to wetland habitats translate to impacts on migratory birds. Migratory birds such as waterfowl, shorebirds, and waders are dependent on wetlands for all life stages including breeding, migration and wintering. In spring 2015, following multiple dry years, locally breeding waterfowl in California reached their lowest population level since 1992.

Migratory fish are impacted as well. Diminished water flow and increasing temperatures impede migration and cause mortality. These physical changes also impact fish hatcheries, which are seeing higher incidences of disease and parasites, lower fish return rates, stress and mortality.

Ongoing drought conditions pose a serious challenge to the resources and ingenuity of USFWS staff in all regions, particularly the West. The need to address significant impacts in the short term must be balanced with planning for long-term solutions to climate change. Johnson noted that the USFWS must become proactive, working with partners to address these critical issues.

Responding to Western Drought: Short-term Interventions

The USFWS has been entrusted with protecting natural resources for the benefit of the American people. These "trust resources" include federally-listed endangered and threatened species, National Wildlife Refuges, migratory birds and fish, and national fish hatcheries. Efforts by USFWS personnel to secure water in the short-term for these resources are based in water law: they work with water management agencies to secure water allocations for ecosystems and ensure that established water rights are protected.

- *National Wildlife Refuges* in the West depend on delivered water to maintain wetlands. Managers monitor water flow at refuges through the USFWS's regional Water Resources Branches. Short-term responses to drought include increased groundwater pumping, strategic drying, and prioritization of high-value habitat areas for water allocations.
- *Endangered Species Act-Listed Species* face an imminent threat of extinction from drought, necessitating short-term emergency responses. These responses include capture and translocation, captive maintenance of stranded fish species, and artificial habitat creation. USFWS managers are pursuing increased collaboration with water management and other agencies to supply water needs of threatened and endangered species.
- *Migratory Birds* are directly affected by the availability of wetland habitats. Efforts to protect these birds have primarily involved the provision of habitat on refuges and private lands. This is done through the use of groundwater to offset surface water reductions, incentives for farmers to flood fields, prioritizing water allocations for wetlands, and translocation of some birds.
- *Fisheries* are challenged by changing flow and temperature regimes. Short-term management responses are limited to fish translocation, increased monitoring of populations for disease and mortality, and collaboration with partners to increase the resilience of streamflows.
- *National Fish Hatcheries* face challenges similar to wild fisheries. Short-term management options include the removal of unhealthy fish, transfer of fish to other fisheries, premature release, monitoring and control of disease outbreaks, water flows and temperatures, and infrastructure and operational changes.

Ongoing drought conditions pose a serious challenge to the resources and ingenuity of USFWS staff in all regions, particularly the West.

Responding to Western Drought: Long-term Solutions

While responding to crises in the short term, USFWS is moving toward development of long-term collaborative solutions to mitigate the impacts of changing water availability on trust resources. Ensuring water security via water rights and allocations is essential for this purpose.

One such effort, the National Fish, Wildlife and Plants Climate Adaptation Strategy, was developed in partnership by USFWS, the National Oceanic and Atmospheric Administration (NOAA) and the Association of Fish and Wildlife Agencies to safeguard fish, wildlife, and plants, as well as the natural systems upon which they depend. Johnson highlighted ongoing efforts by members of this joint initiative and partners in Oregon, California, and the Southwest Region:

- Collaborators in Oregon's Deschutes Basin are currently seeking to analyze water supply and demand, assess how existing operations and infrastructure will perform under projected water supply conditions and demands, and develop and evaluate options for addressing identified imbalances.
- Outreach and collaboration with partners in California has been particularly successful. Johnson highlighted the development of a water allocation optimization model with partners at the University of California–Davis; partnerships with state and conservation organiza-

tions to better estimate water requirements for wetlands in the Sacramento Valley; and sharing of resources and information regarding drought response and planning, as well as water availability in the Central Valley.
- In 2015, the Science Applications Program in the USFWS Southwest Region initiated a project featuring forums to review land and water management practices in individual basins and improve the capacity of resource managers to reliably meet the needs of all water users during drought, including ecosystems.

Landscape Conservation Cooperatives

Landscape Conservation Cooperatives (LCCs) are self-directed partnerships between federal agencies, states, tribes, non-governmental organizations, universities, and others to collaboratively define science needs and jointly address broad-scale conservation issues in a defined geographic area. The vision of these cooperatives is landscapes capable of sustaining natural and cultural resources. Twenty-two LCCs have been established.

LCCs supporting drought-related work are seeking to increase the predictability of water supplies for decision-makers, conduct vulnerability assessments and scenario planning, predict habitat changes and their impacts on species migrations and survival, foster collaboration to design future landscapes, and increase capacity for general drought and climate management. Johnson discussed three LCCs, which exemplify the central elements of predictability, collaboration, and knowledge:

- *Predictability.* A Department of the Interior WaterSMART-funded project at Utah State University has developed predictive tools to assess the risk of extreme wet or dry climate conditions for the next 10-15 years. This project facilitates much-needed enhancements in predictability for decision-making regarding the management of future water supplies.
- *Collaboration*. The Central Valley Landscape Conservation Project was designed to enable natural resource managers, scientists, and policymakers to cooperatively agree on strategic, climate-smart conservation actions to maximize the adaptive capacity of priority species, habitats and ecosystems as part of an ecologically connected landscape. Together, state, federal and local agencies, non-profits and local partnerships developed a suite of plausible futures through scenario planning to assess the vulnerability of key resources and develop adaptation strategies to guide future decisions. An online toolbox and outreach plan were developed to help partners use and apply their results and inform similar efforts.

Population is the primary driver of increased water demand, offsetting efficiency gains in water use.

- *Knowledge*. The value and importance of sharing knowledge, experiences and actions cannot be overstated. On November 2-3, 2015, a Southwest Climate Summit was sponsored by five LCCs, as well as Southwest Climate Centers, federal natural resource agencies and others. The goals of this summit were to discover emerging science, explore adaptive management, share climate-smart conservation results, and discuss management and policy responses. A follow-up summit will be held in February 2018.[29]

The USFWS and LCCs are working to collaboratively develop tools to aid managers in coping with drought. The challenges faced by natural resources, including fish and wildlife, are too expansive and complex for any entity to resolve alone. Solutions require that all parties work together to identify goals and priorities and to meet those needs collectively.

An Approach to Scenario Planning in the Colorado River Basin: The Colorado River Basin Water Supply and Demand Study

Carly Jerla, Lower Colorado Region operations research analyst at the U.S. Bureau of Reclamation, discussed how scenario planning can be used as a tool for promoting the sustainable use of freshwater resources. In this context, Jerla examined the 2010-2012 Colorado River Basin Water Supply and Demand Study, for which she was a study manager.

The Colorado River Basin was divided into upper and lower basins in the 1922 Colorado River Compact. While natural flow is approximately 15 MAF, Colorado River water allocations total

29 More information on the 2015 Southwest Climate Summit, including a summary report of the meeting, is available at http://www.swcsc.arizona.edu/summit/2015.

16.5 MAF, with 7.6 MAF allocated to the upper and lower basins, respectively, and 1.5 MAF allocated to Mexico. While water use patterns are relatively predictable, annual water supply in the Colorado River Basin is highly variable, subject to year-to-year and decadal variations. The basin relies on 60 MAF of storage (approximately 4 times annual natural flow) to balance year-to-year variation in flow.

The Colorado River Basin changed significantly from 1960 to 2010 in terms of demographics, land use, storage capacity, water flow and governance, and it will continue to change during the next 50 years and beyond. Given the uncertainty and numerous variables affecting the basin's future, an infinite number of plausible futures exist, presenting a challenge for resource managers and decision-makers. This uncertainty is driven by potential changes in:

- Natural Systems (streamflow variability, climate change and associated changes in temperature and precipitation, etc.)
- Technology and Economics (water use efficiency, water needs for energy generation, etc.)
- Social and Institutional Systems (population growth, land use changes, regulatory conditions, etc.)

These changes differ in degree of certainty and importance. The most critical uncertainties, for example, are future climate and hydrology. Other changes, such as population, urban growth and agricultural efficiency are important but can be projected with a high degree of confidence. The development of scenario narratives enables planners to weave critical uncertainties into plausible future trajectories. Through this process, i.e. scenario planning, a manageable number of possible future scenarios are developed and analyzed, thus facilitating a measured and informed response to possible future events.

The Colorado River Basin Water Supply and Demand Study was undertaken by the Bureau of Reclamation in collaboration with representatives of the seven Colorado River Basin states (Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming) and stakeholders to assess risks to basin resources. Its objective was to predict and assess future water supply and demand balances over the next 50 years to develop and evaluate opportunities for resolving imbalances. Funding was provided by the Bureau or Reclamation through the Basin Study Program under the Department of the Interior's WaterSMART Program, and basin state agencies.

Jerla noted that this was a planning study that did not result in any decisions. Rather, it provided the technical foundation for future activities in the region.

The study consisted of four phases:

- *Phase 1*: Water Supply Assessment
- *Phase 2*: Water Demand Assessment
- *Phase 3*: System Reliability Analysis (How does the system perform? What do supply and demand scenarios mean for resources?)
- *Phase 4*: Development and Evaluation of Opportunities (Options and strategies to respond to resource vulnerabilities defined in Phase 3)

Phase I featured the identification and quantification of four future water supply scenario narratives:

- Observed Resampled—assume future hydrologic trends and variability will be similar to the past 100 years
- Paleo Resampled—assume future hydrologic trends and variability are represented by the distant past (approximately 1,250 years)
- Paleo Conditioned—assume future hydrologic trends and variability are represented by a blend of the wet and dry states of the paleo-climate record but magnitudes are more similar to the observed period
- Downscaled Global Climate Model (GCM) Projected—assume future climate will continue to warm with

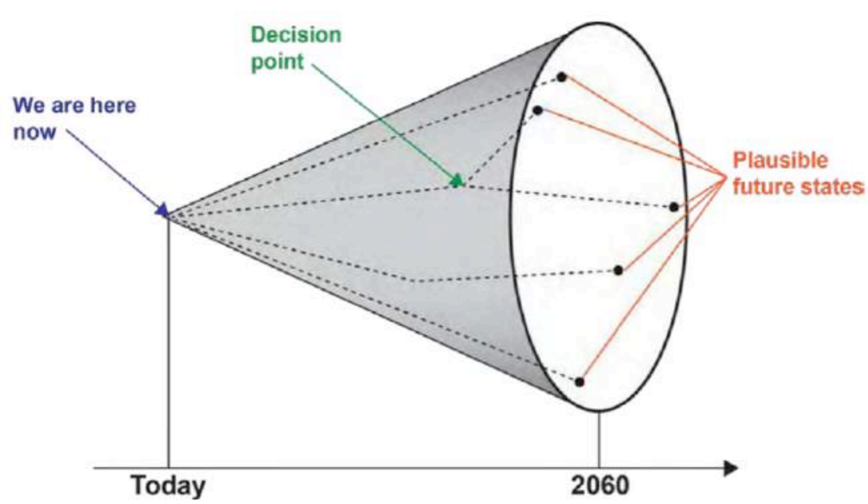

Figure 1: Conceptual Representation of the Uncertain Future of a System, Also Known as "The Scenario Funnel." Adapted from Timpe and Scheepers, 2003. (U.S. Bureau of Reclamation)

regional precipitation trends represented through an ensemble of future GCM projections.

Assessment of historical supply, i.e. trends over the observed period and recent climatological regime, suggested increasingly variable and declining streamflows, and seasonal shifts in streamflow that may be attributable to warming trends. Based on the paleo record, water supply deficits of longer duration and greater magnitude can be expected. Incorporating likely changes in temperature, precipitation, snowpack and runoff due to climate change over the next 50 years indicates that future projected supply will be impacted by warming temperatures, spatially and temporally divergent precipitation patterns, decreased snowpack, and decreased runoff. Most scenarios suggested that dry years will become increasingly common and greater in magnitude than wet years.

Phase II was informed by six water demand scenario narratives:

- Current Projected Growth
- Slow Growth
- Rapid Growth (two variations: slow vs. rapid technology adoption)
- Enhanced Environment awareness (two variations: moderate vs. rapid population growth)

These demand scenario narratives quantified the main forces driving increases in water demand in the Colorado River Basin from 2015 to 2060, i.e. population, per capita water use, and irrigated acreage. Population will increase from 40 million people in 2015 to 49-77 million people by 2060, a 23-91% increase. Per capita water use will decrease by 7-19% from current rates and irrigated acreage will decrease from approximately 5.5 million acres to 5.2-4.6 million acres, a 6-15% decrease. Population is thus the primary driver of increased water demand, offsetting efficiency gains in water use.

Based on these scenarios, and including allocations to Mexico and water loss due to evaporation, Colorado River demand for consumptive use is expected to range between 18.1 MAF (Slow Growth scenario) to 20.4 MAF (Rapid Growth scenario) by 2060. Median supply-demand imbalances amount to approximately 3.2 MAF by 2060.

Scenario planning provided a medium for broad thinking about the future of water resources and set the stage for robust decision-making about the future of the Basin.

Recognizing that no single response option or strategy will be sufficient to resolve supply and demand imbalances in the Basin, the Study evaluated four portfolios of options to respond to projected imbalances. Options assessed acted to increase supply, e.g. desalination, reuse, local supply, watershed management, and importation; reduce demand, e.g. municipal and industrial water conservation, agricultural water conservation, and energy water use efficiency; and modify operations, e.g. system operations and water transfers, exchanges and banking.

Although the portfolios differed in terms of options included and attention to technical feasibility, commonalities include significant agricultural water conservation, municipal and industrial water conservation, and energy use efficiency. By 2060, annual costs of implementing the portfolios ranges from approximately $2 billion to $5 billion in 2012 dollars under different supply scenarios, but could increase to as much as $7 billion under a Downscaled GCM Projected scenario.[30]

Conclusion

For the Colorado River Basin, scenario planning provided a medium for broad thinking about the future of water resources and set the stage for robust decision-making about the future of the Basin. The integration of tens of thousands of supply and demand scenarios enabled a comprehensive assessment of resource vulnerability, the evaluation of different options and strategies to respond to those vulnerabilities, and a method of assessing their relative effectiveness and trade-offs.

Particular strengths noted by Jerla included a mechanism for incorporating differing stakeholder views and values, the transparency of the process, and its emphasis on quantifiable results. These enabled the development of a robust portfolio of options and strategies to mitigate and adapt to future risks in the Colorado River Basin. This was just an initial step, however. The scenario planning process is evolving and results of this study are being updated.

More information about the Colorado River Basin Supply and Demand Study is available at http://www.usbr.gov/lc/region/programs/crbstudy.html or by contacting ColoradorRiverbBasinStudy@usbr.gov.

30 U.S. Bureau of Reclamation. Colorado River Basin Water Supply and Demand Study. Study Report. December 2012.

Appendix A: Congress Registrants

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Appendix B: Congress Program

Tuesday, December 1, 2015

8:00 am – 8:50 am	Continental Breakfast
9:00 am – 9:15 am	Welcome and Opening Remarks **Richard Engberg** Chairman, RNRF Board of Directors North Bethesda, Maryland
9:15 am – 9:45 am	**The Western Water Landscape** An overview of historical water management in the West, including water allocation and infrastructure development. Why is water availability an issue today? **Doug Parker** Director, California Institute for Water Resources and Strategic Initiative Leader, University of California Agriculture and Natural Resources' Water Quality, Quantity and Security Strategic Initiative Oakland, California
9:45 am – 10:15 am	Questions and Discussion
10:15 am – 10:30 am	Break
10:30 am – 11:00 am	Federal, State and Constitutional Law Influences on Water Ownership, Management and Regulation in the West **Barton H. "Buzz" Thompson, Jr.** Robert E. Paradise Professor of Natural Resources Law and Perry L. McCarthy Director, Woods Institute for the Environment, Stanford University Stanford, California
11:00 am – 11: 30 am	Questions and Discussion
11:30 am – 12:30 pm	Lunch
12:30 pm – 3:00 pm	**Panel: Pathways to Sustainable Water Use** As we plan for future population growth, water-related infrastructure investments and environmental needs, how are estimates developed to predict how much water will be available for use on a sustainable basis, particularly in light of climate change? How can surface and groundwater be managed in a holistic and sustainable way? What monitoring, data and regulatory mechanisms are required for sustainable water use?

12:30 pm – 1:00 pm Sustainable Water Use in California

Thomas Harter
Robert M. Hagan Endowed Chair, Water Management and Policy
Cooperative Extension Specialist (Professor), Groundwater Hydrology
Department of Land, Air and Water Resources, University of California, Davis
Davis, California

1:00 pm – 1:20 pm Questions and Discussion

1:20 pm – 1:50 pm Sustainable Water Use in the Arid Southwest

Sharon Megdal
Director, Water Resources Research Center, University of Arizona
Tucson, Arizona

1:50 pm – 2:10 pm Questions and Discussion

2:10 pm – 2:40 pm Sustainable Water Use in the Rocky Mountains

Reagan Waskom
Director, Colorado Water Institute; Chair, Colorado State University Water Center
Fort Collins, Colorado

2:40 pm – 3:00 pm Questions and Discussion

3:00 pm – 3:20 pm Break

3:20 pm – 3:50 pm **Water Transfers**
Inter- and intra-state water transfers enable movement of water to where it is needed. How can water transfer mechanisms be made more effective and useful?

Adam Schempp
Senior Attorney and Director, Western Water Program, Environmental Law Institute
New York, New York

3:50 pm – 4:20 pm Questions and Discussion

Wednesday, December 2, 2015

8:00 am – 8:50 am Continental Breakfast

9:00 am – 9:30 pm **Land-Use Policy Tools**
Can land-use policies and zoning foster sustainable use of freshwater resources by conditioning development upon water availability? Can regional land-use mechanisms be effective?

Ellen Hanak
Senior Fellow and Director, Water Policy Center, Public Policy Institute of California
San Francisco, California

9:30 am – 10:00 am Questions and Discussion

10:00 am – 10:15 am Break

10:15 am – 11:55 am **Panel: Drought and Natural Resources Management**
What are state and federal agencies doing to adapt management of forests, wildlife and ecosystems to changing climate conditions on federal lands in the West?

10:15 am – 10:45 am Forests

David Cleaves
Former Climate Change Advisor, U.S. Forest Service
Washington, District of Columbia

10:45 am – 11:05 am Questions and Discussion

11:05 am – 11:35 am Fish and Wildlife

Kurt Johnson
National Climate Change Scientist, U.S. Fish and Wildlife Service
Arlington, Virginia

11:35 am – 11:55 am Questions and Discussion

11:55 am – 1:00 pm Lunch

1:00 pm – 1:30 pm **Future Scenario Planning**
How can scenario planning best be used as a tool for the sustainable management of freshwater resources? What role does it play in stakeholder engagement and buy-in, as a planning tool, and for public education?

Carly Jerla
Operations Research Analyst, Lower Colorado Region, Bureau of Reclamation
Boulder, Colorado

1:30 pm – 2:00 pm Questions and Discussion

2:00 pm – 2:15 pm Congress Wrap-Up

Robert Day
Executive Director, Renewable Natural Resources Foundation
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