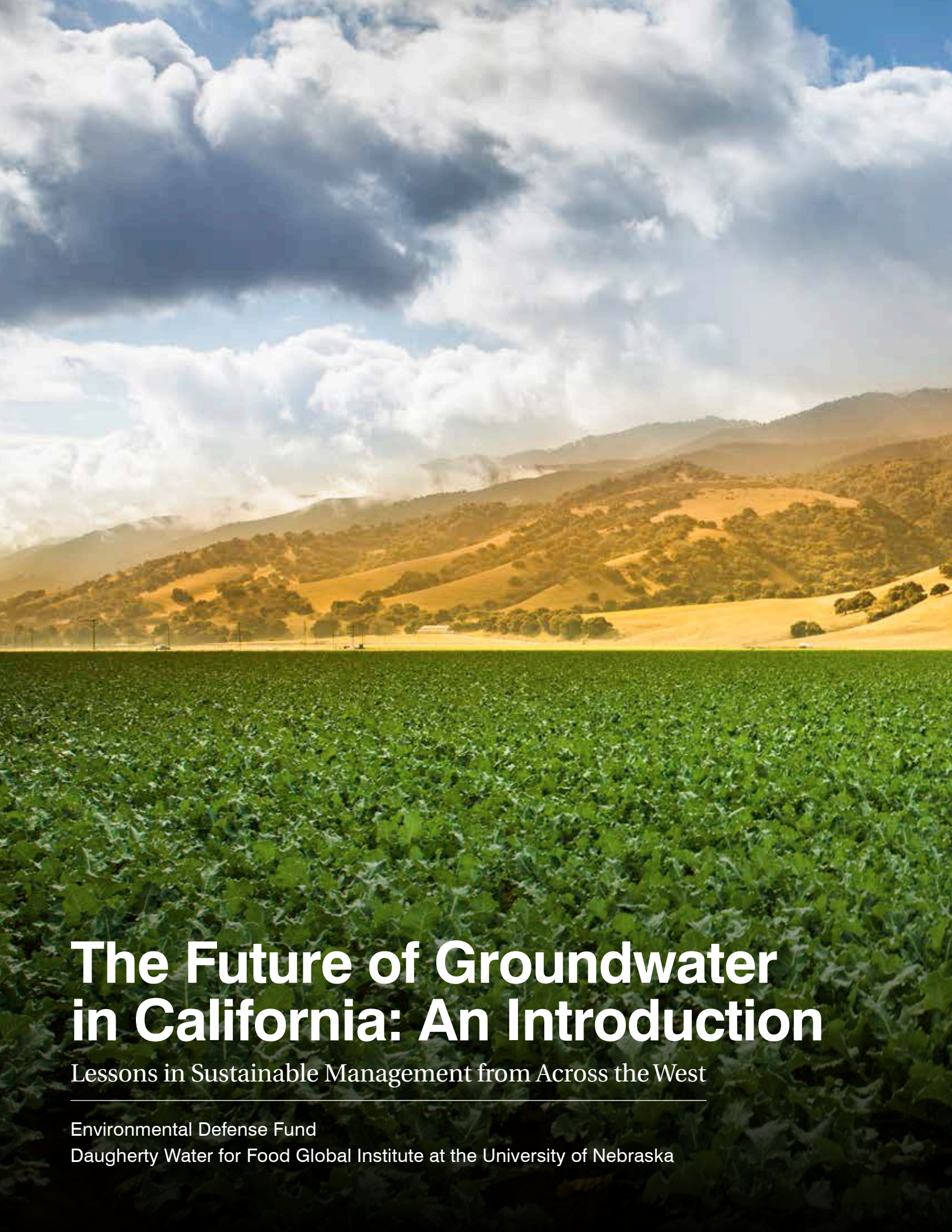


The Future of Groundwater in California: An Introduction

Lessons in Sustainable Management from Across the West

Environmental Defense Fund
Daugherty Water for Food Global Institute at the University of Nebraska

Environmental Defense Fund is dedicated to protecting the environmental rights of all people, including the right to clean air, clean water, healthy food, and flourishing ecosystems. Guided by science, we work to create practical solutions that win lasting political, economic, and social support because they are nonpartisan, cost-effective, and fair.

The Robert B. Daugherty Water for Food Global Institute at the University of Nebraska is working to achieve greater food security with less pressure on scarce water resources by improving water management in agriculture. Through scientific and policy research, education and communication, the institute is helping the world's farmers produce greater yields while maintaining water supplies to meet other vital human and environmental needs.

The Future of Groundwater in California: An Introduction

Lessons in Sustainable Management from Across the West

Authors

Christina Babbitt
ENVIRONMENTAL DEFENSE FUND

Kate Gibson
DAUGHERTY WATER FOR FOOD GLOBAL INSTITUTE
AT THE UNIVERSITY OF NEBRASKA

Scott Sellers
ENVIRONMENTAL DEFENSE FUND

Nicholas Brozović
DAUGHERTY WATER FOR FOOD GLOBAL INSTITUTE
AT THE UNIVERSITY OF NEBRASKA

Anthony Saracino
WATER RESOURCES CONSULTANT

Ann Hayden
ENVIRONMENTAL DEFENSE FUND

Maurice Hall
ENVIRONMENTAL DEFENSE FUND

Sandra Zellmer
ROBERT B. DAUGHERTY PROFESSOR
AT THE UNIVERSITY OF NEBRASKA COLLEGE OF LAW

EDF ENVIRONMENTAL DEFENSE FUND
Finding the ways that work

Water for Food
DAUGHERTY GLOBAL INSTITUTE
at the University of Nebraska

Acknowledgments
Thank you to the following organizations for providing valuable feedback during the preparation of this report. The views expressed in the report are those of the authors and do not necessarily reflect the views of the organizations listed.

Arizona Department of Water Resources
Blankenau, Wilmoth, Jarecke, LLP
Canyon Country Consulting, LLC
Colorado Division of Water Resources
Culp & Kelly, LLP
Davis Engineering Service, Inc.
Deschutes River Conservancy
Edwards Aquifer Authority
Freshwater Policy Consulting, LLC
Friends of the Verde River Greenway
Harris-Galveston Subsidence District
Irvine Ranch Water District
Kings River Conservation District
New Current Water and Land, LLC
North Harris County Regional Water Authority
Olson Policy Services, LLC
Orange County Water District
Oregon Water Resources Department
Rio Grande Water Conservation District
St. Mary's University—Texas
Sustainable Conservation
The Nature Conservancy
United States Geological Survey
Upper Republican Natural Resources District

Cover photo: iStock

The report is available online at edf.org/GroundwaterStudy

Table of contents

Executive summary 4

Background 5

Groundwater management strategies 7

Overview of case studies 9

Summary of lessons learned 15

Building trust 15

The need for data 16

Using a portfolio of approaches 16

Assuring performance 17

Funding 18

ABOUT THE AUTHORS 19

Executive summary

The 2014 Sustainable Groundwater Management Act (SGMA) created, for the first time and on an unprecedented scale, a mandate to change how groundwater is managed statewide in California. While enacting SGMA was a tremendous step forward, communities and water districts now face the considerable challenge of creating successful groundwater management programs.

This report is aimed at helping California's water managers, public water agencies, county commissioners, city planners, and others better understand the suite of tools and approaches that can be used to enhance the sustainable management of groundwater. Specifically, we consider four categories of management tools—regulatory, incentive-based, agency supply augmentation and protection, and education and outreach—to evaluate how these tools are being used to address water quantity, water quality, and surface water and groundwater interaction challenges. We present nine comprehensive case studies of groundwater management across the Western United States to highlight how these tools have been used to address those challenges. The case studies represent basins that have a range of water uses—agricultural, municipal, or mixed water use, as well as basins with diverse hydrologic, political and social settings.

Effective groundwater management takes time and requires significant resources and commitment on the part of water managers and communities. Each groundwater management program presented in this report relies upon a variety of interdependent tools and actions to meet management goals. The case studies illustrate the importance of building trust, having sufficient data, using a portfolio of management approaches, assuring performance, and access to funding. Given the similarities between the goals of SGMA and those described in the case studies, these themes emerge as crucial to the successful implementation of California's landmark groundwater legislation.

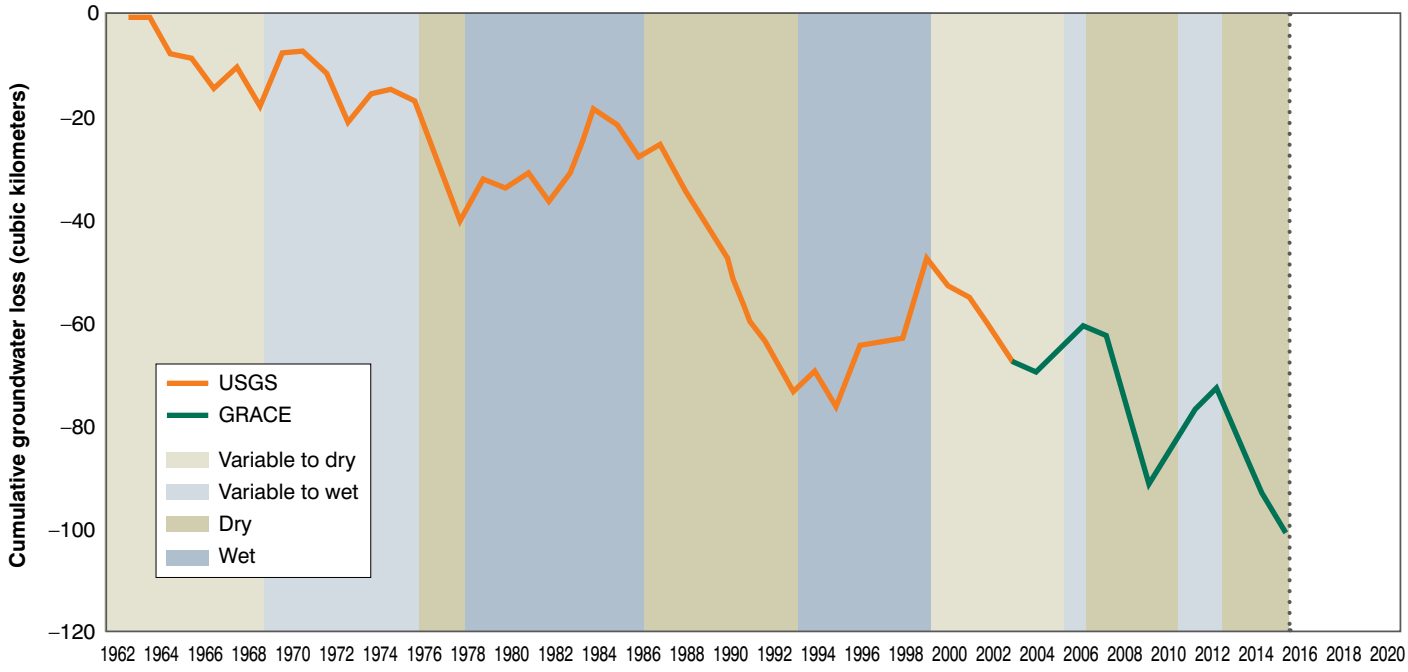
Background

Groundwater provides about 40 percent of California's total annual water supply and serves as a critical buffer against drought and climate change. But while groundwater is an effective buffer during dry periods, the resource needs time to recover after it has been pumped. At current rates of groundwater use, flooding events and wet periods will not be sufficient to recharge groundwater in key basins to support long-term sustained use, as shown in Figure A.1 that highlights cumulative groundwater loss in California's Central Valley since the 1960s.

The trend of increasing groundwater use amid cycles of drought has exacerbated groundwater depletion, water quality degradation, land subsidence, and depletion of interconnected surface water throughout the state. California's SGMA arose out of a recognition that the integrated management of the state's water resources is essential to meeting its water management goals, and that when properly managed, groundwater resources will help mitigate the effects of drought and climate change to communities, farms, and the environment.

FIGURE A.1

Cumulative groundwater loss in California's Central Valley during periods of wet and dry conditions



Source: Union of Concerned Scientists with data from the University of California Center for Hydrologic Modeling (UCCHM). (2015). Sustainable Groundwater Management in California. Retrieved from http://www.ucsusa.org/global-warming/regional-information/california-and-western-states/sustainable-groundwater-management-act. Design: EDF

Growing consumer demand for almonds has led California farmers to plant hundreds of thousands of acres of new trees over the past two decades. Almonds and other permanent crops do not have the flexibility of forgoing water in a dry year, as do annual crops like tomatoes or strawberries.

RICHARD THORNTON/SHUTTERSTOCK

SGMA requires the formation of local groundwater sustainability agencies (GSAs) and the development of groundwater sustainability plans to address the following "undesirable results" as defined in the Act:

- Chronic lowering of groundwater levels
- Degraded water quality, including the migration of contaminant plumes that impair water supplies
- Seawater intrusion
- Land subsidence that substantially interferes with surface land uses
- Reduction of groundwater storage
- Depletions of interconnected surface water that has significant and unreasonable adverse impacts on beneficial uses of the surface water

While California has a long history of managing a complex surface water storage and distribution system, managing surface water and groundwater as an integrated system presents some very distinct challenges. Surface water typically involves public agency control of storage and conveyance infrastructure, and groundwater often involves privately owned infrastructure and land, which can present a challenge for water managers as they attempt to fulfill SGMA's requirements.

Fortunately, groundwater is being managed successfully in many places across the West, and much can be learned from case studies of groundwater management in these areas that include urban and agricultural settings. This report summarizes nine case studies of groundwater management in six states—Arizona, California, Colorado, Nebraska, Oregon, and Texas—and presents key lessons learned in an effort to inform and foster effective groundwater management in California.

Groundwater management strategies

The case studies presented in this report focus on the tools and actions water managers use to directly influence water use and availability and could be considered for inclusion in GSA sustainability plans.

Tools used to achieve management goals

Groundwater management districts featured in the case studies generally rely upon a suite of interdependent tools rather than a single policy or regulation to influence water user behavior. Groundwater management tools fall into four distinct categories: regulatory tools, incentive-based tools, agency supply augmentation and protection, and education and outreach. Specific tools are described in the case studies included in the appendix and, in every case, multiple tools are used simultaneously.

Regulatory tools

Regulatory tools often form the backbone on which more sophisticated incentive-based tools are built. Regulatory tools require water users to take certain actions and are not intended to provide direct incentives, financial or otherwise, for water users. Examples include metering of wells (whether self-reported or monitored), best management practices (BMPs) without cost-share, and moratoria on new wells.

- Moratoria (or limits) on new wells or irrigated acreage
- Permitting system for wells
- Quantified and allocated irrigation or pumping rights
- Certification of irrigated acreage
- Metering of wells (self-reported or monitored)
- BMPs without cost-share (user pays)
- Continuing education requirements

Incentive-based tools

Some groundwater management tools are designed to provide incentives to influence change in water use behavior. Taxes, fees, or surcharges, as well as energy management practices (i.e., load control), are examples of tools that provide financial incentives for behavior change. Other tools, such as land retirement projects, credit-based systems to offset new groundwater development, water transfer systems that allow individuals to move water use to where and when it is most needed (for example by trading groundwater storage credits or use permits within a specific geographic area), and landowner-led recharge, also rely on economic valuations of water or underlying land assets for users who participate. In instances where groundwater managers seek to encourage users to adopt best management practices,

cost-sharing programs can also provide financial incentives to participate while also fostering trust between users and managers.

- Taxes, fees, or surcharges
- Land retirement projects
- Managed aquifer recharge (land-owner is lead)
- Offset programs
- Transfer systems for credits, permits, or rights
- BMPs with cost-share
- Energy management practices (i.e. load control)

Agency supply augmentation and protection tools

Water managers often take additional actions at the district or regional level to achieve sustainable water use. Water supply augmentation and protection measures can support or supplement other management tools that more directly influence water user behavior. For example, water districts may pursue stream augmentation projects to enhance the effect of water user conservation on instream flows, or invest in water recycling systems that contribute to conjunctive use efforts by water users to recharge an aquifer. Conjunctive use efforts led by agencies—for example, construction and maintenance of dedicated recharge basins—also fall under this category.

- Stream augmentation projects
- Managed aquifer recharge
- Aquifer storage and recovery
- Infrastructure upgrades paid for by water supplier or rates
- Reservoir operations
- Seawater intrusion barriers
- Use of recycled water

Education and outreach tools

Water managers can help users better understand the consequences of their behavior and opportunities to improve groundwater sustainability via outreach and education initiatives. Efforts focused on highlighting current and future basin conditions and challenges, such as ongoing overdraft, can promote learning and enhance engagement within communities. Such tools can take many forms, including informational reports, guidance documents, and websites that aim to educate water users on best management practices or update community members on relevant management initiatives and activities. Targeted trainings, workshops, and conferences that engage participants around specific water-focused topics or the development of educational curriculum that advance water education in schools are additional examples.

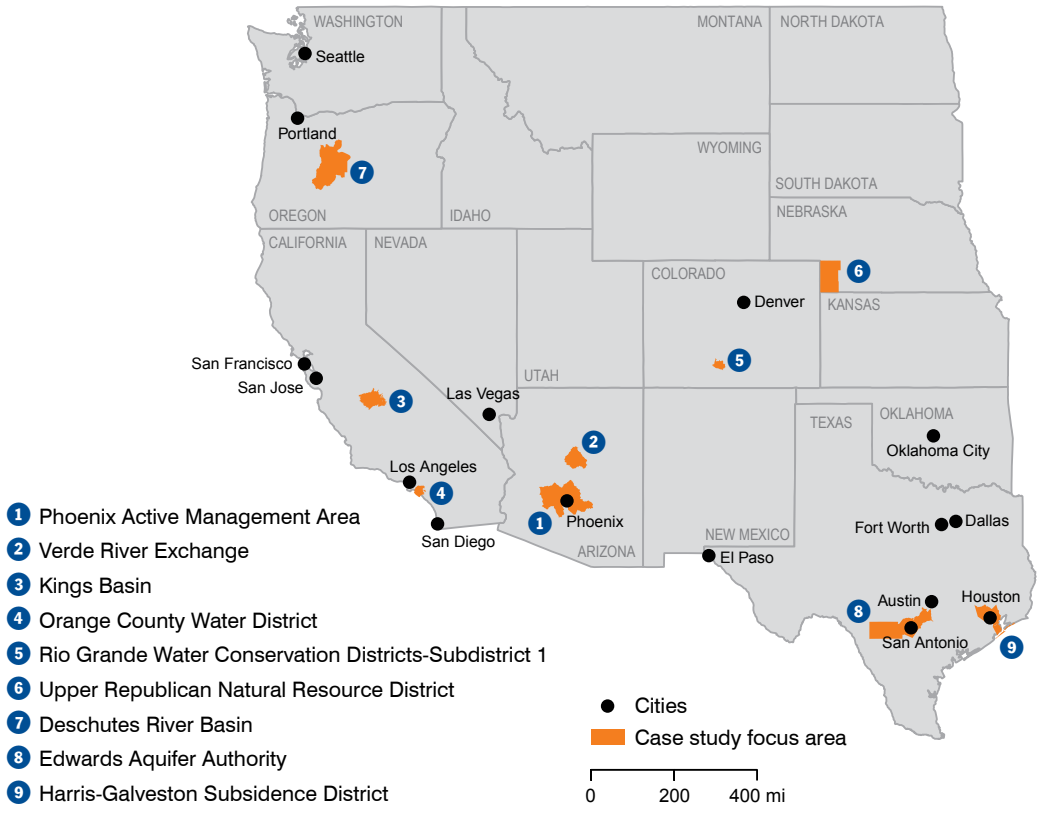
- Educational programs and community engagement events
- Program reports and updates
- BMP guidance documents
- Data tools and informational websites

Overview of case studies

The following case studies demonstrate groundwater management strategies formed in response to a variety of hydrologic challenges and social settings. The case studies bring together research and local insight on the management tools and actions various regions are using to address issues ranging from water quantity and quality to surface water depletion challenges. Tables B.1 through B.4 (pages 10 and 11) highlight prominent groundwater challenges faced across case studies, as well as key regulatory, incentive-based, and agency supply augmentation and protection tools used to address these challenges, respectively. All case studies also employ education and outreach tools to educate water users. While it is often difficult to pinpoint a single policy or tool responsible for the success of each program—and indeed, some of the cases have ongoing management challenges—the most prominent elements of each case study are emphasized in the summary.

FIGURE B.1

Overview map



Source: EDF with case study boundary data from multiple sources. See individual case studies for specific source information.

TABLE B.1

Groundwater challenges across case studies

State	Management area	Dominant water use(s)	CHALLENGES ADDRESSED (SGMA UNDESIRABLE RESULTS)					
			Lowering of GW levels	Seawater intrusion	Land subsidence	Reduction of storage	Surface water depletion	Degraded GW quality
AZ	Phoenix AMA	Ag/Urban	•		•	•		•
	Verde River Exchange	Ag/Urban	•				•	
CA	Kings Basin	Ag	•			•		•
	Orange County Water District	Urban	•	•				
CO	Rio Grande Water Conservation District	Ag	•			•	•	
NE	Upper Republican NRD	Ag	•			•	•	•
OR	Deschutes River Basin	Ag/Urban					•	
TX	Edwards Aquifer Authority	Ag/Urban	•			•	•	•
	Harris-Galveston Subsidence District	Urban	•	•	•	•		

TABLE B.2

Regulatory tools used across case studies

Management area	REGULATORY TOOLS						
	Moratoria or limits on new wells/irrigated acreage	Permitting systems for wells	Quantified and allocated irrigation/ pumping rights	Certification of irrigated acreage	Metering of wells (self-reported)	Metering of wells (monitored)	BMPs without cost share
Phoenix AMA	•	•	•	•	•		•
Verde River Exchange							
Kings Basin							
Orange County Water District					•		
Rio Grande Water Conservation District	•	•	•		•		
Upper Republican NRD	•	•	•	•		•	
Deschutes River Basin	•	•	•		•		
Edwards Aquifer Authority		•	•		•		•
Harris-Galveston Subsidence District		•	•		•	•	

The tables on pages 10 and 11 include information collected during development of this report and are not necessarily comprehensive of all challenges faced or management tools employed in each management area.

TABLE B.3

Incentive-based tools used across case studies

	INCENTIVE-BASED TOOLS						
Management area	**Taxes, fees or surcharges**	**Land retirement projects**	**Managed aquifer recharge** (landowner is lead beneficiary)	**Offset program**	**Recharge, depletion or storage credits**	**Transfer of credits, permits or rights**	**BMPs with cost-share**
Phoenix AMA					•	•	
Verde River Exchange				•	•		
Kings Basin			•			•	•
Orange County Water District	•						
Rio Grande Water Conservation District	•	•		•	•	•	
Upper Republican NRD	•	•				•	•
Deschutes River Basin	•			•	•	•	
Edwards Aquifer Authority				•		•	
Harris-Galveston Subsidence District	•						•

TABLE B.4

Agency supply augmentation and protection tools across case studies

	AGENCY SUPPLY AUGMENTATION AND PROTECTION TOOLS						
Management area	**Stream augmentation projects**	**Managed aquifer recharge** (agency lead)	**Aquifer storage and recovery**	**Infrastructure upgrades** (paid for by agency)	**Reservoir operation**	**Seawater intrusion barriers**	**Recycled water**
Phoenix AMA		•	•	•	•		
Verde River Exchange							
Kings Basin		•		•	•		
Orange County Water District		•		•	•	•	•
Rio Grande Water Conservation District	•	•		•			
Upper Republican NRD	•			•			
Deschutes River Basin	•			•			
Edwards Aquifer Authority	•		•	•			
Harris-Galveston Subsidence District				•	•		

CASE STUDY 1 / ARIZONA

Phoenix Active Management Area

The Phoenix Active Management Area (AMA) encompasses a groundwater basin with agricultural and urban water uses. To address declining groundwater levels and land subsidence within the AMA, water managers established a goal to attain safe-yield, defined as the long-term balance between annual groundwater withdrawals and recharge, by 2025. To work toward this goal, AMA water managers developed a regulatory system to limit irrigated acres and established a system to enhance long-term storage through facilitated groundwater recharge, which takes advantage of conjunctive use mechanisms by using surplus surface water as recharge. While the AMA still struggles with localized areas of groundwater level declines, it has reached its overarching goal of safe yield for the basin.

CASE STUDY 2 / ARIZONA

Verde River Exchange

Arizona's Verde River Valley supports historically dominant agricultural water uses and a rapidly growing, groundwater-dependent urban population. Significant increases in groundwater pumping have lowered groundwater levels in some areas and threaten Verde River surface flows. The Verde River Exchange, administered by local non-profit Friends of Verde River Greenway, is a community-driven, voluntary groundwater mitigation pilot-program designed to support continued development and growth, while protecting river flows and their cultural, economic, and ecological benefits in the region. To do this, the Exchange creates credits by incentivizing Verde Valley water users to voluntarily reduce their water usage. These credits can then be purchased by other Verde Valley water users seeking to reduce their water footprint and the impacts of their groundwater use. Launched in 2016, the Exchange could offer a scalable solution for mitigating the impacts of groundwater pumping on the Verde River and for stabilizing water supplies for future residents.

CASE STUDY 3 / CALIFORNIA

Kings Basin

The Kings Basin is a predominantly agricultural region wherein water managers seek to mitigate groundwater quality degradation and groundwater level declines. To address these issues, the Kings River Conservation District has placed a strong emphasis on community engagement through data-driven educational outreach and other trust-building actions. The district assists growers in irrigation system reviews and water use efficiency and also uses dedicated recharge facilities and on-farm recharge to make use of floodwater. Recharge programs in the district have the capacity to recharge over 100,000 acre-feet annually and have helped reduce rates of groundwater level declines.

CASE STUDY 4 / CALIFORNIA

Orange County Water District

The Orange County Water District is situated in an almost entirely urban area, with 98% of water use going toward municipal and industrial sectors. The district goals are to protect and enhance groundwater quality and availability, which have been impacted by groundwater level declines and seawater intrusion. With no regulatory authority to control pumping, the district employs a pricing mechanism as an incentive for water retailers to purchase water imported from outside of the district rather than pumping groundwater. The District's innovative pricing scheme—in combination with basin recharge, seawater barriers, water recycling, and education and outreach initiatives—exemplify a portfolio of approaches that work together to promote cost efficiency, improved water quality and enhanced basin sustainability.

CASE STUDY 5 / COLORADO

Rio Grande Water Conservation District (Subdistrict No. 1)

Primarily an agricultural region, the San Luis Valley has experienced significant groundwater level declines. The Subdistrict manages water within its boundaries to mitigate stream depletion resulting from local groundwater pumping and thereby remain in compliance with an interstate water use agreement for the Rio Grande and Conejos Rivers. The Subdistrict places a fee on groundwater pumping to encourage irrigators to improve on-farm efficiency, switch to less water-intensive crops, and take advantage of the federal fallowing program Conservation Reserve Enhancement Program (CREP), which pays agricultural producers to take their land out of production permanently or for a certain period of time. The program has succeeded in recharging more water than required to offset surface water depletions.

CASE STUDY 6 / NEBRASKA

Upper Republican Natural Resources District

The Upper Republican Natural Resources District (NRD) manages groundwater level declines, surface water depletion, and groundwater quality degradation in an almost exclusively agricultural basin. Organized in 1972, the NRD uses multiple tools to mitigate groundwater declines and satisfy requirements of an interstate compact with Colorado and Kansas pertaining to surface water flows. Examples include a moratorium on drilling new wells, a well permitting system, "land occupation" taxes, a strict cap on groundwater pumping with both formal and informal water markets, and stream augmentation projects. The NRD also has strong community involvement and support for monitoring and enforcement in the District.

CASE STUDY 7 / OREGON

Deschutes River Basin

The Deschutes Basin aims to maintain instream water rights and scenic waterway flows while accommodating existing agricultural use and population growth through new groundwater development. To accomplish these goals and meet requirements of the state Scenic Waterways

When properly managed, groundwater resources will help mitigate the effects of drought and climate change on communities, farms, and the environment.

ISTOCK

Act, the Deschutes Groundwater Mitigation Bank purchases existing surface water rights and sells corresponding mitigation credits to new groundwater pumpers. These mitigation credits have helped to preserve streamflow while allowing the approval of new groundwater permits in the basin.

CASE STUDY 8 / TEXAS

Edwards Aquifer Authority

The Edwards Aquifer program was established to manage and protect groundwater levels and groundwater-fed spring flows which are critical to the survival of several endangered species in the basin. The Edwards Aquifer Authority uses an aggregate cap on groundwater pumping for its mixed agricultural and urban user base, along with tradable permits to limit groundwater withdrawal. The Edwards Aquifer Authority encourages participation in a water trading market, which has resulted in the maintenance of minimum spring flows, despite a recent drought. Water trading has succeeded as an effective management tool by minimizing transaction costs, developing a functional online trading platform, limiting constraints as to how users divide their allocations, and establishing specific caps in state law.

CASE STUDY 9 / TEXAS

Harris-Galveston Subsidence District

Water use in the Harris-Galveston Subsidence District is mostly industrial and municipal. The District is addressing land subsidence, groundwater level declines, and seawater intrusion by using fees and educational programs to encourage use of surface water in lieu of groundwater. Groundwater usage is limited to a percentage of an individual user's total water demand. If that percentage is exceeded, the user is subject to fees intended to discourage overuse of groundwater. While the district lacks a growth management strategy, rates of groundwater level declines have decreased.

Summary of lessons learned

with implications for SGMA implementation

A review of the case studies reveals several lessons in effective groundwater management that coalesce around five recurring themes: the importance of building trust, the need for data to inform management decisions, using a portfolio of management approaches, assuring program performance, and having sufficient funding. These themes, as described below, can have significant implications for the successful implementation of California's Sustainable Groundwater Management Act (SGMA).

Building trust

Groundwater management often requires asking people to change what they do in a way that has an actual or perceived financial impact. This requires establishing trust within that group of people—acceptance of a fair system that will allow them to use a sustainable amount of groundwater that supports their livelihood over the long-term.

In addition to broad community involvement from the early stages of planning, there are specific things that water managers can do to build trust. Using data to illustrate current groundwater conditions and simulate future impacts can lend credibility to water managers, as well as create a sense of ownership in the future of the program. Water managers in the Kings Basin in California, for example, used data-driven groundwater models to convey how

Agricultural economies, as well as the communities and ecosystems they support, depend on having clean, reliable groundwater resources.

ISTOCK

local areas and individuals' properties could be impacted by future groundwater declines. This educational approach enabled people to see and understand the connection between the goals of the program and their personal situation as landowners and agricultural producers who rely on groundwater to maintain their livelihood.

Effective groundwater management requires sufficient water resources data that water users and community members trust.

ISTOCK

A second method of trust building involves including key stakeholder groups within the community in the planning process so they can understand, support and vouch for the groundwater management program. In the case of Kings Basin, water managers included fisheries groups in the groundwater management process who used their positive past experiences with the community to build trust for the new groundwater policies.

Lastly, providing beneficial resources to the community can strengthen relationships with the same people affected by groundwater management programs. For example, the Upper Republican Natural Resources District manages recreational areas and provides the community with cost-sharing programs for planting trees intended for windbreaks. Such non-adversarial community programs have helped the District build trust and acceptance of challenging groundwater use restrictions in the face of interstate litigation.

SGMA requires sustainability plans developed by a Groundwater Sustainability Agency (Agency) to include an explanation of Agency decision-making methodology and describe how the Agency encourages active involvement of stakeholders in that process. Arguably the most significant lesson learned from the case studies is that meaningful community and stakeholder engagement early in the process helps build trust and cooperation that leads to more effective groundwater management. And while the case studies demonstrate different ways to achieve trust between parties, they all involve building trust slowly and intentionally, which can be the difference between successful and unsuccessful groundwater management programs.

The need for data

As with the Kings Basin, the Edwards Aquifer Authority made water use data publicly available, which increased transparency and helped ensure buy-in from program participants.

In addition to using open data to build trust, data are also critical for effective decision-making. In the Upper Republic Natural Resources District, for example, irrigation wells in the District have been fully metered to measure water consumption since 1981 and the District has also maintained a groundwater well measurement database since 1972. Water level monitoring and water use tracking are used to detect trends and support groundwater policies.

One of the "undesirable results" that SGMA requires Agencies to address is the depletion of interconnected surface water. Minimum thresholds—the rate or volume of surface water depletions caused by groundwater use that has adverse impacts—need to be established and supported by sufficient data that inform computer models or equally effective methods of analysis. Regardless of the analytical method chosen, the case studies indicate that effective groundwater management largely depends on the gathering, management and analysis of sufficient water resources data.

Using a portfolio of approaches

Groundwater management cannot be achieved overnight, nor can it be accomplished by a single policy, regulation or project. It is important to recognize that multiple tools, added and built

upon gradually, are necessary for successful groundwater management. In nearly every basin, including those featured in this report, advances in groundwater management begin with some form of permitting framework, tracking system, educational component, and revenue source for management. After these are in place, additional tools can be added based on local conditions.

For example, prior to implementing a groundwater market in the Edwards Aquifer, groundwater managers had to first establish a system of groundwater pumping permits and then place a cap on overall groundwater use. Only after binding regulatory limits were placed on groundwater did the incentive arise to participate in rights transfers, which could be either permanent or temporary in nature. This example also illustrates that incentives can be a component of a groundwater management portfolio, but they require many other policies to support them. Furthermore, there are limits to what price mechanisms alone can do to reduce water demand, especially in California. While groundwater users may not be required to pay for water directly, they pay indirectly via energy costs and property taxes on irrigated land.

SGMA requires plans developed under the Act to include a description of the projects and management actions the Agency has determined will achieve groundwater basin sustainability. The lessons learned from the case studies clearly demonstrate the benefit of a portfolio approach to groundwater management. Agencies that include a wide-range of actions in their plans will greatly increase both their chances of success and the approval of their plans by the California Department of Water Resources (DWR).

Assuring performance

The case studies demonstrate the importance of sufficient monitoring networks and enforcement protocols. Any policy is only as good as the monitoring and enforcement behind it. Without adequate monitoring to detect noncompliance followed by subsequent enforcement measures, there will often be an inclination to ignore regulatory requirements. Monitoring and enforcement are an underappreciated aspect of groundwater management that incurs monetary, social, and political costs. This is especially true in areas where groundwater managers live and work alongside the very people whose actions they must manage. For this reason, it is critical to have political and community support, as well as sufficient financial and

Successful groundwater management requires a portfolio of approaches, developed and built upon over time.

ISTOCK

personnel resources, to carry out monitoring and enforcement. When routine meter inspection by the Upper Republican NRD revealed that a groundwater user was bypassing the flow meter to irrigate in excess of the allocated amount, the district revoked the violator's right to irrigate their land indefinitely, which resulted in a penalty of millions of dollars of potential crop revenue. The district received wide-spread support from the community for the decision because it trusted and supported the district's management of their valuable resource.

DWR will periodically review approved SGMA Plans to ensure they remain consistent with the Act and are likely achieve the sustainability goal for their respective groundwater basins. This review will include determining whether an Agency has 1) exceeded any established minimum thresholds, 2) implemented projects and management actions consistent with its Plan, and 3) addressed any data gaps to reduce levels of uncertainty.

Funding

It is difficult to imagine a scenario involving effective groundwater management without sufficient funding to carry out appropriate management actions. Virtually all of the case studies directly or indirectly demonstrate the need for sufficient funding to achieve groundwater management objectives. Whether it is the need for infrastructure to shift from groundwater use to surface water, as in the case of Harris-Galveston Subsidence District; the development and use of computer models employed by Kings Basin; the monitoring network established and maintained by the Edwards Aquifer Authority; or, the groundwater recharge facilities constructed and operated by Orange County Water District, they all required significant financial resources to achieve success.

When evaluating SGMA plans, DWR will determine whether the Agency has the financial resources necessary to implement the Plan. Even at their most basic level, GSAs, as envisioned under SGMA, require staff dedicated to engaging stakeholders and preparing groundwater sustainability plans to succeed. Beyond that, significant funding is necessary for implementing the projects and management actions contemplated in the SGMA plans. Securing sufficient funding will be one of the biggest challenges faced by many GSAs as they work to achieve sustainability, and the cases studies included in this report offer valuable insight on a variety of funding mechanisms being used across the west to support successful groundwater management.

About the authors

Christina Babbitt is a senior manager in EDF's California Groundwater Program where she and the rest of the California Groundwater Program are working to advance water trading policy in California and launch replicable groundwater sustainability pilot projects across California's Central Valley. In these efforts, Christina works to build partnerships among NGOs, agencies, water districts, and agricultural partners, and contributes technical expertise on water governance structure and design. Christina holds a PhD in natural resources from the University of Nebraska, Lincoln, an MSc in environmental science from Florida International University, and a BA in international relations from Rollins College.

Kate Gibson is a program coordinator at the Robert B. Daugherty Water for Food Global Institute at the University of Nebraska, Lincoln. She manages policy-focused programs related to groundwater management and water security. Kate holds a Master's degree in agronomy and a Bachelor's degree in water sciences and environmental restoration from the University of Nebraska, Lincoln.

Scott Sellers is a research analyst supporting both the Western Water and Habitat Exchange programs at EDF, helping to develop market-based policies to improve water resource management and habitat conservation in California. Currently, he is working with stakeholders at the local, regional, and state levels to design and implement pilot groundwater management projects, advocate for improved water markets, and transact credits for critical species habitat in California's Central Valley. Scott holds a BA in environmental studies, with a minor in economics, from Davidson College.

Nick Brozović is Director of Policy at the Daugherty Water for Food Global Institute at the University of Nebraska. He works to ensure that the Institute's programs inform public and private sector needs around agricultural water management. Nick has over 15 years of experience in water policy worldwide. A particular focus of his research is on evaluating policies and governance structures for water management, including water market design and implementation. He holds doctoral and master's degrees in agricultural and resource economics from the University of California, Berkeley, a master's degree in geology from the University of Southern California and a bachelor's degree in geology from Oxford University.

Anthony Saracino has over 30 years of experience in water resources consultation. He is a widely recognized expert in California water policy, and has consulted to a variety of state, federal, agricultural, municipal and environmental clients. He was a member of the California Water Commission from 2010 to 2015, serving as Chair of the Commission for the first two years of his term. Anthony holds a bachelor's degree in geology from California State University, Fresno, and a master's degree in geology from Colorado State University.

Ann Hayden is a senior director for EDF's California Habitat Exchange & Western Water Programs. She works to build broad coalitions of state and federal agencies, non-profit partners, landowners and the private sector to support the development and implementation of environmental markets that help increase California's healthy freshwater and terrestrial systems and improve delivery of the environmental services these habitats provide. Ann holds an MESM from the University of California, Santa Barbara.

Maurice Hall is an associate vice president of water for the Ecosystems Program. He oversees Environmental Defense Fund's work to revitalize working rivers and their ability to provide a resilient water supply. He focuses on developing collaborative water management approaches to meet ecosystem needs alongside the needs of farms and cities. A registered Professional Civil Engineer in California, Maurice holds a PhD in earth Resources, watershed sciences from Colorado State University and a BS in chemical engineering from the University of Tennessee, Chattanooga.

Sandra Zellmer is the Robert B. Daugherty Professor of Law at the University of Nebraska's College of Law. She teaches and writes about natural resources, water law, public lands, wildlife,

environmental law, and related topics. Zellmer has published several dozen articles and is a co-author and principal editor of a casebook, *Natural Resources Law* (with Professors Laitos and Wood) (West 2d edition 2012), *Principles of Natural Resources Law: A Concise Hornbook* (with Laitos) (West 2014), and *Water Law in a Nutshell* (with Amos) (West 5th edition 2015). Sandra serves on the Faculty Advisory Panel for the Daugherty Water for Food Global Institute, and is on the Board of Directors for the Rocky Mt. Mineral Law Foundation and the Society for Wilderness Stewardship.

Additional authors—case study reports

Justin Ebrahemi is a Communications and Engagement Manager at CounterPulse—a community arts organization and performance arts theatre in San Francisco—where he strategizes marketing campaigns and engages new audiences. His Master's thesis offers policy recommendations for equitable groundwater management in California using hydrogeology research, policy analysis, and stakeholder interviews. He holds an MA in environment and community from Humboldt State University and a BA in journalism from California State University, Monterey.

Jennifer Hiatt is an urban planner and practicing lawyer in Nebraska. She is currently employed with South Central Economic Development District, Inc., guiding rural communities through the planning process. Jennifer's areas of practice include land use development, natural resource conservation, and the promotion of sustainable practices. Jennifer holds a JD from the College of Law at the University of Nebraska, Lincoln and an MA in community and regional planning from the College of Architecture at the University of Nebraska, Lincoln.

Drew Palmer is a law student at Harvard Law School, interested in macroprudential regulation, administrative law, and economic policy making. Prior to law school, Drew held a two-year position in macroeconomic research at the Federal Reserve Bank of Kansas City,as well as a summer positions at Analysis Group, an economic consulting firm, and at the Environmental Defense Fund conducting economic and policy research. Drew holds a BSc in statistics and a BA in economics from Loyola University Chicago.

Katherine Rittenhouse is currently a PhD Student in the Economics Department at the University of California, San Diego. Previously, she served as an Economic Analyst in the Office of Economic Policy and Analysis at the Environmental Defense Fund, where she helped to research and write economic analyses of energy and environmental issues. Katherine holds a BA in environmental studies and law, letters, and society from the University of Chicago.

Kanishka Singh is an MS candidate in Natural Resources and MPA candidate in Environmental Policy at Cornell University. His prospective theses explore the application of systems theory frameworks and quantitative modeling to watershed management. In the future, he is interested in modeling dynamic mountain systems to better design resilience programs, specifically in the event of glacial lake outburst floods in the Lower Himalayan Ranges.

Paige Orcutt worked as a policy research intern for the Daugherty Water for Food Global Institute from May to December 2016. After graduating from the University of Nebraska Colleges of Law and Business Administration in 2016, Paige successfully completed the Minnesota Bar Examination and currently works as the law clerk to the Honorable Eric L. Hylden, Judge of the Sixth Judicial District of Minnesota.

Chris Kuzdas is an environmental social scientist with a diverse background in the decision sciences, international development and project management. As a member of EDF's Colorado River team, Chris works with partners to explore flexible water management solutions that address future water uncertainty in a just and sustainable manner. He also serves as an associate editor of UNESCO's Global Water Forum, an international hub for resources and discussion related to freshwater governance. Chris holds a PhD in sustainability and a Master of public administration from Arizona State University.

Matthew Zaragoza-Watkins is an Assistant Professor of Economics at Vanderbilt University and an Affiliate at the MIT Center for Energy and Environmental Policy Research. He has previously held positions as the High Meadows Senior Economist in the Office of Economic Policy and Analysis at the Environmental Defense Fund and as an Air Pollution Specialist in the Office of Climate Change at the California Air Resources Board. His research focusses on the design and performance of electricity, natural gas and greenhouse gas markets, and the application of econometric techniques and randomized experiments to evaluate the impact of policy. Matthew holds a PhD in agricultural and resource economics and an MSc in business and public policy from the University of California, Berkeley and a BSc in applied economics and management from Cornell University.

257 Park Avenue South
New York, NY 10010
T 212 505 2100
edf.org

Nebraska Innovation Campus
2021 Transformation Drive
Suite 3220
Lincoln, NE 68508
T 402.472.5145
waterforfood.nebraska.edu