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THE HAMILTON PROJECT

Stanford WOODS INSTITUTE for the ENVIRONMENT

Shopping for Water: How the Market Can Mitigate Water Shortages in the American West

Peter W. Culp, Robert Glennon, and Gary Libecap

THE HAMILTON PROJECT

MISSION STATEMENT

The Hamilton Project seeks to advance America's promise of opportunity, prosperity, and growth.

We believe that today's increasingly competitive global economy demands public policy ideas commensurate with the challenges of the 21st Century. The Project's economic strategy reflects a judgment that long-term prosperity is best achieved by fostering economic growth and broad participation in that growth, by enhancing individual economic security, and by embracing a role for effective government in making needed public investments.

Our strategy calls for combining public investment, a secure social safety net, and fiscal discipline. In that framework, the Project puts forward innovative proposals from leading economic thinkers — based on credible evidence and experience, not ideology or doctrine — to introduce new and effective policy options into the national debate.

The Project is named after Alexander Hamilton, the nation's first Treasury Secretary, who laid the foundation for the modern American economy. Hamilton stood for sound fiscal policy, believed that broad-based opportunity for advancement would drive American economic growth, and recognized that "prudent aids and encouragements on the part of government" are necessary to enhance and guide market forces. The guiding principles of the Project remain consistent with these views.

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Shopping for Water: How the Market Can Mitigate Water Shortages in the American West

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NOTE: This discussion paper is a proposal from the authors. As emphasized in The Hamilton Project's original strategy paper, the Project was designed in part to provide a forum for leading thinkers across the nation to put forward innovative and potentially important economic policy ideas that share the Project's broad goals of promoting economic growth, broad-based participation in growth, and economic security. The authors are invited to express their own ideas in discussion papers, whether or not the Project's staff or advisory council agrees with the specific proposals. This discussion paper is offered in that spirit.

BROOKINGS

Abstract

The American West has a long tradition of conflict over water. But after fifteen years of drought across the region, it is no longer simply conflict: it is crisis. In the face of unprecedented declines in reservoir storage and groundwater reserves throughout the West, we focus in this discussion paper on a set of policies that could contribute to a lasting solution: using market forces to facilitate the movement of water resources and to mitigate the risk of water shortages.

We begin by reviewing key dimensions of this problem: the challenges of population and economic growth, the environmental stresses from overuse of common water resources, the risk of increasing water-supply volatility, and the historical disjunction that has developed between and among rural and urban water users regarding the amount we consume and the price we pay for water. We then turn to five proposals to encourage the broader establishment and use of market institutions to encourage reallocation of water resources and to provide new tools for risk mitigation. Each of the five proposals offers a means of building resilience into our water management systems.

Many aspects of Western water law impose significant obstacles to water transactions that, given the substantial and diverse interests at stake, will take many years to reform. However, Western states can take an immediate step to enable more-flexible use of water resources by allowing simple, short-term water transactions. First, sensible water policy should allow someone who needs water to pay someone else to forgo her use of water or to invest in water conservation and, in return, to obtain access to the saved water. As a second step, state and local governments should facilitate these transactions by establishing essential market institutions, such as water banks, that can serve as brokers, clearinghouses, and facilitators of trade.

Third, water managers should support and encourage the use of market-driven risk management strategies to address growing variability and uncertainty in water supplies. These strategies include the use of dry-year options to provide for water sharing in the face of shortages, and water trusts to protect environmental values. New reservoir management strategies that allow for sophisticated, market-driven use of storage could build additional resilience into water distribution.

Fourth, states should better regulate the use of groundwater to ensure sustainability and to bring groundwater under the umbrella of water trading opportunities. Groundwater reserves are an important environmental resource and provide strategic reserves against drought, but proper management of groundwater is also critical to the development of markets. Markets cannot work effectively if users can delay facing the realities of local water scarcity through the unsustainable use of an open-access resource.

Finally, strong federal leadership will be necessary to promote interstate and interagency cooperation in water management, as well as to coordinate essential state-level gathering of data on water supplies and water use. In particular, the Bureau of Reclamation of the U.S. Department of the Interior plays a central role in water projects across the West, and its actions will be essential in confronting the crisis.

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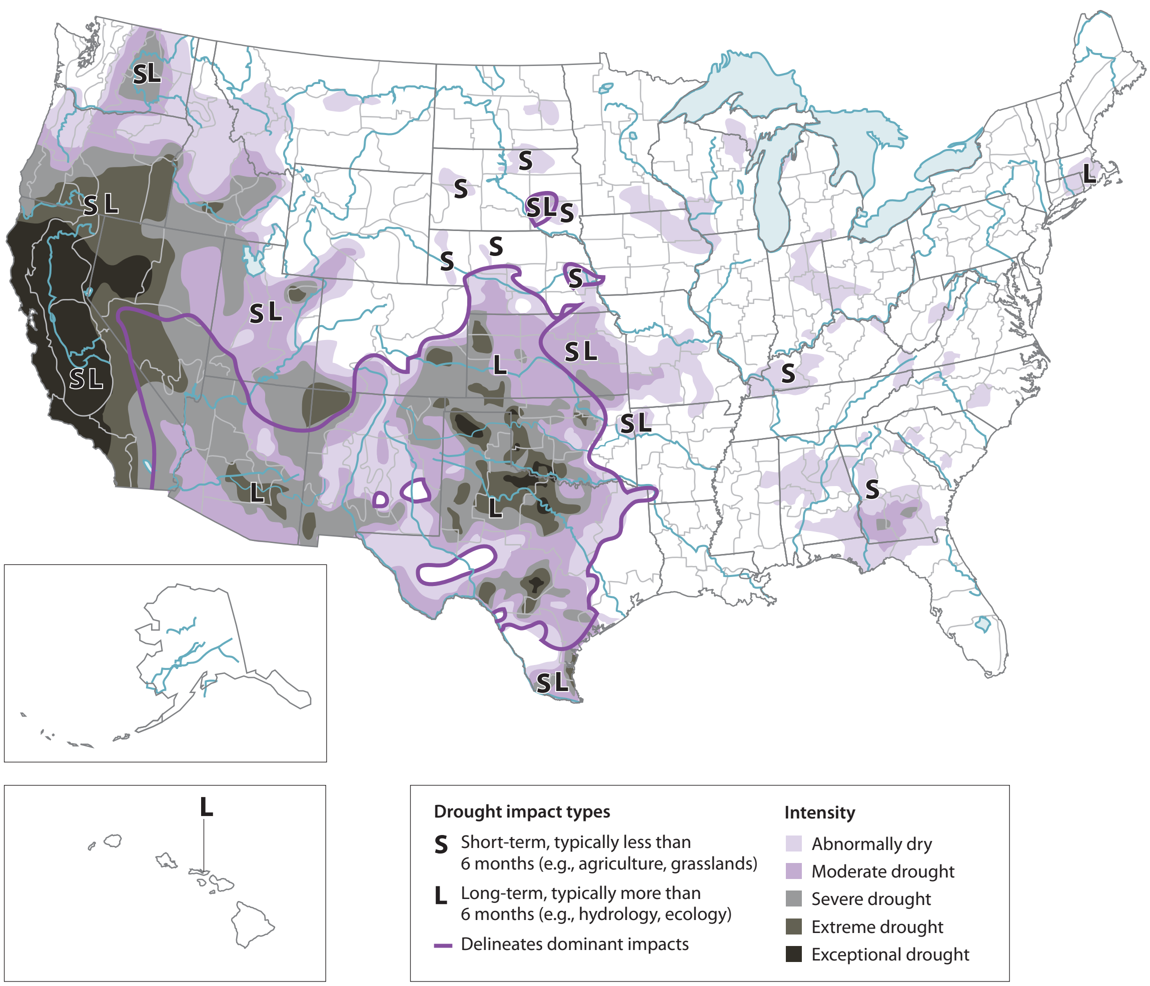
Chapter 1: Introduction

For the past fifteen years, many parts of the American West have been in the grip of a relentless drought. In 2011, the geographic reach of this drought spread east into Texas. Figure 1 presents a map of U.S. drought conditions as of August 19, 2014.

The current drought has highlighted the fact that water users in the West face not only significant imbalances between supply and demand, but also an increasingly unpredictable and variable supply that exposes critical municipal, industrial, agricultural, and ecological values to substantial risks. The drought also provides a sobering example of the enormous economic, political, and social disruptions that water shortages can cause. Since 2006, for example, the canals that carry water from Northern and Central California rivers to supply agricultural users and municipal users throughout the Central Valley and Southern California—known as the State Water Project and the Central Valley Project—have

FIGURE 1.

U.S. Drought Conditions on August 19, 2014



Source: The National Drought Mitigation Center 2014.

not delivered the full allocations of water their users expect (California Department of Water Resources 2014). The winter of 2013–14 saw the Sierra Nevada snowpack, which supplies dry season water as it melts, at just 25 percent of normal. The resulting lack of water forced farmers in the Central Valley to fallow more than 500,000 acres of prime agricultural land, while some rural California towns have come close to running out of water (Postel 2014).

These same challenges are replicated throughout the West. The plains of Southeastern Colorado are experiencing Dust Bowl conditions. In New Mexico, the mighty Rio Grande is running so low that local residents refer to it as the Rio Sand. The drought in Texas has caused more than $25 billion in economic damage. Water shortages have also strained interstate relationships: in recent years Montana has sued Wyoming, Kansas has sued Nebraska, and Texas has sued New Mexico and Oklahoma.

Reliable access to water for manufacturing, cooling, and energy production, not to mention for the support and well-being of the hundreds of thousands of employees who work in these businesses, is as critical to the high-tech industry as it is to irrigated agriculture.

The challenge of increasing water scarcity is most evident in the seven states that constitute the Colorado River Basin: Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming. The waters of the Colorado River Basin currently support more than 40 million people, 4 million acres of irrigated agriculture, and an estimated 27 percent of U.S. national GDP (Bureau of Reclamation 2012). To understand the scale of the current crisis, projections from the Bureau of Reclamation (2013) suggest that within the next few years Lake Mead—the massive water reservoir formed behind Hoover Dam—could decline to levels that would jeopardize both hydropower production at Hoover Dam and the ability of the Southern Nevada Water Authority (SNWA) to divert water from the reservoir to supply the Las Vegas metropolitan area. To address this risk, SNWA is currently undertaking one of the most complex engineering projects in the world, installing a new $1 billion "bathtub drain" intake at the bottom of Lake Mead to supplement two other intakes that could potentially be stranded above the lowered level of the lake.

While the United States used to fret about running out of oil, we ignore the fact that water fuels the American economy just as oil does. The West's agricultural districts produce a vast amount of the nation's food; California alone produces nearly half of the total U.S. vegetable crop and more than half of U.S. fruits and nuts (California Department of Food and Agriculture 2013–14). Renewable energy from hydropower dams in the West accounts for approximately 25 percent of the energy produced in thirteen Western states (National Hydropower Association 2012).

While many Americans seldom think about water, many businesses are becoming concerned about future supplies. In a 2013 survey by Deloitte Consulting of 184 of the world's largest companies, fully 70 percent identified water as a substantial business risk, either in their direct operations or in their supply chains (Carbon Disclosure Project and Deloitte Consulting, LLP 2013). Even Silicon Valley giants like Intel, Cisco, Google, and Facebook rely on huge volumes of water. According to Cisco, whose switches and routers provide the backbone of the Internet, 2 trillion minutes of video traversed the Internet each month in 2012 (Glanz 2013). More than one hundred hours of video are uploaded to YouTube every minute. What makes this possible, beneath the surface of cushy high-tech campuses, is the not-so-soft underbelly: heavy manufacturing to produce computer hardware and semiconductors, used in thousands of large data centers. These server farms (as Google calls them) require vast air conditioning units to dissipate the heat generated by thousands of servers (Glennon 2009). Some server farms use as much energy as a midsized city. Reliable access to water for manufacturing, cooling, and energy production, not to mention for the support and well-being of the hundreds of thousands of employees who work in these businesses, is as critical to the high-tech industry as it is to irrigated agriculture.

Historically, solutions to the West's water-supply challenges have focused on diverting more water from rivers and lakes, building more dams and reservoirs, or pumping more groundwater. These options, with few exceptions, are no longer physically, politically, or economically viable. A few high-concept strategies still persist in policy discussions, such as towing icebergs from the Arctic or diverting water from the Missouri River for use on the other side of the Rocky Mountains (Bureau of Reclamation 2012). But in most places in the West, we must use the water that we already have—in the places that we already have it—more efficiently, more effectively, and more thoughtfully.

There are many tools available to stretch local supplies further, including continued focus on water conservation in urban areas, reuse of treated municipal wastewater (often called effluent), and desalination of seawater and brackish water. But we must do more. In this discussion paper, we will focus on five proposals to encourage the use of market mechanisms to increase flexibility and resiliency in water management:

- **Reform legal rules that discourage water trading to enable short-term water transfers.** Western water law creates significant obstacles to water transactions that, given the substantial and diverse interests at stake, will take many years to reform. However, Western states can immediately act to allow more-flexible use of water resources by authorizing simple, short-term water transactions.

- **Create basic market institutions to facilitate trading of water.** To facilitate and promote longer-term water transactions and transfers, state and local governments should establish essential market institutions, such as water banks and exchanges.

- **Use risk mitigation strategies to enhance system reliability.** Water managers should support and encourage the use of market-driven risk management strategies to address growing variability and uncertainty in water supplies. These include the use of dry-year options to provide for water sharing in the face of shortages, and water trusts to protect environmental values. New reservoir management strategies that allow for sophisticated, market-driven use of storage could build additional resilience into water distribution.

- **Protect groundwater resources.** In order to preserve essential groundwater reserves, protect important environmental values, and support the development of effective markets, states should better regulate the use of groundwater by monitoring and limiting use to ensure sustainability, and by bringing groundwater under the umbrella of water trading opportunities.

- **Continue and expand federal leadership.** To make water markets work at scale, strong federal leadership will be necessary to promote interstate and interagency cooperation in water management, as well as to coordinate essential state-level gathering of data on water supplies and water use. The Bureau of Reclamation plays a central role in water projects across the West; as it negotiates contracts, shapes policy, and updates infrastructure, its actions will be central in addressing the crisis.

In other settings, markets have encouraged efficiency by stimulating innovation, promoting specialization, and allowing commodities to shift from one use to another through voluntary exchange, while generating prices as evidence of willingness to pay for (and thus evidence of the value of) different uses. The deployment of market tools could powerfully address the Western water crisis through these same mechanisms. Market pricing for water can encourage conservation and wise use of water in our cities and industry. Farmers who have an opportunity to sell or lease a portion of their water have an incentive to conserve, invest in more-efficient irrigation systems, and/or adjust existing cropping patterns in order to free up water for trade. Risk management tools, such as options and insurance, can limit physical, economic, and political uncertainty associated with volatile drought cycles. By tapping into the power of markets we have an opportunity to design better tools to protect our environment, halt the excessive pumping of our aquifers, avoid the construction of costly and environmentally destructive infrastructure, improve the efficiency of our water use, safeguard the future of our farming communities, and ensure a supply of water for domestic, job-generating companies (Glennon 2012).

Chapter 2. The Western Water Crisis: Long Time Brewing, Now on the Boil

There's an old saying in the West: "Whiskey is for drinking and water is for fighting." And another: "In the West, water flows uphill—toward money." More than a century of water conflict, and growing cooperation—between new users and old, upstream and downstream users, and among municipal, agricultural, and environmental interests—has produced a complex legal environment for allocating water rights in the West. This wide array of interests has also created an equally complex system of dams and canals for collectively storing, pumping, and diverting water.

This system of moving water has powerfully shaped the physical, cultural, and ecological landscape of the West. Over the past century, public management of water in the West has changed the course of innumerable rivers and allowed the building of great cities and vast agricultural enterprises in the midst of once-arid landscapes. This vast and impressive infrastructure now supports trillions of dollars in commercial, industrial, and recreational activities; tens of millions of people; internationally significant agriculture; and globally significant landscapes, ecosystems, and wildlife.

However, the water systems of the West have come under increasing stress. The ongoing, lengthy drought is partly to blame. In addition, population and economic growth have steadily increased demand for water, at the same time that environmental and social concerns over diversion of water have risen to prominence. Even after the current drought ends, the water challenges facing the West will continue due to these pressures and the increasingly visible impacts of climate change, which are expected to drive the West's historically variable precipitation to even greater extremes (Bureau of Reclamation 2012; U.S. Global Change Research Program 2014). To make matters worse, groundwater reserves—which have been the primary source of water for many Western communities—are also declining in many areas, as agricultural, municipal, and industrial interests have exploited and consumed in decades the groundwater supplies that have taken Mother Nature millennia to accumulate (Glennon 2002).

The legacy of growth and economic prosperity in the West—a legacy built on access to water resources in a dry landscape—has stretched Western water resources to their limits. A future shadowed by the prospect of water shortage threatens farm and ranch economies and lifestyles of rural communities, creates unwelcome uncertainty for fast-growing urban areas, and foreshadows harsh environmental consequences.

THE CHALLENGE OF POPULATION GROWTH AND URBANIZATION

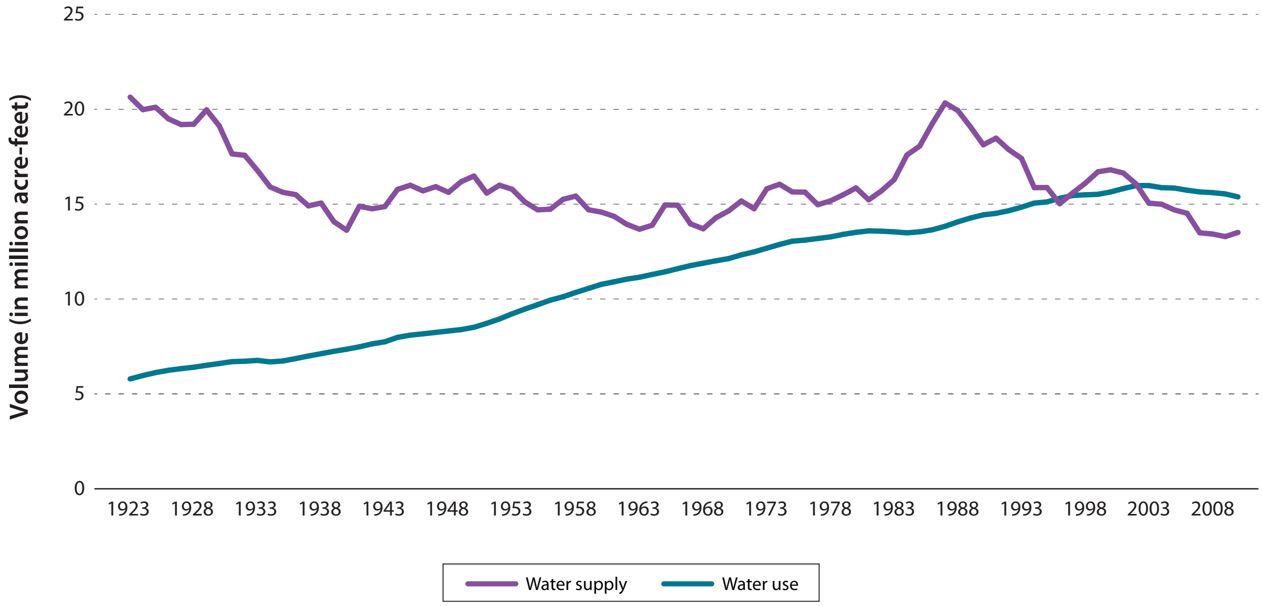
The arid regions of the Western United States are home to many of the nation's largest metropolitan areas and industrial centers, including Dallas/Fort Worth, Denver, Las Vegas, Los Angeles, Phoenix, Salt Lake City, and Silicon Valley. The West has also seen some of the highest growth rates in the nation, having gained an increasing share of the total U.S. population every year since 1900. The comparatively arid states of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming saw their populations grow from approximately 14 million people in 1950 (approximately 10 percent of the population) to more than 56 million people in 2010 (more than 18 percent of the population) (U.S. Census Bureau 1995, 2012). The arid West additionally supports a huge, internationally significant agricultural base. California alone produced nearly $45 billion in agricultural products in 2012, led by California's Central Valley and the major Southern California agricultural districts (Pacific Institute and Natural Resources Defense Council 2014). In Arizona, the Yuma region annually produces nearly 90 percent of the winter lettuce for the United States.

In December 2012, the Bureau of Reclamation released a comprehensive analysis of water supply and demand in the Colorado River Basin. This study, known as the 2012 Colorado River Basin Water Supply and Demand Study, involved a remarkable collaborative effort among federal and state agencies, municipal and agricultural water users, tribes, and nongovernmental organizations. The Study not only evaluated a variety of different agricultural, municipal, and industrial demand scenarios throughout the Basin, but also matched them to a series of future water-supply scenarios, including scenarios built with climate change models (Bureau of Reclamation 2012).

As shown in figure 2, the Study estimated that average demand for water in the Colorado River Basin has exceeded the average available supply every year since 2003. In looking ahead, the

FIGURE 2.

Historical Ten-Year Running Average Colorado River Basin Water Supply and Use, 1923–2010



Source: Bureau of Reclamation 2012.

Study concluded that the long-term projected imbalance in future supply and demand in the Basin would continue to increase, and would average 3.2 million acre-feet[1] per year by 2060—an imbalance that is equivalent to approximately 20 percent of current Basin-wide demands. A worst-case scenario in the Study suggested a potential imbalance of more than 8 million acre-feet per year—greater than 50 percent of current demands (Bureau of Reclamation 2012).

THE GROWING ENVIRONMENTAL TRAGEDY

Like water from the Colorado River, virtually all water in Western rivers and streams is already designated for some sort of use: that is, the water is fully appropriated. In some rivers, water has even been over-appropriated, with greater legal entitlements to the use of water than there is water to support them. The withdrawal of so much water from rivers creates significant trade-offs between human and ecological uses of water, particularly in times of shortfalls. Recent drought conditions have forced reductions in agricultural diversions throughout Colorado, and what little was left for stream flows was inadequate to support the state's rafting and fishing industries. In 2014, low flows in the San Joaquin River in Central California prompted an environmental organization, American Rivers, to name it the most endangered river in the country (American Rivers 2014).

Many other Western rivers, including the Colorado, Gila, Green, and Klamath Rivers, have made the "most endangered" list in recent years. In 2014, the Sacramento River became so shallow due to diversions and drought that young Chinook salmon could not navigate their way downstream to the ocean. In a desperate effort to save these endangered fish, federal and state wildlife officials used climate-controlled tanker trucks to transport 30 million salmon fry (hatchlings) hundreds of miles from hatcheries to the ocean (Chea 2014). Similar issues in Oregon and Washington have caused significant, well-publicized conflicts between agricultural users and endangered salmon runs. In other cases, the consequences of overuse of water resources have been less visible to the public. Perhaps nowhere is this more apparent than in the management of groundwater resources.

Groundwater has been the saving grace for many parts of the water-starved West. Following the advent of high-lift turbine pump technology in the 1930s, many regions had access to vast reserves of water in underground aquifers that they have tapped to supply water when surface water supplies were inadequate (Glennon 2002). A recent study looked at data on freshwater reserves above ground and below ground across the Southwest from 2004 to 2013. It found that freshwater reserves had declined by 53 million acre-feet during this time—a volume equivalent to nearly twice the capacity of Lake Mead! The study also found that 75 percent of the decline came from groundwater sources, rather than from the better-publicized declines in surface reservoirs, such as Lake Mead and Lake Powell (Castle et al. 2014). Much of this decline occurred because some Western states, including California, have historically failed to regulate, or do not adequately regulate, groundwater withdrawals (Chappelle, Hanak, and Mount 2014). As a result, groundwater aquifers are effectively being mined to provide water for day-to-day use. In response to the ongoing drought, California farmers continue to drill new wells at an alarming rate, lowering water tables to unprecedented depths (Weiser 2014).

Allowing unregulated access to a finite common supply has created the recipe for a classic tragedy of the commons (Hardin 1968). In the absence of controls over a shared resource such as groundwater, users have an economic incentive to exploit the resource: each individual user obtains 100 percent of the benefits from pumping groundwater, while the costs are spread among all groundwater users. Depending on the size and characteristics of the aquifer, these impacts can potentially occur across enormous geographic areas. In the San Joaquin Valley of California, excessive groundwater pumping caused the water table to plummet and the surface of the earth to subside more than twenty-five feet between 1925 and 1977 (Glennon 2002). Another well-known example of unsustainable groundwater extraction is the exploitation of the massive Ogallala Aquifer, which underlies much of the Central Western area of the United States.[2] Unsustainable pumping of this aquifer has led to widespread groundwater declines from South Dakota to Texas (Glennon 2002).

THE EMERGING CHALLENGE OF WATER RELIABILITY

Some of the West's most significant water problems concern not so much the quantity of the available water supply as they do the reliability of those supplies in the face of normal (or abnormal) hydrologic cycles. Decades ago when engineers designed our water infrastructure, they understandably assumed that the hydrological processes that drive the availability of water in a particular watershed from year to year would mirror what had been observed historically, and would thus continue to occur within a relatively predictable range. Storage dams, delivery canals, and other infrastructure were designed and sized based on these assumptions. In watersheds that experienced frequent droughts and floods, engineers believed that future droughts and floods would follow historical patterns of severity, duration, and frequency.

However, these assumptions are no longer reliable. Reconstructions of the flow history of Western watersheds over the past several thousand years show that historical variations in water supplies have often been far greater than we have recently observed (Bureau of Reclamation 2012). Moreover, in the face of climate change, the patterns of precipitation, evaporation, groundwater infiltration, surface runoff, upstream use, and other key aspects of the hydrologic cycle have recently departed substantially from our historical experience (U.S. Global Change Research Program 2014). As climate changes continue, scientists expect droughts and floods to become more frequent and extreme, average yields in many watersheds to drop, and year-to-year fluctuations to become less predictable.

These stresses increase the risk that the variability of water resources will overwhelm the resiliency of our water infrastructure, creating a greater threat of economic and ecosystem losses. The Bureau of Reclamation's 2012 study projected that the pressures of growth, inherent natural variability, and climate change will subject Colorado River water users to ever-growing levels of uncertainty and vulnerability. In the Lower Basin states of Arizona, California, and Nevada, the risk of water shortages on the Colorado River is projected to eventually rise to as much as 70 percent in any given year.

This growing uncertainty over the adequacy of water supplies means that the West's water users must adapt water management to address the physical and ecological fragility of the water supply and plan for meeting urban, agricultural, and ecological needs under more-extreme conditions. Simply developing new infrastructure to access additional supplies—or gradually reallocating water resources from traditional agricultural uses to meet growing urban demand—will not solve this problem. In the future, our water delivery systems must be nimble enough to adapt to ongoing variability and the inevitable year-to-year disruptions in water supplies.

THE WIDENING DIVIDE IN WATER RIGHTS AND PRICES

The physical and legal infrastructure for Western water developed when the urban population was relatively small and when urban economies were a small percentage of the regional economy. Farms and ranches were, and in many places still remain, the economic backbone of Western communities, generating billions of dollars in economic activity (see table 1). As a result of that legacy, agriculture today consumes far more water than municipal and industrial interests—using more than 80 percent of water consumed in the West.[3]

Given this same history, the pricing of water also differs considerably between and among different regions and users in the West. Farmers usually pay a comparatively modest cost for the water they use (Solley, Pierce, and Perlman 1998). Federally subsidized water projects and low-cost hydroelectric energy have translated into agricultural water bills as low as a few pennies for a thousand gallons of water (Glennon 2009). The costs for urban water users tend to be substantially higher, typically in the range of $1 to $3 for a thousand gallons, or even higher in many block rate systems that charge increasing amounts for increasing levels of use of the same volume (Hutchins-Cabibi, Miller, and Schwartz 2006). Even among urban users, however, most people pay less for water than they do for cell phone service or cable television. In short, there is an astonishing disconnect among and between regions, and between and among users, in water supply, water demand, and the prices paid for the water users receive.

TABLE 1.

Irrigated Land and Farm Production in Selected Western States

State	Estimated irrigated acres (in 2008)	Total farm production (farm gate value, in millions of 2011 dollars)	Production value ranking		
			First	Second	Third
Arizona	876,158	$4,372	Dairy	Vegetables, beef	Cotton, grains, nursery plants
California	8,016,159	$43,544	Dairy	Fruits, nuts, vegetables/ melon crops	Beef, nursery plants, hay
Colorado	2,867,957	$7,076	Beef	Corn, dairy	Wheat, hay
Idaho	3,299,889	$7,328	Dairy	Beef, vegetables, potatoes	Grains, hay
Montana	2,013,167	$3,542	Wheat	Beef	Hay
Nevada	691,030	$680	Beef	Hay	Dairy, vegetables
New Mexico	830,048	$4,106	Beef	Dairy	Hay, fruit, cotton
Oregon	1,845,194	$4,624	Nursery plants, grains	Beef, dairy	Vegetables, fruit, hay
Texas	5,010,416	$22,681	Beef	Cotton, dairy, poultry	Grains, hay, nursery plants
Utah	1,134,144	$1,607	Dairy	Beef	Hogs, hay, grains
Washington	1,735,917	$8,666	Fruits, wheat	Grains, beans, vegetables	Dairy, beef
Wyoming	1,550,723	$1,450	Beef	Hay	Other

Source: Pacific Northwest Project 2013.

Note: This table provides data on recent irrigated land use and farm production in the Western United States. The first column shows the estimated acres irrigated, the second shows total farm production revenues for the state, and the remaining columns list the most significant types of crops produced, ranked by economic significance. Farm gate value refers to the price at which agricultural products are sold by the farmers producing those products, prior to shipping, subsequent processing, storage, and distribution. The farm gate value is normally substantially lower than its retail value.

Such gaps in prices can only persist, the discipline of economics implies, if there are limitations or restrictions that prevent users who pay lower prices for water from selling that commodity to users who pay a higher price for water. As we discuss below in the section "Reforming Western Water Law and Policy," a myriad of physical, legal, and regulatory restrictions operate to inhibit the movement of water from one user to another and from one type of use to another. Perversely, however, while the water itself cannot easily be traded, the commodities that are produced with water are easily traded. In 2013, Southern California farmers used more than 100 billion gallons of Colorado River water to grow alfalfa (a very water-intensive crop) that was shipped abroad to support rapidly growing dairy industries, even as the rest of the state struggled through the worst drought in recorded history (Culp and Glennon 2012; Putnam, Matthews, and Summer 2013). If those same farmers had had the opportunity to sell that water to their water-starved neighbors in other parts of the state, it might have alleviated some of the economic damage to California's economy caused by the drought while simultaneously generating higher economic returns for the farmers.

Many restrictions on the movement of water are, of course, practical ones, especially the physical difficulty and expense of moving large quantities of water from one place to another, unless there is a river or canal to carry it. Relative water scarcity in one watershed versus another can lead to significant differences in price (Charles 2014). For example, in one well-publicized case, Prescott Valley, Arizona, sold a quantity of municipal effluent to Water Property Investors of New York for nearly $24,000 per acre-foot in 2007; by contrast, groundwater rights in the Phoenix, Arizona, area were trading for less than $1,500 per acre-foot at the same time (Glennon 2009).

The substantial disparities in water availability and price suggest the significant economic efficiencies that might come from increases in water trade. For example, consider that (depending on location and soil) it takes roughly 135,000 gallons (approximately 0.4 acre-feet) of water to produce 2,000 pounds (one ton) of alfalfa, while the same volume of water could produce approximately 11,000 pounds of head lettuce in Yuma. At the same time, it takes less than ten gallons of water for the Intel Corporation to produce a Core 2 Duo microprocessor; that's 32,500 chips per acre-foot. That ton of alfalfa might fetch up to up to $340 (U.S. Department of Agriculture 2014), while the 11,000 pounds of lettuce might fetch closer to $2,000 at the farm gate (Schuster et al. 2012). In other words, an acre-foot of water used to grow alfalfa generates approximately $920; if used to grow lettuce in Yuma, it would generate approximately $6,000; if used by Intel, it would generate $13 million (Glennon 2009).

The arithmetic is intriguing. For example, if agricultural users reduced water consumption by around 9 percent—from the current level of 84.5 percent to 75.5 percent of total water use—that reduction would free up a water supply equivalent to the water currently used by all residential, commercial, and industrial users put together. That supply could not only meet the demands of growth for many years to come, but could also potentially make more water available for higher-value agricultural production.

There is also widespread potential for reducing the quantity of water used in the West. Thanks to investments in water efficiency, many of the West's largest cities, such as the City of Phoenix, use less water today than they did several decades ago—despite the doubling or tripling of their populations during that period. Some agricultural regions, such as the Yuma, Arizona area, have massively grown their agricultural productivity over the past few decades without increasing their water demand. But other urban and agricultural users have not followed this pattern.

Despite these opportunities for trade, physical restrictions on the movement of water, together with the potential for adverse social and environmental consequences from water trade, will remain substantial obstacles to the movement of water in many watersheds. However, not all restrictions on the movement of water are physical in nature; legal impediments are an equally important driver of relative water scarcity and existing price disparities. Our policy suggestions in the next section focus on legal, regulatory, and organizational changes that could serve to reduce these barriers.

Chapter 3. Reforming Western Water Law and Policy

We cannot resolve the water crisis in the American West by simply relying on the traditional approaches to water scarcity: diverting more water from rivers, constructing more dams and reservoirs, or pumping more groundwater. We can provide incentives for urban households to use less water (for example, by setting water prices so that moderate quantities of water have a lower price per unit while higher quantities of water have a higher price per unit). We can find ways to reuse municipal effluent. We can, within reason, develop some new supplies—for example, through desalination. In addition, however, we need to create institutions that would make water allocations more flexible and more resilient so that cities, farms, industries, and environmental interests can thrive even in the face of substantial disruption of water supplies. Water markets represent an important tool for achieving this flexibility.

Some Western water users are extremely hostile to water marketing. Water users staunchly defend their water rights as essential attributes of private property, but they also view local access to water as an inherent entitlement that water rights owners should never bargain away. Local communities across the West routinely resist efforts by cities, industries, and private investors to move water away from its place of origin, and many regard such efforts as either a form of economic imperialism or as a byproduct of shameless speculation by outsiders. Rural areas fear that water resources will be "stolen" by larger communities, repeating some of the infamous water grabs of the past (Libecap 2009), and there is an understandable reluctance to allow critical resources to change hands in the absence of reliable institutions that could ensure access to those resources again in the future. In light of the often contentious history of water in the West, these concerns are understandable and in many cases well justified.

Some existing procedural and regulatory restrictions on water transfers reflect legitimate efforts to manage the real costs of changing the use of water resources, including addressing environmental externalities or third-party impacts generated by the movement of water. In such cases, the high transaction costs that these rules generate are not necessarily undesirable or inappropriate, even if they result in fewer trades than might otherwise occur. Trade in water may cause congestion in delivery systems, environmental damage from altered flow regimes, changes in water quality, and construction of prohibitively expensive new infrastructure. Transfers should not externalize the costs that they may impose on third parties, public infrastructure, or the environment.

By establishing essential market institutions and removing unreasonable barriers to trade, states can play an important role in encouraging—and regulating—the responsible trading of water resources. Water trading offers a means of managing growing demands, adapting to increasing uncertainty in the face of climate change, and generating accurate price signals that drive incentives for increasing efficiency, while preventing or mitigating harm to third parties and the environment. We next examine five proposals for moving down this path.

REFORM LEGAL RULES THAT DISCOURAGE WATER TRADING TO ENABLE SHORT-TERM WATER TRANSFERS

Markets for the transfer of water have developed in some parts of the West, but not as readily as one might expect given the large gap in water prices that persists between different regions and users. At least in part, this lack of development relates to the nature of water rights themselves.

Markets fundamentally depend on a system of property rights; put simply, exchanges cannot realistically take place in the absence of recognized owners and legally enforced contracts. In turn, an efficient system of property rights requires three elements: (1) a complete definition so buyers and sellers know what is being exchanged; (2) exclusivity, meaning the right to exercise control over the asset; and (3) transferability, or the ability to sell or bequeath ownership (Glennon 2005; Libecap 1989). In most Western states, water rights holders are theoretically free to transfer their rights to upstream or downstream water users. But the reality is more nuanced, with transfers complicated by a series of procedural and regulatory requirements that characterize Western water rights, making it very difficult to transfer water rights.[4]

A number of legal doctrines impede the transfer of water in the West. Table 2 lists some prominent legal rules and doctrines governing water rights that tend to impede water transfers. These legal and regulatory restrictions originally developed because water is typically used and reused within the same watershed. Due to this mutual interdependence of water users

TABLE 2.

Legal Rules and Doctrines that Impeded Water Transfers

Name of rule or doctrine	Description	Effects
Appurtenancy doctrine	Legally links the ownership of water rights to the ownership of those particular lands.	This doctrine creates an important barrier to water trade; typically, special procedures must be followed to sever and transfer the right from one place of use to another.
No-harm-to-juniors rule	Permits surface water transfers only if the owner of the rights shows that the transfer will not harm other appropriators.	This rule significantly increases the transaction costs of any exchange, and thus generates a disincentive to transfer by prolonging the transfer process and creating uncertainty about the scope of water rights.
Anti-speculation doctrine	Requires the applicant for a transfer to demonstrate precisely the new location, purpose, and use of the water.	This doctrine raises the transaction costs of exchanges and therefore discourages transfers in many states.
Beneficial use doctrine	Requires that all water be used for a beneficial purpose. Water not used may be deemed abandoned or forfeited.	This doctrine creates incentives for water owners to ensure its use every year, regardless of efficiency or the potential consequences, in order to avoid the permanent loss of the water right.
Salvaged water doctrine	Prohibits water users from obtaining the benefits of water that they conserve because the conserved water will be used by other senior appropriators.	This doctrine effectively encourages overuse of water because it does not allow farmers and other parties who reduce their water use to use, lease, or sell conserved water.

and uses, water rights doctrines evolved to limit the ability of users to change their water-use patterns—including a change in one user's method of irrigation, cropping patterns, timing, or point of diversion—because such changes could potentially interfere with the rights of downstream users.

Comprehensive reform of these doctrines would be controversial and could take decades to implement. However, states could immediately act to facilitate effective short-term water trading. Particularly important would be for states to encourage existing water users to invest in conservation by allowing users who free up water to lease their water savings on a short-term basis to other users. This strategy offers obvious, real-world opportunities for win-win solutions, benefitting all parties and increasing economic efficiency. Municipal and industrial users, as well as farmers with investments in high-value or permanent crops, could provide the capital to modernize farm distribution and irrigation systems in neighboring areas, thus allowing farmers to grow the same amount of product (or a higher-value product) with less water, while freeing up conserved water for municipal, industrial, or higher-value farming uses. An increase in short-term leases would create opportunities for municipal, industrial, environmental, and agricultural users to gain experience with water transfers, develop trust in water management institutions, and create a platform on which to build more-extensive policies and regulations around larger or more-permanent types of water transfers.

However, even allowing these limited kinds of water conservation/short-term lease transactions will require some adjustments to the no-harm-to-juniors, anti-speculation, beneficial use, and salvaged water doctrines to create exceptions for short-term transactions. States will also need to address the impediments to transfers that some local institutions, such as irrigation districts, place on the choices available to individual farmers.

The No-Harm-to-Juniors Rule

In every Western state, the prior appropriation doctrine prevails, at least with respect to surface water rights. This "first-in-time, first-in-right" rule assigns a senior or junior status to appropriators, depending on the date when they first diverted water from a river and put that water to beneficial use (which in practice is virtually any use). Senior rights are the most secure; during drought conditions, users that are more junior may be cut off. While this historical system of appropriation established identifiable property rights in surface water, it also generated ongoing uncertainties with regard to the status, amount, and reliability of water rights (Libecap 2011).

On major Western rivers, the sheer number of users typically generates conflicts. In some states, water claims by users far exceed the amount of water that is actually in the river, leading to a curious dichotomy between "wet water" and "paper rights." California has granted rights to five times the state's average annual flow of surface water (Boxall 2014). In many parts of the West, there is simply not enough water to satisfy the theoretical rights to water that exist on paper (Glennon 2002). To manage these conflicts, states have set up complicated procedures known as general adjudications, which bring all claimants in a particular river system into a single court case to have their competing claims sorted.

Some Western states, such as Colorado, have adjudicatory mechanisms that function smoothly. In other Western states, adjudications are moving more slowly or, as in Arizona, have essentially stalled for decades, leaving streams and rivers over-allocated and subject to a confusing mix of paper rights and wet water. Arizona's Gila River adjudication involves tens of thousands of claimants, each with water rights adverse to every other claimant. Complex priority systems governing the allocation of water during shortage conditions further muddy the waters and make it difficult to value water rights. Particularly in the face of growing climate risk, this combination of legal and physical uncertainty is paralyzing.

Under the appurtenancy doctrine, which is an essential feature of most prior appropriation systems, water rights are legally attached to a particular place of use—usually a specific parcel of land. Obtaining permission to change this place of use (and in most cases the point of diversion) via a water transfer usually involves invocation of the no-harm-to-juniors rule, which permits transfers of water rights from one place of use to another only if the transfer does not harm other appropriators. Given the reality that Western rivers may have hundreds or thousands of different appropriators, protecting the interests of other appropriators necessitates an inquiry into whether a transfer from one appropriator to another would harm a third party. This rule creates enormous disincentives to transfers by driving up the transaction costs of any exchange, typically requiring a fact-specific, cumbersome, time-consuming, and expensive inquiry into return flows, irrigation ratio efficiencies, and consumptive use patterns of various crops in an effort to predict the real-world impacts of a proposed transfer. It may even, as in Colorado, require a similarly fact-intensive inquiry into the historical, beneficial use of the water right to ensure that the water rights holders transfer only the quantity of water for which they can demonstrate historical use.

As an alternative approach, we embrace Professor Mark Squillace's recommendation to link water rights to the amount *consumed*, rather than to the amount *diverted* (Squillace 2012). Most surface water rights are quantified as a right to divert a certain quantity of water. Of that amount, often as much as half is not consumed by the crops but instead either returns to the river through runoff or percolates into the soil to recharge a local aquifer. When an appropriator attempts to transfer a right under existing rules, her action initiates a process of determining whether the transfer would injure any junior appropriator due to changes in runoff and percolation. Redefining the water right in terms of the amount of water *consumed* by the crops would eliminate the need for a "no-harm-to-juniors" inquiry because junior appropriators never had access to consumed water. For example, in the Mexicali Valley of northwestern Mexico, water rights are based on a consumptive use quantity per hectare of water rights that is applied uniformly across the Valley, and that has effectively incorporated losses to evaporation or conveyance through irrigation canals. This system allows rights to be freely transferred from one place of use to another within the Mexicali Valley without considering potential third-party impacts.[5]

To follow this recommendation and thus make water rights more easily tradable, states should authorize their water resource agencies to establish presumptively valid consumptive use quantities for various crops under various soil and weather conditions. This reform would shift the burden of proof from a potential seller of water rights having to demonstrate that no other party is adversely affected, to the challenger having to demonstrate that the agency's presumptive values for water consumption are inaccurate and that they would be harmed by the water transfer (Squillace 2012).

Although the implementation of a one-size-fits-all system to support long-term or permanent transfers might produce unintended consequences, such a system could encourage short-term transfers of water between buyers and sellers at substantially lower risk. This change would dramatically reduce transaction costs and give putative buyers and sellers greater confidence that negotiations could potentially result in a successful transfer. It would also allow buyers and sellers to develop real-world operating experience and to measure the actual effects of conservation activities and transfers; that would, in turn, provide essential data that could be used to develop rules for long-term water transfers.

The Anti-Speculation Doctrine

The anti-speculation doctrine, an offshoot of the appurtenancy doctrine, requires an applicant for a water transfer to demonstrate precisely the new location, purpose, and use of the water before a state water agency can authorize a transfer. The purpose is to ensure that water is transferred for a particular use rather than for speculative purposes. This doctrine made sense in the context of initial applications for water rights under the rules of prior appropriation, when an appropriator could acquire a new water right for little more than a small fee paid to a state agency.

However, the anti-speculation doctrine makes little sense in the context of the transfer of an existing water right. An entity purchasing an existing water right, such as a real estate developer, will have reasons other than speculation to acquire the right in advance of knowing the specifics of how she will use the water. Consider the example of a developer who waits to acquire water rights until she has secured all necessary zoning permits. She could face years of delay, or even be unable to obtain access to a necessary water supply. In a recent example in Colorado, the state supreme court applied the anti-speculation doctrine to prevent the transfer of water to a development project that still had some uncertain details, despite the fact that the developer had already spent millions of dollars in pursuit of approvals.[6] States should jettison the anti-speculation doctrine because it operates to discourage transfers in many states; at a minimum, states should provide an exception to allow for short-term transactions.

The Beneficial Use and Salvaged Water Doctrines

The beneficial use doctrine, prevailing in all Western states, further adds to uncertainty. Under this doctrine, all water must be used for a beneficial purpose; otherwise, the water may be deemed abandoned or forfeited, which results in extinguishing the underlying water right. This doctrine impedes the development of water markets because it creates incentives for the owner of a water right to exercise that right every year, regardless of efficiency or the consequences to other uses, simply to avoid losing it through abandonment or forfeiture.

The related salvaged water doctrine, which exists in Colorado, among some other states, holds that any conserved water becomes an entitlement of other appropriators in order of seniority.[7] Common sense suggests that if a water user takes steps to use water more efficiently by converting to a more efficient form of irrigation or by lining a leaky irrigation ditch, that water user should gain the benefit from the conserved water. But the salvaged water doctrine effectively encourages overuse of water because it does not allow farmers and others who reduce their water use to use, lease, or sell the conserved water.

California's law regulating the lease or sale of conserved water provides a potential model that other states can follow (Water Code [California], § 1241). Its statute provides that water produced through conservation efforts is not subject to the forfeiture rule, which applies to extinguish water rights not used for five years. Instead, California allows the conserved water to be sold, leased, or exchanged.

As another modification to the forfeiture/abandonment rules, state laws should expressly allow for the temporary or seasonal suspension of irrigation of high-water-use crops without risking the forfeiture of water rights. For example, states could and should instruct water resource agencies to develop guidelines, rules, and regulations that would encourage suspending irrigation at the height of the summer to generate water savings that could be transferred. This reform is especially critical in certain areas of California and Arizona, where irrigation of alfalfa may use four times more water during the summer than during other months of the year, yet produce lower overall yields that are of lesser quality (Glennon 2009).

The Farmer and the Irrigation District

Up to this point, the discussion of potential water trades has assumed that farmers and other users own the water rights. In many irrigation districts, however, the district has legal title to the rights—for the benefit of its individual users. If irrigation districts refuse to allow farmers the flexibility to lease or sell some portion of the water allocated to them, that restriction encourages perverse incentives with regard to water use. Without options or opportunities associated with refraining from using an entire allocation, farmers have no incentive to use less water, to shift from one irrigation method to a more efficient one, or to spend money improving the on-farm infrastructure.

Irrigation districts control an enormous amount of water, often in key regions. One of the country's largest irrigation districts, the Imperial Irrigation District of Southern California, encompasses more than 500,000 acres of farmland and several small urban areas; it annually diverts approximately 3 million acre-feet of Colorado River water. That's nearly two thirds of California's legal share of the Colorado River, and nearly 20 percent of the entire annual flow of the Colorado River (Glennon 2009). The structure of irrigation districts, which are the most important and common form of agricultural water-supply organization, has profound implications for water transfers and the operation of contemporary water markets (Libecap 2011).

Agricultural water-supply organizations take many forms: from community-based organizations, such as acequias in Northern New Mexico, to mutual water companies in Colorado and Utah, and to irrigation or water delivery districts in most other Western states. In some cases, the water rights of farmers in these districts are relatively clear. In mutual water companies, for example, each irrigator typically owns stock in the company, often referred to as a ditch company. Each share entitles the owner to a specified quantity (or a proportionate share) of the company's water rights, obligates the owner to pay a similarly proportionate share of the company's costs, and grants the owner voting rights equivalent to the number of shares she owns. Typically, the shares are freely transferable within the company, making it easy for members to transfer water to other members. But transferring water outside of a mutual water company or an irrigation district can be considerably more difficult.

Irrigation districts are generally political subdivisions of the state with substantial powers, including the ability to levy taxes, exercise the power of eminent domain, issue tax-free bonds, and make rules and regulations for the distribution of water within their boundaries. The irrigation district normally owns the water rights within it, typically holding those rights in trust for the landowners in the district. Landowners are entitled to delivery of a certain quantity of water and must pay district assessments to cover operating costs. Although landowners may usually transfer water rights within a district, the district's governing board can often exercise veto power over any transfer of water rights outside of the district. In some states, such as Arizona, irrigation districts have veto power over transfers between farmers within their boundaries, and additionally have the ability to limit transfers by other districts in their same watershed.

Voting rights in irrigation districts vary tremendously depending on the underlying requirements of state law. Some districts allow any registered voter in the district to vote for the board of directors, while other districts allow only property owners to vote, frequently on a one-vote-per-acre basis. These differences affect the willingness of an irrigation district to engage in water marketing with external municipal and industrial interests, and can sometimes result in substantial conflicts of interest between the governing board and the district's landowners (Glennon 2009).

Because a substantial portion of the water rights that could participate in voluntary water transactions are located within irrigation districts, state legislatures should require districts to develop rules and regulations that quantify the water rights of farmers in the districts, and that create incentives for farmers to use less than their full allotments. As an example of how this might work, states could allow farmers to enter into short-term leases for unused water up to a fixed percentage of their overall allotments of water from the irrigation district, say 25 percent. To address the potential for third-party impacts from these kinds of transfers, districts could require that a fixed percentage of the water from such leases, the revenue, or both be returned to the district to mitigate third-party impacts or ecological consequences. If these criteria were met, the transfer of water could proceed irrespective of otherwise applicable requirements that farmers obtain district approval for water transfers outside the district.

CREATE BASIC MARKET INSTITUTIONS TO FACILITATE TRADING OF WATER: WATER BANKS AND EXCHANGES

Robust market exchanges imply more than just a bundle of legal rights—they commonly also involve a set of supporting institutions. Depending on physical and geographic constraints, water infrastructure, and regulatory restrictions, water markets could potentially operate at a variety of scales—within watersheds, within regions, or within the boundaries of urban areas or agricultural districts. Establishing effective frameworks and trading platforms for markets to operate at these various scales is a key responsibility and prerogative of state, district, and local governments. Properly assembled, these frameworks can employ market forces to achieve water management goals.

An exchange trading platform—for example, online software that allows listings or online buying and selling of the exchange's product—helps all parties, particularly small users, locate one another, and facilitates the listing of offer and bid prices and volumes. To provide more basic trading frameworks, state legislatures should authorize the development of local and/or regional water banks to facilitate the transfer of interests in water. Water banks function similarly to regular banks, effectively holding deposits of water rights until the depositor decides to use them, or to lend, give, or sell them to someone else. Existing water banks in the West serve as brokers by helping sellers find buyers and vice versa, as clearinghouses by holding water rights in order to pool supplies from willing sellers and make them available to buyers, and as facilitators by performing other functions, such as using storage entitlements to trade water rights (Ronstadt 2012).

Water banks can help to achieve important policy goals. They can administer state or local programs that restrict or reduce water rights during droughts or under other shortage conditions. They can also pool together water saved by conservation for delivery or use by other users, or to meet other system-level needs. Water banks can help ensure the availability of supplies during dry years, maintain environmental flows to protect in-stream values, promote water conservation by establishing mechanisms to deposit conserved water in the bank, or ensure compliance with interstate agreements. Particularly when water users may face significant exposure to shortage risks, such as urban areas with low risk tolerance, state legislatures may mitigate those risks by authorizing the development of regional water banks, which could confront those issues through voluntary, market-driven transactions. In short, water-banking arrangements provide an extremely important tool to increase system flexibility and/or reliability (Ronstadt 2012).

BOX 1.

The Santa Fe Demand-Offset Approach

In Santa Fe, New Mexico, in response to a drought that severely stressed local water supplies, the city council adopted a conservation regulation in 2002 that required all new construction to offset the water that it would use through reductions in existing demand (Glennon 2009). This system essentially required developers to underwrite new water conservation measures. Most developers liked this system, at least as compared with its alternative: a ban on new construction in the face of water scarcity. As an example, developers could obtain a permit to build if they retrofitted existing homes with low-flow toilets. Residents of these homes welcomed the chance to get free toilets, and Santa Fe plumbers jumped at the opportunity for new business. Within a couple of years plumbers had swapped out most of the city's old toilets with new high-efficiency ones. Water that residents would have flushed away now supplies new homes.

Building on this successful program, the Santa Fe City Council turned to more-direct use of water markets. In 2005, it began to require developers to tender water rights sufficient to serve their developments to the city with their building permit applications. In short order, a market emerged as developers began to buy water rights from farmers.[8] Developers deposited the water rights in a city-operated water bank; when the development became shovel-ready, the developer withdrew the water rights for the project. If the project stalled, the developer could sell the rights to another developer whose project was farther along. Santa Fe also enacted an aggressive water conservation program and adopted water rates that rise on a per unit basis as households consume additional blocks of water. Thanks to the innovative water-marketing measures, the conservation program, and tiered water rates, water use per person in Santa Fe has dropped 42 percent since 1995 (Glennon 2012).

Santa Fe's water rights transfer process could serve as a model for other cities in the West. To facilitate the use of this process, states should explicitly authorize local governments to link land use decisions with available water supply. Construction should occur only if there is water to support it, but mechanisms would be available to reallocate water supplies from existing uses. The costs of acquiring the water needed for economic growth would thus be absorbed into the cost of new development. A similar approach could be used in preserving groundwater: that is, those who wish to draw more from groundwater would need to first identify a demand offset in the form of some existing groundwater user who would withdraw less.

While implementation details of water banking vary, they generally operate through a broker, typically a state agency or other administrative body that solicits buyers and sellers and communicates available amounts for trade as well as bid and offer prices (where price flexibility is permitted). Water banks can also serve other market functions, such as verifying the validity of water rights to be banked and the quantity of water actually saved in a transaction, establishing contract terms, facilitating regulatory compliance, or managing transactions and banked water to meet system reliability objectives.

At their core, both water banks and more-sophisticated exchanges depend on the existence and operation of the basic legal framework for water transfers already discussed. To facilitate the exchange of information, states should develop a central registry of water rights that includes characteristics such as location (watershed), designation of surface or ground, priority, type of use (e.g., agricultural or municipal), list of rights holders, diversion amounts, historical consumptive uses, and recent exchanges, including amounts, duration, and prices paid. Expressly allowing for certain types of water transfers between parties, such as short-term leasing arrangements, would be sufficient for a bank- or exchange-driven market to operate, as long as the rules of transfer are not too restrictive. For example, California has existing water banks, but the state has historically regulated the prices paid to those who provide water to its banks (Brewer, Fleishman, et al. 2008). Because the state set low prices, it reduced the incentive to conserve water and increased the incentive to draw on the banks. By setting such low prices, the state undermined the essential market role that water banks can play, especially in quickly moderating the effects of drought.

By supporting transaction activity, water banks and other market institutions can also stimulate water conservation and increase the efficiency of water use by encouraging the reallocation of water from lower- to higher-value uses or facilitating more-rapid adaptation to changes in available water supplies in the face of drought. Water banking agreements with individual parties can also help to guarantee that at least minimum environmental flows reach downstream.

Certain localities are already beginning to consider the establishment of new water banks or exchanges. For example, the province of Alberta, in Canada, has been considering

BOX 2.

The Arizona Water Bank and Other Examples

Arizona provides an example of how a water bank–style institution can conjunctively manage surface and groundwater resources. Although not yet developed into a formal exchange, Arizona has been at the cutting edge in developing groundwater recharge and recovery projects and a supporting statutory framework to help enhance the reliability of water supplies (Megdal, Dillon, and Seasholes 2014).

Arizona allows municipal users, industrial users, and various private parties to store water in exchange for credits that they can transfer to other users. Because water stored underground in aquifers is not subject to evaporation, groundwater that is deliberately created through recharge activity can be stored and recovered later. This recharge and recovery approach is facilitated by Arizona laws that restrict the use of groundwater in several of the state's most important groundwater basins; these restrictions prevent open access to the resource. Restrictions on open access, combined with statutory and regulatory provisions that allow for the creation and recovery of credits, created the essential conditions for trade in stored groundwater. As a result, numerous transactions have occurred between various municipal interests, water providers, and private parties.

Operating within this framework, the Arizona Water Bank operates to store excess Colorado River water from the Central Arizona Project (CAP) in Central Arizona's aquifers. This water bank has acquired and stored millions of acre-feet of water underground in order to protect urban users against large-scale Colorado River shortage conditions. The Arizona Water Bank has also provided for a limited form of interstate banking through agreements with other Colorado River users. Under an agreement with SNWA, when Nevada needs additional supplies it may call on Arizona to reduce its take on the Colorado River. When that occurs, Nevada will use some of Arizona's Colorado River water and Arizona will use the stored groundwater.

Another example of large-scale water banking is under discussion in the Upper Colorado River Basin. The states of Colorado, New Mexico, Utah, and Wyoming are considering the use of a water bank to store water in a major downstream reservoir, Lake Powell. Such storage would insulate Upper Basin users from the potential risk of a call under the 1922 Colorado River Compact, which would require them to forgo water use in order to meet legal water delivery obligations to the Lower Basin states of Arizona, California, and Nevada. As part of the program, banking agreements with individual parties could also help to guarantee minimum environmental flows downstream of those users along important river reaches.

whether to create a water exchange that would provide a low-cost, transparent, regulated, and standardized mechanism for trading water (Gibbins and Zehnder 2010).

USE RISK MITIGATION STRATEGIES TO ENHANCE SYSTEM RELIABILITY

The development of simple water trading opportunities, together with basic market institutions like exchanges or water banks, creates the opportunity to deploy more-sophisticated market-based tools that help to manage risk and vulnerability in other market settings. In the case of agricultural commodities, for example, a farmer in Iowa may spend substantial time behind a computer screen, managing the risk of variations in prices or crop yield with tools, such as a contract for delivery of a certain quantity of corn at a future date. Insurance companies, farmers, commodities brokers, investment banks, mutual funds, and hedge funds have each developed risk management tools of varying degrees of sophistication to control or hedge against market, weather, and environmental risks.

Water markets should borrow some of these risk mitigation strategies. By developing similar tools for water resource management, we can build resiliency into and reduce the vulnerability of our water management institutions and infrastructure.

Water Trading to Mitigate Water-Supply Risk

Agricultural crop and livestock producers regularly face multiple risks, including natural disasters, disease and pest outbreaks, hail and frost, flood and drought, changes in commodity prices, movements in exchange rates, and water-supply risks. To manage these risks at the farm level, farmers employ a variety of existing market-based tools to protect themselves (above and beyond the protections offered to farmers through federal price supports, government insurance programs, and the like). For example, growers frequently diversify sales among buyers or sell into private cooperative pools or processing cooperatives. For some crops, on-farm or centralized storage can help to hedge commodity price spikes through crop sales over time or across several different markets. Particularly in areas subject to systemic yield risks—such as when many farmers are affected by the same risks—farmers frequently rely on the negative correlation between yield and price to stabilize income. That is, when farm yields fall across the board, prices for the underlying commodity tend to increase, which can partially offset farmers' losses from reduced yields. In addition, the use of forward contracting mechanisms to manage price risks—by direct sales to end users or through commercial banks—is increasingly common among farmers, as is the use of futures and option contracts.

In general, agricultural risk management approaches have revolved around self-determination principles, with individual farms undertaking risk management for normal risks, and government programs, such as the large-scale protections that are available against disease or floods, addressing exceptional risks. Traditional approaches to managing the risk of drought (both in agriculture and otherwise) have tended to treat drought as an exceptional risk to be managed through government intervention. However, climate change is forcing us to rethink what risks are normal and what risks are exceptional.

In 2014 in East Texas, traditionally the water-rich part of the state, uncertainty in water supply prevented farmers from being able to obtain crop insurance (Satija 2014). Also in 2014, low allocations to farmers in California from the State Water Project led Moody's, the credit rating firm, to declare that the State Water Project's decision negatively affected the credit of California water agencies (Chin 2013). In other words, irrigation districts must now pay more to borrow money. That translates directly into higher costs for growers. The risk of future water shortages makes it more difficult for farmers to borrow money, get mortgages, obtain insurance, sell or lease their water rights, or obtain credit from suppliers (e.g., feed, pesticide, fertilizer, or farm implement dealers) (Caldecott, Howarth, and McSharry 2013).

Water trading offers flexibility that can allow water users to adapt to variable supply-and-demand conditions, and to control the physical and economic risks of shortages. Combined with simple transactional tools, such as the use of option contracts that allow users to shift water risk through voluntary arrangements, water trading can help to protect cities, farmers, and industries by providing additional tools to manage drought risks.

In Australia, robust water markets have incentivized farmers to use water more efficiently from year to year: farmers purchase water on the market to expand operations when water is more abundant and cheap, and sell water during dry periods (Grafton et al. 2011). Because the value of water tends to rise as the availability of water declines, a farmer's ability to trade water helps to mitigate the impacts of drought on farm incomes. The Australian strategy has helped to keep farms in production that might otherwise have failed during dry conditions, especially those farms with permanent crops, such as orchards or vineyards.

The latter point is particularly important, because drought does not affect all farmers in the same way. Fruit and nut trees take multiple years before they begin producing fruit, but will die if they go without water for a single season. In contrast, the failure to water an annual crop, such as broccoli, would cost a farmer that season's revenue, but she would not suffer the same loss of capital as the orchard owner whose trees die from lack of water. As the drought in California worsened in 2014, fruit and nut producers scrambled to enter short-term contracts with vegetable and grain producers in order to obtain enough water to keep their trees alive (Strom 2014). The spot market saw price gyrations that put some nut and fruit producers in a bind. But one of the largest nut producers in the country had entered into a water-supply contract four years earlier that now provided water when the farm most needed it. The farmer lost money on the contract the first two years, but when the drought worsened, the contract paid off (Strom 2014).

With this in mind, it is perhaps unsurprising that a recent National Science Foundation study on water markets in the West (with two of this discussion paper's authors as principal investigators) found that voluntary water transfers are mostly between farmers, rather than between farmers and other users (Brewer et al. 2007; Brewer, Glennon, et al. 2008). Spot markets provide a critical tool for farmers to mitigate water-supply risk by hedging commodity price swings: the buyer secures water at a critical time, and the seller obtains a revenue stream from selling the water that hedges the risk of commodity price fluctuations. The California example cited above, along with the larger Australian experience with water trading, suggests a very important lesson for the United States: the ability for farmers to easily engage in short-term trades enables them to manage uncertainty and risk within and between irrigation seasons.

Tradable Reservoir Storage to Manage Water-Supply Risks

Most reservoirs serve multiple uses, such as satisfying water-supply needs, controlling floods, and providing for the generation of hydropower. Frequently, reservoir storage space is allocated to one or more of these uses, with operational rules built on a risk analysis derived from the historical record. For example, a large portion of available reservoir storage may be dedicated to meeting water-supply needs. At lower levels, releases may be restricted to prevent shortages and preserve hydropower, while at higher levels extra water may be deliberately released to free up reservoir space needed for flood control. However, the rules governing reservoir storage may create perverse incentives when it comes to water use by individual users; in most cases, for example, if a water user fails to use water to which she is entitled, the water reverts to the system and is automatically available to be diverted by someone else. This "use it or lose it" system creates few

BOX 3.

Potential Options and Futures Contracts for Water Markets

Once basic mechanisms for the lease and transfer of water rights are in place, creative transactions to manage the risk of water fluctuations can evolve organically through private-market mechanisms. Several types of option contracts could be used to create flexibility in water use.

Under **dry-year options** water users with a low tolerance for loss of water supply—including municipal water users or citrus tree growers—enter into a contract to pay a seasonal agricultural user who has more flexibility to accommodate changes in water supply a certain amount of money each year. In dry conditions, the buyer of the option would have a right to use the seasonal agricultural user's water, while the interrupted seasonal user would use the money received to offset the costs or losses associated with the reduced water supply, such as adjustments to the types of crops grown or the amount of land in production.

A **fixed-price option** also hedges the risk of water price fluctuations for buyers, ensuring the availability of water at a certain price in the future, regardless of changes in the commodity price of water. In such a case, the seller of the option (say, a farmer) absorbs the risk that the value of the commodities that could be produced with that water will rise in the future, and charges the buyer proportionately more for the privilege of holding the option.

Put options, by contrast, could give a seller the ability to transfer water at a prearranged price, effectively allowing the seller to hedge against the risk that the seller cannot productively use water in a particular year.

A relatively recent example of a dry-year option contract is a fallowing agreement entered into between farmers in the Palo Verde Irrigation District (PVID) and the Metropolitan Water District of Southern California (MWD) (Glennon 2009). MWD purchased an option to call on PVID farmers to fallow a certain number of acres during a given year, with the resulting water savings transferred to MWD for urban use. MWD paid the participating farmers a fixed amount per acre (approaching the fair market value of the underlying land) to subject their lands to a fallowing obligation. Participating farmers then received an additional price per acre for the water transferred to MWD, an amount that now approaches $700 per acre, which in most cases is more than PVID farmers would have likely realized were they to have grown crops on the land. This option ensures MWD has access to water at a fairly predictable price over time, and provides farmers with a revenue stream at least equal to what they might generate through farming. It also mitigates a portion of the farmers' risk that weather, changing commodity prices, pests, or other risks might wipe out their crops and thus their revenues.

A variety of other approaches are available. For example, a commitment to selling or buying a future quantity of water at a particular price could be linked to consumer price indexes, changes in commodity prices, or changes in the cost of municipal water supplies or water-supply infrastructure. One creative proposal in the Philippines involved the use of a reservoir index insurance framework to enhance a dry-year option between an urban water supplier and an irrigated agriculture producer. Under this approach, an insurance contract designed to cover the costs associated with the exercise of dry-year options would allow an urban water supplier to pay a relatively stable annual premium to an insurer (who absorbed the risk of price variations) in lieu of the variable costs that would otherwise have been associated with the exercise of a dry-year option (Brown and Carriquiry 2007).

incentives for individual users to forgo use of water or invest in conservation activities that would preserve water in storage, even when reservoir levels are declining in the face of drought.

Another market-based risk management tool is to allow water rights holders whose water comes from reservoirs to carry over their water from season to season for later use, instead of requiring users to use their entire water allocation each year. Adoption of such carryover rules is an effective way for reservoir operators to encourage both water trading and conservation. We propose that reservoir operators—whether at the federal, state, or local level—adopt such carryover rules wherever feasible. Implementation of a carryover mechanism essentially requires a reservoir operator to allocate a portion of available reservoir storage space to be used (temporarily) for such carryover storage, and to adopt an accounting system that permits individual users to order their carryover water in subsequent years. These policies enable users to make better individual choices about the use of water from year to year, as well as to improve their ability to manage risks associated with dry cycles. In particular, the ability to carry over water to a subsequent season eliminates counterproductive "use it or lose it" disincentives that encourage use of currently unneeded water—even if such use causes shortages in a subsequent year (Productivity Commission, Commonwealth of Australia 2006).

A slightly more complex approach defines entitlements to delivery of water from storage (such as a common reservoir) in terms of a share of the available active storage capacity, with each entitlement holder receiving a share of inflows and outflows, reduced for evaporation and seepage loss. Entitlement holders then determine the releases that they need, allowing each user to manage her own water supply and the associated risks of supply shortfalls across seasons.

The Intentionally Created Surplus (ICS) rules that operate on the Lower Colorado River provide an example of a successful reservoir storage mechanism. These rules permit water users to conserve water they would otherwise have put to use, and then to store it in the reservoir system for delivery in a later year. Users can also transfer the water for the use of another contractor in the same state. The stored water is charged for evaporation each year and is treated as top storage—that is, it occupies the empty storage on top of the other water in the reservoir. In the event that the reservoir is forced to spill water during flood conditions, the stored water is lost—but it is lost at a time when water is plentiful. By contrast, if the reservoir falls too low the stored water cannot be released until reservoir levels recover to a minimum level. Thus, the ICS rules incentivize conservation by individual users in order to generate storage for use in future years, while using the resulting stored water to guard against shortages and to help preserve hydropower production (U.S. Department of the Interior 2007).

The ICS rules also encourage water transactions by allowing one user (such as a municipality) to work with another user (such as a farmer) to generate conserved water for future diversion. For example, the municipality could pay a farmer to fallow fields, or could finance farm efficiency measures, generating credits for water left in storage that the municipality can use later. Though the ICS rules do not allow water to be moved from one state to another, they gingerly lean in that direction by allowing states to make joint investments in system conservation projects that reduce system losses or increase the amount of water available to the system as a whole (Glennon and Kavkewitz 2013).

An example of an ICS project is the construction of the Drop 2 reservoir in California, which captures water that downstream irrigation districts order out of the major Colorado River reservoirs but subsequently do not use. Paid for through a cooperative agreement among SNWA, MWD, and the Central Arizona Water Conservation District (CAWCD), which operates the CAP canal, Drop 2 conserves water each year that would otherwise be unusable inside the United States (although this water is available for use in Mexico). In exchange for financing the project, SNWA, MWD, and CAWCD each receives ICS credits that allow them to divert additional water from Lake Mead.

The United States and the Republic of Mexico recently extended the ICS concept under a binational agreement that similarly allows Mexico to store and recover conserved water in U.S. reservoirs. The same agreement also permits the exchange of stored water between the two countries, which is allowing municipal interests in the United States to help finance infrastructure improvements in Mexico in exchange for the right to use a fixed amount of water, equivalent to a portion of the water conserved (Entsminger and Culp 2013).

These types of carryover and storage rules can significantly expand potential trading opportunities, because they grant water users the ability to store and trade seasonally available water over multiple years, instead of on only a year-to-year basis. They also provide each user with greater certainty regarding water supplies. Each user can decide how best to manage her available storage based on information about current water levels and projected inflows, while being partially insulated from the consequences of other parties' decisions. Particularly on smaller reservoirs, where the rules governing allocations tend to be less complex, reservoir system operators should consider allocating storage space on an individual basis, allowing each user to manage her own water-supply risks. Such rules would expand potential trading opportunities and decrease uncertainty associated with fixed delivery rules that require the release of water regardless of whether it is needed.

Tradable Delivery Capacity to Mitigate Water Infrastructure Risk

Complications inevitably arise once parties start moving water from one place to another. For example, the physical capacity to move purchased water to its intended destination may not be available, or such movement may create undesirable congestion during key periods of the year. Similarly, the transfer of water outside of an existing delivery system may increase the relative cost of operating the delivery system to the remaining users of that system.

To enhance water transfers involving the use of major public infrastructure, we propose that legislatures, as well as infrastructure operators and managers, consider the authorization of distinct and tradable entitlements for delivery capacity, or wheeling, within local and regional infrastructure. Wheeling rules can provide a mechanism to ration access to delivery capacity, prevent system congestion, and create transparency in managing the costs of transfers (Productivity Commission, Commonwealth of Australia 2006).

Separating the ownership of water rights from delivery capacity can also strongly encourage trading by increasing the number of products that can be traded among water users. The ability to trade water rights and the *timing* of the deliveries—or the ability to trade water rights without losing future access to the distribution system needed for the longer-term use of those rights—can allow for more-nuanced and more-flexible reallocation of water among users, both year to year as well as during the course of a single year.

For example, in a system in which delivery capacity and water rights are owned separately, a farmer who is willing to engage in a short-term, seasonal lease of her water rights for use outside of her district would retain ownership of and the obligation to pay for her delivery capacity in the district infrastructure. This would allow the farmer to resume her regular water deliveries in a later year, but would prevent the costs of maintaining the unused delivery capacity from being passed on to other users in the district. Alternatively, that same farmer could rent the resulting seasonal excess delivery capacity to another farmer in the same district who needs the extra capacity to irrigate a higher-water-use crop. Similarly, other farmers within that district would be able to trade both their water rights and/or the capacity to deliver water rights during a particular irrigation season, allowing the timing and volume of water use on lands within the district to adjust year to year in response to changes in the market price of the commodities produced on those lands.

In 2014, a proposal for a creative blend of aquifer-storage rights and delivery-capacity rights involved farmers in the area of Bakersfield, California. Producers of grapevines and pistachio and pomegranate trees want to pump recharged groundwater into the California Aqueduct. The additional water would actually reverse the flow in the aqueduct for a thirty-three-mile stretch, providing needed water to keep the vines and trees alive ("California Drought" 2014).

Water Trusts to Control Environmental Risks

The concept of land trusts, which are nonprofit organizations that conserve land for open spaces or other purposes, has recently spilled over into the area of water. Water trusts, which are typically nonprofit organizations, acquire water rights through outright purchases, leases, dry-year options, donations, or investments in water conservation in partnership with traditional users. They then dedicate that water to maintain minimum flows for the benefit of fish, vegetation, and wildlife. In times when the water is not needed, water trusts can lease water back to agricultural or other uses and thereby generate revenue to support the operations of the trust. Active water trusts now operate in a number of Western states, funded from a variety of state, federal, and charitable sources. The Freshwater Trust in Oregon is one prominent example of such a trust (Brewer et al. 2007).

Healthy ecosystems are critical to sustaining the components of the larger water cycle, such as land and forest cover, soil, wetlands, and floodplains, each of which provides important ecosystem services. Failure to protect and maintain ecosystems can require expensive intervention to replace ecosystem services through artificial means, or can generate significant regulatory constraints, such as mandatory restrictions on water use to protect species that have become threatened or endangered. Because water trusts create the opportunity to protect environmental values through voluntary, market-based transactions, they will and should have growing importance in controlling environmental risk in Western water management.

Making water trusts work on a large scale will require the development of consistent, substantial revenue streams to allow for the purchase of in-stream rights and other environmentally beneficial water transactions. Most of the existing, highly successful water trusts—for example, those in the Pacific Northwest—rely on substantial revenue streams from the operators of hydropower dams, which provide this funding as mitigation for the harm they cause to the habitat of endangered species. Federal and state governments and water managers should encourage and expand the use of water trusts as a means of limiting systemic risks by ensuring that the funding essential to these institutions is made available, such as through the use of user fees, mitigation requirements, or dedication of other public revenues.

The tactics employed by water trusts, including the purchase and lease of water rights in order to control systemic risks, is likely to have significant value beyond just environmental contexts. Consider a 2014 proposal for a pilot Colorado River System Conservation Program (Brean 2014). The idea is for urban interests to pay water users to take less water from the Colorado River—not for purposes of transfer, but for purposes of limiting risks to the system as a whole. As part of a small-scale pilot, SNWA, CAWCD, MWD, and Denver Water are each contributing $2 million; the Bureau of Reclamation will add another $3 million, for an initial total of $11 million. The money will fund agricultural conservation programs (initially in the Lower Basin, but eventually expanding to the Upper Basin), thereby conserving water that would otherwise be consumed. The unusual wrinkle is that the municipal users do not get to use the conserved water; rather, the water will be left in the Colorado River system to help buffer the potential impact of low reservoir water levels that could otherwise jeopardize not just urban water supplies, but also hydropower production, recreational uses, and other needs.

PROTECT GROUNDWATER RESOURCES

Lack of groundwater management is one of the most significant barriers to water trading in the West, and is one of the areas in most critical need of reform. Think of the local groundwater supply as a giant milkshake glass, and of each user who drills a well as putting a straw in the glass. Some

Western states allow a limitless number of straws in the glass. This open access to groundwater resources is at the heart of the West's growing tragedy of the water commons, damaging our aquifers, rivers, and streams, and reducing groundwater reserves that we might otherwise use to mitigate future risks of water-supply disruption.

In Texas, for example, the law governing groundwater use employs the right of capture—a right to pump a limitless amount of water.[9] Arizona and California (setting aside a few specially regulated groundwater basins) follow the closely related reasonable use doctrine, which allows a user to pump an unlimited quantity of water as long as the water is applied to the parcel of land for a beneficial purpose; in practice virtually any purpose qualifies as reasonable. This doctrine allows continued pumping even if it interferes with other well owners, drains the underlying aquifer, or reduces flow to connected springs, rivers, and other surface water systems supported by that groundwater. A use remains reasonable even if it causes land subsidence that jeopardizes homes, canals, roads, and other critical infrastructure (Glennon 2002).

Some Western states have established priority systems that rank groundwater pumpers as junior or senior to each other, depending on when they commenced pumping. States such as Colorado and Idaho have also integrated their surface water priority system with the groundwater system, lending a measure of coherence and hydrologic soundness to the legal system and limiting the potential for overexploitation of groundwater resources. However, in parts of the West there is no such integration. Some states maintain different legal rules for governing surface water in rivers and streams, storm water that is captured before it reaches a natural channel, groundwater, and treated effluent—despite the fact that these are closely connected in reality. As a result, a senior owner of a surface water right in a stream might see the value of that right undermined by a junior user pumping groundwater and drying up that same stream.

The failure of some states to regulate groundwater use has created an ongoing open-access resource problem causing widespread ecological degradation, property damage, and continuing erosion of private property rights in both land and surface water (Glennon 2002). In addition, open access to groundwater substantially impedes the development of markets for water (both in groundwater and with respect to other water resources) because a prospective water user frequently has the option of access to free groundwater in lieu of paying for access to a more sustainable but comparatively expensive, scarce, and tightly regulated supply of surface water. Open access to groundwater thus inhibits the development of real markets for water and distorts the prices we pay. Basically, why pay for something that you can get for free? Not surprisingly, a primary response across the Southwestern states to the drought of the past fifteen years has been to increase pumping of groundwater reserves (Castle et al. 2014).

Defenders of the policy of allowing landowners to drill wells on their property without restriction sometimes claim that such open access to groundwater is an essential feature of private property. However, in practice this legal doctrine offers little or no actual protection to the landowner, because it does not protect any property interest in the water itself. A homeowner on a well may be harmed by neighboring landowners who drill adjacent wells that drain water away, lower the water table, raise pumping costs, or even completely cut the landowner off from access to water. The latter happened in 2014 in Stanislaus County, California, where the wells of sixty-nine homeowners dried up because open access to groundwater allowed new wells, whose pumping caused the water table to decline (Sbranti 2014). Thus, rules that allow unlimited pumping of groundwater actually undermine private property rights in overlying land and connected surface water, pose substantial physical and ecological risks, and create long-term economic insecurity associated with uncontrolled overdraft and the depletion of shared aquifer resources. In this context, regulation of groundwater can substantially *enhance* the value of private property.

California's response to the ongoing devastating drought, which has resulted in increasingly heavy groundwater pumping and widespread groundwater declines in many parts of the state, is the legislature's recent adoption of a hard-fought legislative package to regulate pumping, consisting of three bills: AB 1739 (Dickinson), SB 1168 (Pavley), and SB 1319 (Pavley). The Sustainable Groundwater Management Act compels local water managers in a series of high- and medium-priority groundwater basins (exhibiting substantial overdraft conditions based on studies undertaken by the state) to craft groundwater management plans and associated programs that would reduce groundwater use to sustainable levels by 2040 (Allshouse 2014). These plans, which are required to be coordinated with local land use planning, are subject to regular, periodic updates and review by the California Department of Water Resources. Although the Act embraces a preference that "groundwater management in California is best achieved locally," as the governor said in his official signing message (ibid.), the law also authorizes the state to step in to regulate if local efforts fail. In addition to mandating the adoption of groundwater management plans, the law authorizes expanded local authority over groundwater under the auspices of groundwater sustainability agencies (GSAs), which can be specific local water agencies or cooperative efforts among agencies. These GSAs may require the installation of meters, the registration of wells, and reporting of pumping. GSAs may also charge fees for water use, conduct inspections, and regulate groundwater extraction to achieve sustainability within local water budgets.

Arizona leads the nation in the development of groundwater recharge and recovery programs, which allow for the replenishment of overused groundwater supplies with surface water and effluent. But prior to 1980, Arizona followed the reasonable use doctrine in all parts of the state, which had resulted in widespread aquifer declines. In 1980, as part of an agreement brokered among water interests to develop the CAP canal, Arizona broke this cycle of overuse with enactment of the Arizona Groundwater Management Act, which applied a series of new restrictions to some of the state's largest agricultural areas and the rapidly urbanizing regions of Central Arizona. The Act took three steps critical to sensible water management: First, it heavily restricted the drilling of new water wells in already stressed areas. This step halted, or at least significantly slowed, the progression of the tragedy of the commons. Second, the Act quantified the rights of existing pumpers, abandoning the vague reasonable use doctrine in favor of specific entitlements to the use of groundwater. Third, it made those rights at least partially transferable, and allowed for the development of tradable credits in reclaimed water. The workability of the Arizona Water Bank system described earlier is based on the 1980 groundwater protection legislation.

The Arizona system provides a model that California's newly minted GSAs could use as they begin to manage precious groundwater resources: first, GSAs should quantify existing pumpers' groundwater rights, require existing well owners to register with the state, and require that well owners install water meters that measure the water pumped. Second, GSAs must invest in better groundwater data collection and reporting—probably the most-neglected category of water data collection throughout the West. Some states have little idea how many groundwater wells have been drilled or how much water those wells pump. Even in Arizona, the state requires groundwater use to be measured and reported in only seven of the state's fifty-one groundwater basins. Prior to its recent legislation, California failed to regulate how much water well owners may pump or even require well owners to report how much water they *do* pump (Pitzer 2014; Weiser 2014). Farmers, especially, have resisted state efforts to obtain well pumping data in California (Stapley 2014).

Third, GSAs should adopt groundwater management rules that will halt or reverse groundwater declines by requiring groundwater use to be based, where possible, on established water budgets for individual groundwater basins. This step will protect surface water users from the effects of groundwater pumping, and protect groundwater pumpers from each other.

Across the West in states that lack integrated management of surface water and groundwater, states should consider, where feasible, allocation of groundwater based on sustained-yield budgets that ensure groundwater withdrawals neither undermine the contribution of groundwater to surface water systems nor degrade the environment. In aquifer systems that lack hydrological interconnections with surface water, groundwater allocations should be based on safe-yield budgets that balance aquifer recharge and groundwater withdrawals (and any natural discharges) over time. In areas where groundwater recharge is feasible, states should develop rules and regulations that provide incentives for groundwater recharge and recovery programs. These programs should create tradable credits for recharged water, both as a means to increase the resilience of water management in the face of potential shortages and as a means to offset new or expanded groundwater use.

To limit the harm from access to groundwater as a common-pool resource, states should require permits for drilling new water wells. As a condition of issuing such a permit, states should require that any new pumper offset or mitigate aquifer impacts by acquiring and retiring an existing pumper's rights. Utah has enacted a demand-offset system that provides one example of how this can work (Glennon 2009).

Finally, proper management of groundwater will also require significantly improved understanding of many aquifer systems, a burden that will fall to both the U.S. Geological Survey and to state departments of water resources. At a minimum, states will need to focus on studies of water basins

Some states have little idea how many groundwater wells have been drilled or how much water those wells pump.

where groundwater overdraft has reduced surface flows, or already caused other observable problems. This will require increases to agency budgets, which have been cut significantly at both the federal and state levels.

CONTINUE AND EXPAND FEDERAL LEADERSHIP

Although the management of water rights largely rests with state governments, the federal government has played an enormous role in the development and management of water in the Western United States (Glennon 2005). The Bureau of Reclamation has developed, managed, and operated most large dams, reservoirs, diversions, pipelines, and irrigation projects across the region. In addition, because many irrigation projects originated under Reclamation, the laws and policies governing these projects have significant implications for the conditions that govern water storage and transfers. Uncertainties related to these rights have broad impacts across the West. The federal government has a key role to play in assisting the development of water markets through its leadership on water issues, facilitating large-scale planning and interstate cooperation, developing critical data and information, modernizing the management of existing federal projects, and reforming existing federal agricultural policies.

Reclamation has emerged as a leader in efforts to reform Western water management, confront growing imbalances in water supply and demand, face the realities and uncertainties of climate change, address past environmental harms, and engage in efforts to adapt to increased uncertainty and manage water-supply risk. Most importantly, Reclamation's role has been growing as an effective facilitator of interstate communication, the development of new interstate agreements, and stakeholder-driven cooperative efforts on Western water management.

The 2012 Colorado River Basin Water Supply and Demand Study (Bureau of Reclamation 2012), discussed earlier, demonstrates this facilitative leadership role, bringing together a diverse set of stakeholders across seven Western states to develop a common understanding of water resource challenges and potential multistate solutions, including water banking and other market-driven solutions. Reclamation is currently undertaking similar studies in twenty-two river basins across the West—providing a venue for interstate and inter-stakeholder planning, supported by extensive federal technical expertise, in which exploration of both traditional water management solutions and new potential market-based solutions can occur.

In many parts of the West, water management is impeded because water diversions are only estimated and are not measured, or are not reported at all. A critical aspect of the Western water crisis is the lack of reliable information about the quantity of water available and actual water use, which hampers both effective water management and the development of water markets. As one step in the direction of improved data, the Bureau of Reclamation should require as a condition in new contracts or renewal of existing contracts that contractors have meters or other effective measurement devices to measure the quantity of surface water diverted or groundwater pumped. More broadly, the federal government has an important role to play in supporting and coordinating state and local efforts to generate accurate data with regard to stream flows and diversions, water quality and salinity levels, groundwater pumping, and the ultimate uses of water in rural and urban areas.

Reclamation's vast infrastructure of dams and canals will also ensure it has a critical role in hindering or facilitating transfers. Much of this water-related infrastructure is decades old, with some of it going back a century. As Reclamation prepares to modernize its infrastructure, the enormous costs involved will guarantee active engagement by members of Congress, federal agencies, state governments, water users, and the environmental community.

As Bureau of Reclamation contracts come up for renewal, federal courts have recently insisted that Reclamation take a fresh look at environmental issues that were not on the radar in the mid-twentieth century when the Bureau built much of its infrastructure.[10] The enormous infusion of new funds to rehabilitate aging dams and canals will create an opportunity for Congress to revisit and modify some of the subsidy assumptions built into early contracts and to address whether and how contractors will be able to transfer rights to Reclamation project water.

The federal government could also provide increased certainty to districts and farmers by altering its approach to the administration of contracts and water rights in order to provide a stable platform for trading. Building on existing efforts, Reclamation could heighten its impact on water management through pro-conservation regulations and programs. For example, Reclamation could encourage, within its jurisdiction, rules and regulations that require irrigation districts to allow individual farmers an opportunity to benefit from conserving water; it could also undertake pilot projects to test the viability of conservation approaches (e.g., using drip irrigation to grow alfalfa or suspending summertime irrigation of alfalfa). Congress could also play a role by authorizing water transfers from Reclamation projects by individual farmers and not just by irrigation districts. In 1992, Congress took this approach in the Central Valley Project Improvement Act (Thompson 1993). As a step toward broader water marketing, Congress should require irrigation districts to allow farmers to transfer a portion of the water they use.

Federal agricultural policies, including the substantial subsidies and price supports afforded to many agricultural users of water, also have a significant impact on Western water. In many cases these policies have encouraged less-efficient agricultural production and higher water use, and have served as a brake on water marketing. A 2006 Congressional Budget Office (CBO) report documented how these policies discourage the reallocation of water (CBO 2006). Any major effort at water reallocation to meet the uncertainties and growing water demands will necessitate a reexamination of current federal agricultural policies. For example, federal support for dairy producers, such as by purchasing surplus dairy products when prices are low, encourages the use of water to grow alfalfa. Through price supports for sugar beets, the federal government similarly encourages Western farmers to grow one of the most water-intensive crops (CBO 2006). The federal Environmental Quality Incentives Program, which originally aimed to conserve water by financing more-efficient irrigation systems, has reportedly led to increases in water use as farmers irrigate more acres with the resulting conserved water (Fereday and Creamer 2010; Nixon 2013).

The importance of these and other potential federal roles as a leader of change in Western water is difficult to overstate. While Western water management has been and will remain the province of state governments, states are also subject to powerful political pressure from an ever-changing constellation of interests—sometimes farm groups, sometimes municipal interests, sometimes environmental interests—to take steps that inhibit flexibility in water management that would allow for water trading. These pressures are particularly strong in the interstate context, where states are often reluctant to allow more water to leave the state. Interstate cooperation has generally been difficult to achieve without strong federal facilitation (and, occasionally, the threat of federal intervention in the event that interstate cooperation cannot be achieved). Continuing federal leadership will be essential to encouraging more-flexible water management, reducing barriers to trade, and developing essential market institutions.

Chapter 4. Questions and Concerns

Won't water marketing hurt American farmers and rural communities?

Farmers are savvy businesspeople who understand the opportunities markets provide. If a housing developer approaches a farmer with an offer to purchase water rights, the farmer has four options. First, the farmer might decline the offer, whether because the offered price is too low or for any other reason. Second, the farmer might look around and notice that the forty acres behind the barn have mostly clay soil, with a low crop yield in bushels per acre. The farmer might decide to fallow this land and sell the conserved water to the developer for profit. Third, the farmer might sell the conserved water and use the proceeds to modernize the farm's irrigation infrastructure. In the case of one rancher in Oregon, $700,000 offered by the Oregon Water Trust allowed a ranching family to install a center-pivot irrigation system. The new system enabled that family to grow just as much alfalfa with less water—a win-win solution (Glennon 2009).

Finally, the farmer may adjust the crop mix by entering higher-value niche markets or identifying new growing techniques. One niche market, baby lettuce, has boomed in popularity over the past decade. Farmers who shift from iceberg lettuce to baby lettuce and spring mixes generate higher revenues with lower labor costs and lower water consumption. In California's Coachella Valley, some farmers have switched from flood to drip irrigation, and have moved from growing alfalfa to growing higher-value dates, fruits, and vegetables. Their income has risen as their water use has dropped (Glennon 2009).

Farmers have considerable experience in making adjustments, as weather and market conditions for inputs and crops shift every year and over time. Water markets offer farmers increased flexibility to look after their own economic interests.

It is true that many water transfers will involve moving water from agriculture to other uses, as discussed earlier. However, this reduction need not come at the expense of the value of farm output, or at the expense of rural communities, particularly if it is accomplished by modernizing agricultural infrastructure. For example, almost half of the 60 million irrigated acres in the United States are watered by flood irrigation, despite its relative inefficiency. By contrast, the most efficient method of irrigation—micro-irrigation, which emits a precise quantity of water to each plant or tree—is used on only 6 percent of the West's irrigated fields (Sabo and Glennon 2013). Recent experiments with the installation of subsurface drip irrigation systems on alfalfa farms suggest that these systems can result in both higher yields and lower water use. In every Western state there are more acres of irrigated alfalfa than any other crop; as such, the water savings from scaling up subsurface drip irrigation could potentially be enormous (Blake 2009).

> Water markets offer farmers increased flexibility to look after their own economic interests.

Not surprisingly, the farming areas that have achieved the greatest efficiency gains with reduced water typically grow the highest-value crops (such as the lettuce fields of Yuma or the citrus and nuts of Central California), or have been subject to regulatory requirements that have mandated specific levels of agricultural water-use efficiency (such as in Central Arizona). Were states to make short-term leasing options readily available as we have proposed, these options would drive municipal and industrial users to help fund irrigation modernization in exchange for use of the water conserved—allowing farming communities to remain vibrant as they grow the same (or greater) amounts of product with less water.

Does water marketing transform water—a resource essential to life—into just another commodity?

Some critics of water marketing believe that it values water as just another marketable commodity, no different from oil and lumber. But in the United States water is already treated as an economic good, though in an incomplete and disjointed manner. Ever since the 1850s, with the development of the prior appropriation system, states have recognized rights to the use of water. These use rights are property rights; in some states they are even conveyed by a deed, just as is the sale of one's home. Most U.S. households and firms pay a monetary bill for the water they consume.

Rather than decrying a system already in place, we should employ it to help us solve the water crisis. Treating water as a property right but failing to clearly define that right got us into the crisis in the first place. By allowing limitless straws in the milkshake glass, we have encouraged grotesque overuse of a critical public resource. It is a classic example of the tragedy of the commons: because no one had exclusive rights to the resource, everyone had an incentive to exploit it. If we strengthen the use rights that farmers, industry, and others already have in water by permitting them to sell or lease their water, we create incentives to utilize the resource more productively.

What about environmental and cultural values linked to water?

Water has economic value but it is also a public resource with important cultural, spiritual, and environmental values. The state should play a role in protecting these noneconomic values. Securing water for high-value urban projects should not come at the expense of those other interests, and continued state and federal oversight and regulation of water will remain critical to protecting those values.

The current system of granting property rights to water and allocating water supplies often does too little to protect these noneconomic values. During the early stages of water infrastructure development in the West, ecological values received scant attention. Consequently, few rivers have protections for minimum flow levels. Most water infrastructure projects, particularly dams, were not designed to incorporate the protection of environmental or ecosystem values into their operation; where they are included, they are typically included only to the extent necessary to meet specific regulatory objectives, such as the protection of an endangered species. As a result, ecological values face significant exposure to water-supply risk within Western water management systems, an exposure that peaks during dry conditions.

A greater use of clear property rights and water trading can benefit the environment by reducing pressure to build more dams, divert more surface water, and drill new wells in order to meet the needs of growing populations, agriculture, and industry. In the absence of more-flexible approaches to managing demand and the risk of disrupted water supplies, growth will continue to drive these environmentally harmful alternatives.

Environmental interests can also potentially use market transactions to create direct environmental benefits through the use of water trusts and similar institutions. As noted above, water trusts have successfully purchased or leased water from ranchers and farmers in many Western states to secure flows for critical reaches of rivers. Environmentally conscious landowners have partnered with the Nature Conservancy in hundreds of transactions that have protected sensitive streams and rivers.

In order for water trusts to work at scale, however, water trusts will need access to consistent, substantial revenue streams to allow for the purchase of in-stream rights and other environmentally beneficial water transactions. These funds cannot realistically be derived from charitable sources; it is neither feasible nor desirable to place the entire burden of protecting critical Western ecosystems on nonprofit environmental organizations. Thus, making water markets work for the environment will require not just rules to protect critical resources, but also the dedication of public funds to meet environmental needs. Australia, for example, is known worldwide for its strong support of water markets. Less well known is that most of the transfers have been government-funded acquisitions of agricultural water rights, which the Commonwealth then dedicated to in-stream flows in the Murray-Darling Basin. The Commonwealth spent between $5 billion and $6 billion retiring lands, fallowing fields, lining canals, and modernizing irrigation systems (Grafton et al. 2011).

The West has a proud social, cultural, and environmental heritage built on the availability of secure supplies of water, local control over community destiny, and the preservation of agricultural and ranching enterprises, public lands and resources, and rural and urban quality of life. Preservation of that heritage is a worthy end in itself. However, the growing water crisis in the West also fundamentally threatens those same values. Faithful to that heritage, market-oriented reforms will encourage conservation, stewardship, and reallocation.

Won't water marketing just allow historical users to reap windfall profits?

Some people object to the idea that farmers who paid nothing for the right to use water under the prior appropriation or reasonable use doctrines should be able to turn around and sell the water for a huge profit. This concern is particularly acute given that tens of thousands of Western farmers and ranchers receive water through historically subsidized Bureau of Reclamation irrigation projects. The federal government built the infrastructure and then asked the beneficiaries to repay only a fraction of the costs, often in the form of zero-interest loans stretched out over fifty years. The government, some argue, should reap the benefit from its largesse, rather than allow farmers and ranchers to realize windfall profits.

From a fairness standpoint, this argument has some merit, but it is worth remembering that many of the original recipients of the windfall are long gone. Subsequent purchasers of lands irrigated by those projects paid higher prices because of the value of the water subsidy included with the purchase. It is impossible to turn back the clock and try to claw back the value of water contracts given many decades ago. But whatever the philosophical merits of trying to go beyond voluntary transactions and seize water rights back from farmers at below-market rates, such an approach would create a legal and political snarl that would last for decades.

The practical question for the present is how to deal with the facts on the ground. If existing water rights holders cannot profit from leasing or selling water, which they have the legal rights to use, they will keep using that water to grow crops—and in some cases, relatively water-intensive, low-value crops. It is that simple. If we want to encourage agricultural producers to shift away from water-hungry, low-value crops, we must give them an incentive to do so. And that incentive is money. Given a choice between allowing farmers and ranchers to profit from the lease or sale of water rights on the one hand, and incentivizing them to continue to use large quantities of water to grow a low-value crop on the other, we think the choice is easy.

Where water is transferred for urban use, the cities that purchase water can spread the costs across a significant economic base, including the developers and industry that will benefit most from new supplies. Our focus should be on the current ownership and value of the water, not on how we might have preferred water rights law to have evolved in the past, nor on what the farmers originally paid for it.

Chapter 5. Conclusion

The management of water has shaped the physical, cultural, economic, and ecological landscape of the American West. More than a century of human effort and large-scale public investment has produced a system of water infrastructure and water delivery that rivals any in the world in its breadth and scope. That system is now in crisis. Yet many of us—especially those of us who live in urban areas—scarcely think about water.

Expanding water trading can help us to change the use of water in the West. As impressive as our water infrastructure may be, over the decades, water management in the West has also created perverse economic and legal incentives that have led to the overdraft of critical groundwater reserves and depleted reservoirs, and that have promoted the overallocation of Western rivers and streams.

Some farming regions have made enormous investments in efficiency, vastly increasing yields on the same or smaller supplies; some cities have aggressively embraced water conservation, having doubled or tripled their populations without increasing their water use. Others have not made investments in efficiency or commitments to conservation, and have little incentive to do so. Some Western farms and cities are facing substantial shortfalls, even as others have abundant, high-priority supplies.

This growing tension is reflected in the substantial and increasing disparities in price for water supplies that exist between and among urban and agricultural users—a tension maintained in part by the legal and institutional rules governing the movement of water. Yet even as we restrict water trade, we support broad and open trade in the commodities produced with water. It seems perverse that farmers in California use so much water to grow alfalfa for export to China, the United Arab Emirates, and Japan, even as the state struggles through the worst drought in memory.

Don't get us wrong: We are not opposed to using water to produce crops for the agricultural export market. The United States, after all, is the largest indirect exporter of water on the planet. This export is mostly in the form of water embedded in wheat, corn, and soybeans. But we would like our farmers—for example, alfalfa farmers who often use large volumes of water to produce extra cuttings in the heat of summer—to have the option to use less water and to sell or lease their surplus water to protect thirsty cities, high-value permanent crops endangered by drought, and job-creating industries.

Water trading can facilitate the reallocation of water to meet the demands of changing economies and growing populations. It can play a vital role in encouraging conservation and stewardship of water supplies in a way that can address cultural, social, and environmental priorities. It can facilitate building a structure for managing the ever-increasing risks of greater variability in water, including through methods such as insurance contracts, hedging tools, water banking, and other mechanisms. Deploying market tools in the allocation of water can help us to overcome the growing fragility and vulnerability of the water management institutions and infrastructure in the American West.

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In 2010, the Society of Environmental Journalists gave *Unquenchable* a Rachel Carson Book Award for Reporting on the Environment, and *Trout* magazine gave it an Honorable Mention in its list of "Must-Have Books" ever published on the environment.

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Endnotes

1. An acre-foot of water is the amount of water it takes to cover an acre of land to the depth of 12 inches, roughly 325,000 gallons.
2. One of the world's largest aquifers, the Ogallala Aquifer underlies portions of eight states: Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming.
3. This figure comes from the U.S. Geological Survey's "Estimated Use of Water in the United States in 1995" (Solley, Pierce, and Perlman 1998). The Survey publishes this estimate every five years. The 1995 report was the last one in which the Survey calculated the consumptive use of water in agriculture. According to the 1995 estimate, nationwide consumption of water was approximately 100 billion gallons per day (BGD). Irrigation consumed 81.3 BGD and livestock consumed another 3.2 BGD, for a total of 84.5 percent of water consumed. In contrast, nationwide domestic consumption in 1995 was 6.7 BGD, commercial was 1.3 BGD, and industrial was 0.7 BGD, for a total of 8.7 BGD (ibid.). More-recent U.S. Department of Agriculture estimates conclude that agriculture consumes more than 80 percent of the nation's water generally, and more than 90 percent in many Western states (USDA 2008a, 2008b).
4. In most states, a sale or conveyance of a water right in connection with the property on which it is used—which does not involve a change in the place or purpose of use—is relatively simple to process.
5. An alternative and relatively similar approach used in other jurisdictions, most notably in Australia, has also demonstrated that allowing the separation or unbundling of water entitlements from land is an important reform that can facilitate water trade (Grafton et al. 2011).
6. High Plains A&M, LLC v. Southeastern Colorado Water Conservancy District, Supreme Court of Colorado, 120 P.3d 710 (2005).
7. Southeastern Colorado Water Conservancy District v. Shelton Farms, Inc., 529 P.2d 1321 (Sup. Ct. of Colorado, 1974).
8. This new market was possible because, among Western states, New Mexico has some of the most precisely defined water rights, which assists in the operation of water markets.
9. Edwards Aquifer Authority v. Day, Supreme Court of Texas, 369 S.W.3d 814 (2012).
10. Natural Resources Defense Council v. Jewell, F.3d (9th Cir. en banc) (April 16, 2014).

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Highlights

Peter Culp of Squire Patton Boggs, Robert Glennon of the University of Arizona, and Gary Libecap of the University of California, Santa Barbara, propose the establishment and use of market mechanisms to encourage reallocation and trading of water resources and to provide new tools for risk management. Together, the reforms would build resilience into our country's water management systems and mitigate the water-supply challenges that plague many areas of the West.

The Proposal

Reform legal rules that discourage water trading to enable short-term water transfers. Western states would remove or provide exceptions to a number of legal doctrines in order to authorize simple, short-term water transfers between parties.

Create basic market institutions to facilitate trading of water. Trading platforms, such as water banks, would promote longer-term water transactions and transfers and allow markets to operate at a number of scales, such as within regions or within the boundaries of urban areas or agricultural districts.

Use risk mitigation strategies to enhance system reliability. The use of market-driven risk management strategies would address growing variability and uncertainty in water supplies. These tools include the use of dry-year option contracts to provide for water sharing in the face of shortages, and water trusts to protect the environment and limit supply risks. New reservoir management strategies that allow for market-driven use of storage would build additional resilience into water management systems.

Protect groundwater resources. States would better regulate the use of groundwater, including monitoring and limiting use to ensure sustainability, in order to preserve essential groundwater reserves, protect against environmental damages, and support the development of effective markets.

Continue and expand federal leadership. Strong federal leadership, from both Congress and the Bureau of Reclamation, would help markets work at scale and promote cooperation between states and agencies in water management.

Benefits

The deployment of market tools in the water sector could help mitigate the Western water crisis by facilitating the reallocation of water to meet the demands of changing economies and growing populations. Market mechanisms can also play an important role in encouraging conservation and stewardship of water supplies in a way that can address economic and ecological priorities. Overall, market tools would help overcome the increasing fragility and vulnerability of the water management institutions and infrastructure in the West.

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