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Water, Agriculture, and Drought in the West Under Changing Climate and Policy Regimes

ABSTRACT

Agriculture is the largest water user in the West, and it will play a central role in balancing water supplies with competing water demands in light of climate change. Water resources that are already over allocated face competing demands from growing urban populations, unresolved tribal water claims, and for maintenance of riparian habitats. While many believe we can meet these demands by reallocating water from agriculture, climate change complicates this calculus. Warmer temperatures and longer droughts will reduce regional water supplies and increase agricultural water demands, making transfers more costly. Hydrological-economic modeling studies suggest agricultural water use will decline, leaving urban use relatively unchanged. Although this agriculture-to-urban reallocation of water is often treated primarily as an engineering problem, many legal and institutional barriers exist to large-scale water transfers. Technological fixes to conserve and transfer agricultural water to other uses will likely fail to facilitate climate adaptation unless changes in water management institutions, policies, and economic incentives accompany those technological fixes.

I. INTRODUCTION

This article is motivated by two recent events. The first is the 2014 publication of the Third National Climate Assessment by the U.S. Global Change Research Program (USGCRP).[1] The Global Change Research Act of 1990 requires the Federal Coordinating Council on Science, Engineering, and Technology, through the USGCRP, to provide the President and Congress with a comprehensive report every four years. The Act calls for an Assessment that:

> integrates, evaluates, and interprets the findings of the Program and discusses the scientific uncertainties associated with

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[1] CLIMATE CHANGE IMPACTS IN THE UNITED STATES: THE THIRD NATIONAL CLIMATE ASSESSMENT (Jerry M. Melillo, Terese Richmond & Gary W. Yohe eds., U.S. Global Change Research Program, 2014).

> such findings; analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources . . . and projects major trends for the subsequent 25 to 100 years.[2]

The Assessment summarizes the state of scientific knowledge and uncertainties regarding climate change by economic sector and region. The Assessment uses information and analysis from a number of regional technical assessments. This article focuses on the Assessment's implications for the agricultural sector in the Southwest United States.[3] The technical assessment for the Southwest considered the substantial body of research conducted over the past five to six years on climate change implications for agriculture and water resources.[4] A review of this consolidated research identifies recurring findings, which, taken together provide technological opportunities and institutional challenges for adapting to climate change in the Southwest.

The second motivating event was the passage of the 2014 Farm Bill: The Agricultural Act of 2014 (P.L. 113-79).[5] As with previous farm bills, the 2014 Act suspends permanent price support authority under the Agricultural Adjustment Act of 1938 and Agricultural Adjustment Act of 1949 until the program authority of the current act expires (in this case in 2018).[6] If Congress had not passed this new farm bill, U.S. farm programs would have reverted to those under Depression era and World War II

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[2] Scientific Assessment, 15 U.S.C. § 2936 (2012).

[3] The Assessment defines the Southwest to include California, Nevada, Utah, Arizona, New Mexico and Colorado. Gregg Garfin & Angela Jardine, *Overview*, *in* ASSESSMENT OF CLIMATE CHANGE IN THE SOUTHWEST UNITED STATES: A REPORT PREPARED FOR THE NATIONAL CLIMATE ASSESSMENT 21, 22–23 (Gregg Garfin, Angela Jardine, Robert Merideth, Mary Black & Sarah LeRoy eds., Washington, DC, Island Press, 2013).

[4] For agriculture and ranching effects, see George B. Frisvold, et al., *Agriculture and Ranching*, *in* ASSESSMENT OF CLIMATE CHANGE IN THE SOUTHWEST UNITED STATES: A REPORT PREPARED FOR THE NATIONAL CLIMATE ASSESSMENT 218 (Gregg Garfin, Angela Jardine, Robert Merideth, Mary Black & Sarah LeRoy eds., Washington, DC, Island Press, 2013). For water, see Bradley Udall, *Water: Impacts, Risks, and Adaptation*, *in* ASSESSMENT OF CLIMATE CHANGE IN THE SOUTHWEST UNITED STATES: A REPORT PREPARED FOR THE NATIONAL CLIMATE ASSESSMENT 197 (Gregg Garfin, Angela Jardine, Robert Merideth, Mary Black & Sarah LeRoy eds., Washington, DC, Island Press, 2013). Other chapters of the report considered effects on Indian tribes, border communities, natural ecosystems, energy, transportation, coastal areas, urban areas, and human health.

[5] House and Senate conferees reported out a conference agreement on January 27, 2014. The full House and Senate approved the agreement on January 29 and February 4. The President signed the bill into law on February 7, 2014. The Agricultural Act of 2014, Pub L. No. 113-79, 128 Stat. 649.

[6] RALPH M. CHITE, THE 2014 FARM BILL (P.L. 113-79): SUMMARY AND SIDE-BY-SIDE 6 (2014).

legislation.[7] The new Farm Bill eliminates annual, lump-sum payments (called direct payments) to farmers and "counter-cyclical" payments, which provide farmers of select program crops with additional payments when market prices fall below target levels. In their place, the law establishes a permanent disaster assistance program and greatly expands crop insurance programs. Earlier disaster assistance programs had been criticized for encouraging agricultural production in areas prone to risks, including climate variability.[8] Federally subsidized multi-peril crop insurance, delivered by private insurers, was intended to replace *ad hoc* disaster payments.[9] Disaster assistance payments continue, however, despite the fact that the share of acres covered by crop insurance has expanded greatly since 1994.[10] Crop insurance, moreover, sustains criticisms similar to critiques for disaster assistance payments. Such criticisms include that crop insurance encourages farmers to plant acreage in risky production environments and creates economic disincentives to limit production losses from climate variability and other factors.[11] The new Farm Bill may consequently continue institutional barriers to technocratic opportunities to adapt to climate change.

This article begins with an overview of agricultural production and water use in the Southwest, highlighting how each sector will be affected by, and respond to, climate change. Second, the article considers

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[7] The 2008 farm bill expired in 2012, but the 112th Congress extended the law leaving consideration of a new farm bill to the 113th Congress. American Taxpayer Relief Act of 2012, Pub. L. No. 112-240, 126 Stat. 2313; *see* CHITE, *supra* note 6, at 2.

[8] Bruce L. Gardner, *Risks Created by Policy in Agriculture*, *in* A COMPREHENSIVE ASSESSMENT OF THE ROLE OF RISK IN U.S. AGRICULTURE 489–510 (Richard E. Rust & Rulon D. Pope eds., Boston, Kluwer Academic Publishers, 2002); U.S. GOV'T ACCOUNTING OFFICE, DISASTER ASSISTANCE: CROP INSURANCE CAN PROVIDE ASSISTANCE MORE EFFECTIVELY THAN OTHER PROGRAMS 3 (Washington, DC, USGAO, 1989); Vincent H. Smith & Myles Watts, *The New Standing Disaster Program: A SURE Invitation to Moral Hazard Behavior*, 32 APPLIED ECON. PERSP. AND POL'Y 154, 154–69 (2010).

[9] Robert Dismukes & Joseph Glauber, *Why Hasn't Crop Insurance Eliminated Disaster Assistance?*, AMBER WAVES (June 1, 2005), http://www.ers.usda.gov/amber-waves/2005-june/why-hasnt-crop-insurance-eliminated-disaster-assistance.aspx#.VQ5XsMJ0yM9; Brian Davern Wright, *Multiple Peril Crop Insurance*, 29 CHOICES 1, 2–3, (3rd Qtr. 2014), http://www.choicesmagazine.org/choices-magazine/theme-articles/3rd-quarter-2014/multiple-peril-crop-insurance.

[10] Dismukes & Glauber, *supra* note 9.

[11] DANIEL A. SUMNER & CARL ZULAUF, ECONOMIC AND ENVIRONMENTAL EFFECTS OF AGRICULTURAL INSURANCE PROGRAMS (2012); Jeffrey T. LaFrance, Jason Shimshack & Steven Wu, *Subsidized Crop Insurance and the Extensive Margin* (Dep't of Agric. and Resource Econ. and Policy, Univ. of Cal., Working Paper No. 912, 2000); Ruben N. Lubowski, Shawn Bucholtz, Roger Claassen, Michael Roberts, Joseph Cooper, Anna Gueorguieva & Robert Johansson, U.S. DEP'T OF AGRIC. ECON. RESEARCH SERV., ECON. RESEARCH REPORT NO. 25, ENVIRONMENTAL EFFECTS OF AGRICULTURAL LAND-USE CHANGE: THE ROLE OF ECONOMICS AND POLICY (2006).

the central role of agriculture to southwest regional adaptation to climate change. Most studies and projections envision agriculture making large adjustments in water use, leaving urban water users relatively unaffected. Policy makers often treat reallocating water across sectors—from agriculture to urban or environmental uses—or across regions as largely an engineering and infrastructure problem. Such technocratic solutions often ignore complexities in water rights and allocation mechanisms and these approaches are unlikely to succeed unless they are accompanied by institutional change.

In light of these challenges and general solutions, the third part of the article considers different national initiatives to influence farm level adaptations to drought and climate change. This section discusses the potential to improve irrigation technologies and information systems to aid adaptation. The section concludes that these technological fixes suffer from implementation challenges, which can only be addressed by changing institutions, policies, and economic incentives to encourage adaptation.

Fourth, the article reviews two other programs included in the 2014 Farm Bill: agricultural disaster assistance and crop insurance. There is a real danger that, even as other solutions in the Farm Bill encourage adaptation, these programs create economic incentives to encourage risky behavior. This occurs if federal programs, despite providing farmers with technologies and information to adapt to climate variability, provide them with generous payments when they do not adapt.

II. SOUTHWESTERN AGRICULTURE AND WATER SUPPLIES

The Southwest region accounts for more than half of U.S. production of high-value specialty crops (fruits, vegetables, and nuts).[12] Specialty crops account for a large share of total agricultural sales across the southwest, especially in California (Figure 1). Other areas where specialty crops are important include southwestern Arizona, Colorado's San Luis Valley, and New Mexico's chili- and pecan-growing areas.[13] Major field crops include cotton in California, Arizona, and New Mexico; durum wheat in southern California and Arizona; winter wheat in Colo-

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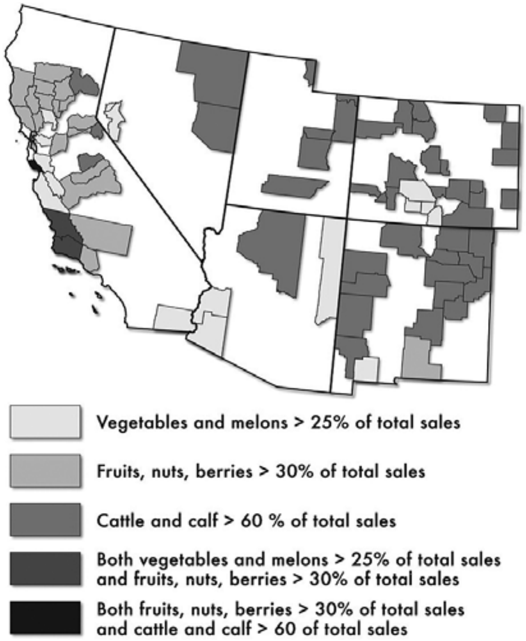
[12] U.S. DEP'T OF AGRIC., 2012 CENSUS VOLUME 1, CHAPTER 2: STATE LEVEL DATA, *available at* http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_2_US_State_Level/ (last visited Mar. 27, 2015) (follow Table 2: Market Value of Agricultural Products Sold Including Direct Sales: 2012 and 2007, Pages 269–70, 273–74, 276). The categories include vegetables, melons, potatoes, and sweet potatoes and fruits, tree nuts, and berries.

[13] U.S. DEP'T OF AGRIC., AC-07-A-51, 2007 CENSUS OF AGRICULTURE UNITED STATES SUMMARY AND STATE DATA 303, 304, 308, 508, 542, 555 (2009).

rado and California; and corn in eastern Colorado. Thus, the region is characterized by a great diversity of crops, with field crops, which fetch relatively low market prices, grown in proximity to high-value specialty crops.[14] As will be discussed below, this diversified cropping pattern conditions how agriculture will respond to water shortages and climate change.

Figure 1. Agricultural sales by county[15]



Cattle ranches and dairies are also economically important to the region. Cattle account for most of the agricultural sales in many New Mexico and Colorado counties (Figure 1).[16] Cattle ranches rely on rain-fed forage on grazing lands, making them especially sensitive to climate variability. Much acreage and irrigation water is devoted to alfalfa, other

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[14] *Id.* at 447, 448, 452, 465, 466, 475, 476, 488.

[15] U.S. Dep't of Agric., 07-M021, 07-M022, 07-M029, 2007, Census Agriculture Atlas Maps: Economics (2013), *available at* http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Ag_Atlas_Maps/Economics/.

[16] *Id.* Counties not shown in Figure 1 did not meet the minimum sales percentages listed (i.e. vegetable and melon sales were less than 25 percent of total county sales, fruit, nut, and berry sales were less than 30 percent of county sales, and cattle and calf sales were less than 60 percent of total count sales). Thus, counties not shown tend to have more diversified production patterns, at least at the county level.

hay, corn silage, and irrigated pastures that provide feed for the region's dairies as well as supplemental cattle feed.[17]

Irrigation is critical for agriculture throughout the region. Excluding Colorado, which has significant dryland wheat production, more than 97 percent of the region's harvested cropland is irrigated.[18] Irrigated crops account for an even larger share of sales revenues.[19] Agricultural water use accounted for 81 percent of all the Southwest's freshwater withdrawals in 2005.[20] Consequently, small changes in agricultural water use significantly alter the share of water available for households, industrial use, and riparian ecosystems. For example, if agricultural water withdrawals fell from 79 percent to 71 percent of total water withdrawals (a 10 percent reduction in agricultural water use), this volume of water would be equivalent to a 38 percent increase in water withdrawals by all other sources combined.

The Southwest distributes water for use across the region through extensive surface water infrastructure, such as dams, reservoirs, canals, pipelines, and pumping stations. The U.S. Bureau of Reclamation, state water agencies, and local irrigation districts manage this infrastructure.[21] These systems not only capture and store vast quantities of water, they also transport it over large distances.[22] This means that for many water

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[17] U.S. DEP'T OF AGRIC., *supra* note 15, 07-M020; U.S. DEP'T OF AGRIC., 07-M209, 2007 CENSUS AGRICULTURE ATLAS MAPS: CROPS AND PLANTS (2013), *available at* http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Ag_Atlas_Maps/Crops_and_Plants/; U.S. DEP'T OF AGRIC., AC-07-SS-1, 2007 CENSUS OF AGRICULTURE: FARM AND RANCH IRRIGATION SURVEY 148 (2009). The 2008 Farm and Ranch Irrigation Survey (FRIS) is a supplement to 2007 Census of Agriculture. It expands upon the basic irrigation data collected in the Census of Agriculture. Irrigated farms surveyed in the 2007 Census of Agriculture serve as the basis of the sampling frame for FRIS, which was conducted in 2008.

[18] That is, irrigated harvested cropland as a share of total harvested cropland in California, Nevada, Arizona, Utah, and New Mexico combined. U.S. DEP'T OF AGRIC., CENSUS OF AGRICULTURE, IRRIGATION: 2012 AND 2007 (2012) at 236–37, 332–33, 339, *available at* http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_2_US_State_Level/st99_2_010_010.pdf.

[19] Noel Gollehon & William Quinby, *Irrigation in the American West: Area, Water and Economic Activity*, 16 INT'L J. WATER RES. DEV. 187 (2005).

[20] Agriculture includes irrigation, livestock watering, and aquaculture. U.S. GEOLOGICAL SURVEY, U.S. DEP'T OF THE INTERIOR, CIRCULAR 1344, ESTIMATED USE OF WATER IN THE UNITED STATES IN 2005 6, 24, 27 (2009), *available at* http://pubs.usgs.gov/circ/1344/pdf/c1344.pdf (Table 2B, Total water withdrawals by water-use category, 2005, in thousand acre-feet per year).

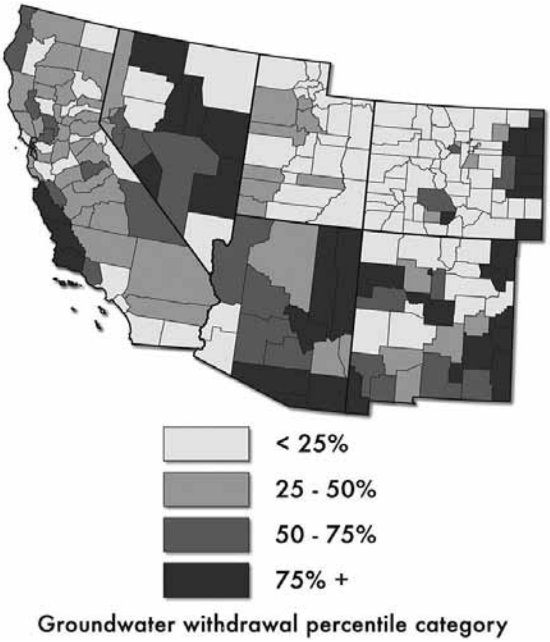
[21] BUREAU OF RECLAMATION, U.S. DEP'T OF THE INTERIOR, COLORADO RIVER INTERIM GUIDELINES FOR LOWER BASIN SHORTAGES AND COORDINATED OPERATIONS FOR LAKE POWELL AND LAKE MEAD (2007), *available at* http://www.usbr.gov/lc/region/programs/strategies/FEIS/.

[22] *Id.*

users, their water supplies depend on climate factors in distant jurisdictions. For example, surface water supplies available to agriculture in central Arizona depend on snowmelt from the Colorado Rocky Mountains.[23]

Not all agricultural areas have access to this extensive surface-water network, instead depending on groundwater for irrigation (Figure 2). Depletion of groundwater resources in these areas presents problems for irrigators, including increased costs of energy to pump the water higher to reach the surface. If groundwater levels fall sufficiently, irrigators may incur additional costs to lower pumps within the well, deepen wells, or dig replacement wells. From 1994 to 2008, depth-to-water for irrigation wells increased in all states but Nevada[24] (Figure 3).

Figure 2. Groundwater irrigation withdrawals as a share of total irrigation withdrawals[25]



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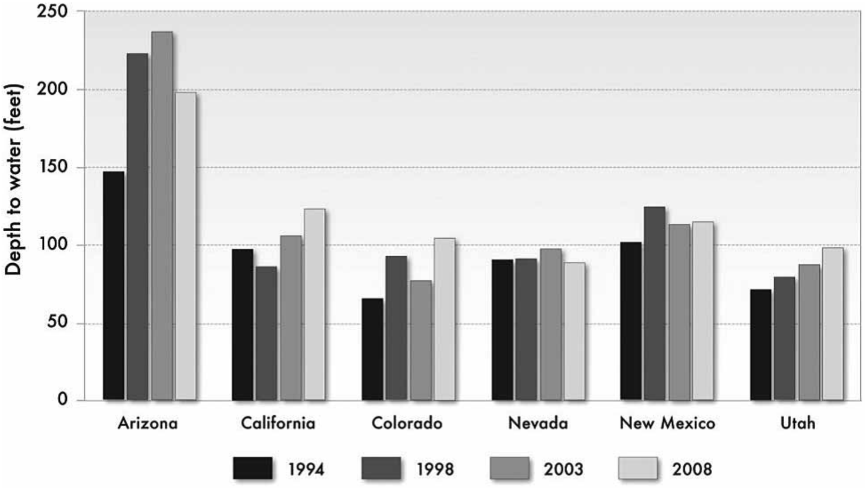
[23] *Id.* at 1-9, A-2, B-1.

[24] U.S. Dep't of Agric., *supra* note 15.

[25] Joan F. Kenny et al., U.S. Dep't of the Interior, U.S. Geological Survey Circular 1405, Estimated Use of Water in the United States in 2005 (Kay E. Hedrick ed., 2009), *available at* http://water.usgs.gov/watuse/data/2005/.

Figure 3. Depth to water of irrigation wells[26]



The current structure of agriculture is diverse. The region grows high value specialty crops and low value livestock feed. Most of the agriculture depends on surface water conveyance and storage, but some areas also rely on groundwater. Regardless, the vast majority of agriculture in the region depends on irrigation. As discussed in the next section, however, this structure will likely change as the cost of water increases.

III. HYDRO-ECONOMIC MODELS: THE ROLE OF AGRICULTURE IN BASIN-WIDE CLIMATE ADAPTATION

A number of studies predict likely results of climate change in the Southwest based on hydro-economic models. These studies combine hydrological models, which estimate levels and changes in water supplies, with economic models of water demands, including agricultural demands, and then predict how different areas of the Southwest may respond to different drought, water shortage, or climate-change scenarios.[27] They vary in the degree of model complexity and richness in capturing either hydrological or economic details. In general, these models find the least-cost response to water shortages given system constraints. As discussed below, a common finding of these studies is that

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[26] U.S. DEP'T OF AGRIC., *supra* note 15.

[27] Climate change scenarios may include changes in temperature, level and type of precipitation, and the timing of mountain snowmelt and runoff into lower elevation agricultural regions. Daniel R. Cayan et al., *Climate Change Scenarios for the California Region*, 87 CLIMATIC CHANGE S21, S22 (2008).

the agricultural sector makes large adjustments in water use, land use, and cropping patterns that allow urban and industrial water uses to remain largely unchanged.

Based on these simulations, agriculture would be the sector that alters its use of water the most to adapt to regional water shortages and protect municipal and industrial (M&I) uses. A study conducted by Harou et al. examined the effects of severe, sustained drought in California on agriculture and the rest of California's economy in 2020.[28] The model simulated allocation and storage of water to minimize costs of water scarcity and system operation.[29] The costs in the drought scenario were borne largely by agriculture, along with urban costs in Southern California, which limited costs to the state's overall economy.[30] Large differences in scarcity costs across sectors and regions created incentives to transfer water from lower-valued agricultural to higher-valued urban uses, where value is determined by user willingness to pay for additional water.[31] In the water market system, water use moved out of agriculture because it was higher valued in urban areas.

Predictions for climate change scenarios in 2050 show similar results. The Howitt et al. study, commissioned by the Sacramento California Climate Change Center, simulated the effects of changes in water availability and crop yields in California in 2050.[32] While statewide agricultural land use and water use were projected to decline by 20 percent and 21 percent, total urban water use fell by just 0.7 percent.[33] The Medellín-Azuara et al. study examined the consequences of various adaptation measures in California for 2050 in a dry-warming climate change scenario, making assumptions about baseline changes to water de-

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[28] Julien J. Harou et al., *Economic Consequences of Optimized Water Management for a Prolonged, Severe Drought in California*, 46 WATER RES. RESEARCH W05522 (2010). The study's drought simulations, based on records of paleo-climates, assumed streamflows that are 40 percent to 60 percent of the current mean flows, with no intervening year, are wet enough to fully replenish reservoirs. This drought scenario is similar to the effects under "dry forms" of climate warming, which are those with projected reductions in precipitation. *Id.* at 1.

[29] *Id.* at 4.

[30] *Id.* at 4–5.

[31] *Id.* at 6–8.

[32] Richard Howitt et al., Sacramento: California Climate Change Center, ESTIMATING THE ECONOMIC IMPACTS OF AGRICULTURAL YIELD RELATED CHANGES FOR CALIFORNIA FINAL REPORT CEC-500-2009-042-F 26 (2009), http://www.energy.ca.gov/2009publications/CEC-500-2009-042/CEC-500-2009-042-F.pdf.

[33] Richard Howitt et al. *Climate change, markets, and technology* 25(3) CHOICES 2–3 (2010).

mand.[34] The model allocated water to maximize net benefits of the state's water supply, given infrastructure and physical constraints, through water markets that implicitly allowed water to flow to higher-valued urban uses.[35] The model indicated that urban water users in Southern California would purchase water from central and Northern California. Agriculture in the Sacramento, San Joaquin, and Tulare basins would face large economic losses because water would be less available and crops would have lower yields.[36] Southern California agriculture would maintain senior water rights to the state's allocation of Colorado River water.[37] According to this study, water would both shift regionally, from Northern California to Southern California, and by use, from agriculture to urban.

Yet another study, Tanaka et al., combined climate scenarios for 2100 with economic and land use projections for California.[38] Climate scenarios were based on both wet and dry forms of climate warming.[39] Like the Medellín-Azuara et al. study, water flowed from lower-valued uses to higher-valued uses given hydrologic and conveyance constraints.[40] Dry warming scenarios presented the greatest challenges to California agriculture.[41] Modeled simulations projected the transfer of water from Southern California agricultural users to Southern California urban users.[42] Indeed, many of these transfers have since occurred.[43] Agricultural water users in the Central Valley, meanwhile, were the most vulnerable to dry warming under this simulation; under the driest scenarios, their water use declined by one-third.[44] Although Southern California agriculture may be somewhat insulated from water loss, these studies all demonstrate strong shifts to urban water use.

For the Upper Rio Grande Basin, Booker et al. examined the role of water transfers in mitigating costs of severe, sustained drought in

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[34] Josué Medellín-Azuara et al., *Adaptability and Adaptations of California's Water Supply System to Dry Climate Warming*, 87 (Suppl. 1) CLIMATIC CHANGES S75 (2008).

[35] *See id.* at S-82.

[36] *See id.* at S-81.

[37] *See id.*

[38] Stacy Tanaka et al., *Climate Warming and Water Management Adaptation for California*, 76 CLIMATIC CHANGE 361 (2006).

[39] *Id.* at 373. Changes in the model's seasonal water flows ranged from a 4.6-million-acre-foot (maf) increase to a 9.4 maf decrease. *Id.* at 369.

[40] *See id.* at 371–73.

[41] *See id.* at 373.

[42] *See id.* at 371–73.

[43] Tanaka, *supra* note 38, at 371.

[44] *Id.* at 381–83.

southern Colorado, through New Mexico, and into West Texas.[45] Their modeling framework was not based on a specific climate-change scenario, but considered droughts that reduced basin inflows to 75 percent and 50 percent of the long-term mean.[46] According to the scenario based on existing institutions, surface-water allocations did not transfer between different institutional users, such as cities and irrigation districts.[47] The cities of Albuquerque and El Paso shifted to more expensive groundwater sources instead of altering consumption. In contrast, agriculture accounted for the bulk of water-use reductions and economic losses.[48] Regardless of geographical idiosyncrasies, the studies all indicate that the agricultural sector will buffer urban users from water shocks. Agriculture, thus serves an important insurance function for other users as the climate begins to change.

Agriculture will also likely bear the largest costs of complying with environmental regulations, especially those that protect endangered aquatic species. A study by Ward et al., which modeled impacts of severe drought in the Upper Rio Grande Basin,[49] combined increasingly severe drought scenarios with minimum requirements for instream flows to protect endangered fish.[50] Agriculture, again, absorbed most of the shock in response to water shortages, but it also bore the greatest cost in response to environmental requirements.[51] Agriculture suffered losses both in terms of reduced water use and economic losses.[52] The largest absolute losses were in Colorado's San Luis Valley, which grows relatively high-value crops.[53] Similarly, the Harou et al. study[54] calculated costs of maintaining required environmental flows in California. It found these costs could be quite high, especially for the Sacramento-San Joaquin River Delta.[55] Dry warming scenarios in the Tanaka et al. study[56] also indicated substantially increased costs to agriculture (and other

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[45] *See* James F. Booker et. al., *Economic Impact of Alternative Policy Responses to Prolonged and Severe Drought in the Rio Grande Basin*, 41 WATER RES. RESEARCH W02026 (2005). The 1938 Rio Grande Compact governs water allocations between the three states. *Id.* at 12.

[46] *Id.* at 6. In 2002, inflows had already fallen to 37 percent of the annual mean. *Id.*

[47] *Id.* at 7.

[48] *Id.*

[49] *See* Frank Ward et al., *Economic Impacts of Federal Policy Responses to Drought in the Rio Grande Basin*, 42 WATER RES. RESEARCH W03420 (2006).

[50] *Id.* at 2.

[51] *Id.* at 8–10.

[52] *Id.*

[53] *Id.*

[54] Harou, *supra* note 28.

[55] *Id.*

[56] *See* Tanaka, *supra* note 38.

users) to maintain water supplies for environmental protection.[57] Thus agriculture not only bears the largest share of the costs of adjusting water use in the face of climate change, it also bears relatively more of the costs of water allocations to protect environmental resources.

Agriculture, however, has options. Although fallowing irrigated land is one response to drought, growers also have numerous lower-cost solutions. A recent U.S. Bureau of Reclamation's Final Environmental Impact Statement (EIS) for actions including coordinated operation of Lakes Powell and Mead assessed the regions in Arizona that would be most affected by fallowing during water shortages.[58] The study assumed the only adaptation mechanism available to agriculture was land fallowing.[59] The model fallowed land that grew crops providing the lowest returns per acre-foot of water. Fallowing occurred for alfalfa, durum wheat, and cotton, while high-value specialty crops remained in production. For most shortage scenarios, the bulk of shortage costs would be felt in central Arizona and in Mohave County in northwest Arizona.[60] Fallowing land provides one way to drive water to more cost-effective uses.

Other studies, however, identify alternatives to fallowing. Frisvold and Konyar simulated the impacts of reducing agricultural water supplies in Arizona, Colorado, Nevada, New Mexico, and Utah.[61] The model did not include potential barriers to transferring water across state lines or watersheds within a region, nor did it include urban sectors, but the model accounted for regional agricultural market connections to the broader U.S. and export markets.[62] The study concluded that agriculture could also adapt to water shortages by implementing deficit irrigation,[63] changing the crop mix, and changing input mix.[64] Water shortages to irrigated agriculture cost 75 percent less when farmers used a combination of these strategies compared to a scenario where farmers

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[57] *Id.* at 387–88.

[58] BUREAU OF RECLAMATION, *supra* note 21, at Appendix H: A.1–A.2.

[59] *Id.* at Appendix H: H-60.

[60] *See* BUREAU OF RECLAMATION, *supra* note 21, at Appendix H: H-13 to H-39.

[61] *See* George Frisvold & Kazim Konyar, *Less Water: How Will Agriculture in Southern Mountain States Adapt?*, 48 WATER RES. RESEARCH W05534 (2012).

[62] *Id.* at 3; *see supra* Figure 2.

[63] Rather than emphasizing maximizing yield (crop output per acre), deficit irrigation focuses more on achieving greater output per unit of water applied. The strategy can involve some sacrifice of yield, but can use less water. *See* Elias Fereres & Maria A. Soriano, *Deficit Irrigation for Reducing Agricultural Water Use*, 58 J. EXPERIMENTAL BOTANY 147 (2007).

[64] See MICHAEL COHEN ET AL., WATER TO SUPPLY THE LAND: IRRIGATED AGRICULTURE IN THE COLORADO RIVER BASIN (Pacific Institute 2013) for additional discussion of scope for using deficit irrigation and changing crop mixes to reduce water use in the Lower Colorado Basin. Changing input mix means substituting among different production inputs: land, labor, capital, fertilizers, agricultural chemicals, and energy.

only used land fallowing.[65] The Frisvold-Konyar study further indicated that agricultural output declined primarily for commodity crops, particularly cotton and alfalfa, with little change to high-value specialty crops.[66] Although the model treated the entire region in aggregate, the largest reductions came from crops grown in central Arizona,[67] which holds junior water rights to Colorado River water.[68] Crops grown in western Arizona were little affected.[69] With high-value crops and senior rights to Colorado River water,[70] western Arizona would remain a national center of specialty crop production. Model results also suggested there would be relatively large losses to livestock and dairy producers from reduced supplies and higher prices of alfalfa and feed grains.[71] However, by shifting to less water intensive crops and applying less water per acre on crops (especially lower valued crops) farmers can conserve water at far lower cost than through fallowing alone.

In the Howitt et al. study, California agricultural land use and water use were projected to decline by 20 percent and 21 percent, but total agricultural revenues fell by less: just 11 percent.[72] Howitt et al. assume that dairy production is unaffected by climate change and constrains their model to supply sufficient corn silage to dairies.[73] The model shows that production does not decline proportionally across other crops. Grape and orchard production falls by less than 11 percent. Production of field crops, cotton, rice, corn, and grains fall between 22 percent and 49 percent, while pasture production falls by more than 95 percent.[74] In Southern California agriculture, two factors reduced negative impacts to farmers: first, crop prices increased when production fell, and second, farmers shifted to high-value crops.[75] The greatest reductions in output were among field crops, with relatively less change among fruit and vegetable crops. Absent climate change, the Howitt et al. study predicts that agricultural revenues in California's Central Valley would increase by 42 percent by 2050. Under the dry-climate warming scenario, revenues would still grow, but by a lower, 26 percent.[76]

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[65] Frisvold & Konyar, *supra* note 61, at 10.

[66] *Id.* at 7.

[67] Frisvold & Konyar, *supra* note 61.

[68] CENTRAL ARIZONA PROJECT, COLORADO RIVER SHORTAGE 1 (Oct. 2014), *available at* http://www.cap-az.com/documents/planning/Shortage_Issue_Brief.pdf.

[69] Frisvold & Konyar, *supra* note 61, at 7–8.

[70] CENTRAL ARIZONA PROJECT, *supra* note 68, at 1.

[71] Frisvold & Konyar, *supra* note 61, at 10.

[72] Howitt et al. (2009), *supra* note 32; Howitt et al. (2010), *supra* note 33.

[73] Howitt et al. (2009), *supra* note 32, at 12.

[74] *Id.* at 17.

[75] *Id.* at 15.

[76] Howitt et al. (2010), *supra* note 33, at 4.

According to the Tanaka et al. model,[77] agricultural producers altered irrigation technology in response to water shortages.[78] While statewide agricultural water deliveries fell 24 percent and irrigated acreage fell 15 percent, agricultural income reduced only 6 percent.[79] Income fell less than water deliveries because farmers adapted by changing both irrigation technologies and crop mix.[80] Farmers produced fewer lower valued crops, while continuing to produce higher valued crops.[81]

Perhaps most importantly, water transfers may significantly reduce the costs of adjusting to water shortages under dry warming scenarios. In the Medellín-Azuara et al. study, grower losses would be at least partially compensated by revenues from water sales to urban areas.[82] Similarly, the Tanaka et al. study found that agricultural producers received some compensation from agricultural-to-urban water use transfers, although it was insufficient to compensate for all the costs of reduced water supplies.[83] Thus, agriculture stands to lose the most from water scarcity and to sacrifice the most so that other uses are maintained. It remains an open policy question whether and how agriculture-to-urban transfers can be structured to adequately compensate rural communities for losses from reduced water use.

Currently, however, many laws and procedures may restrict or create economic disincentives for the transfer of water across jurisdictions, watersheds, or state lines. These include case law and state laws governing transfer approval to protect third parties, ambiguous property rights, beneficial use provisions, laws governing use and transfer of salvaged water, area of origin protection, as well as public interest and public welfare clauses.[84] The Medellín-Azuara et al. simulation projected that statewide costs would rise substantially if water markets were geographically restricted.[85] The Booker study on the Upper Rio Grande Basin, suggests *potential* gains from expanded water trading.[86] It found that if trades were allowed between all users in New Mexico and Texas, then El Paso and Albuquerque would lease water from the Middle Rio Grande

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[77] Tanaka et al., *supra* note 38.

[78] *Id.* at 372.

[79] *Id.*

[80] *Id.*

[81] *Id.*

[82] Medellín-Azuara et al., *supra* note 34, at S81.

[83] Tanaka et al., *supra* note 38, at 371–73.

[84] Bonnie G. Colby, *Estimating the Value of Water in Alternative Uses*, 29 Nat. Resources J. 511, 511–27 (1989) (Economic impacts of water law, state law and water market development in the Southwest); *see* Jonathan H. Adler, *Water Marketing as an Adaptive Response to the Threat of Climate Change*, 31 HAMLINE L. REV. 730 (2008).

[85] Medellín-Azuara et. al., *supra* note 34, at S84.

[86] Booker et al., *supra* note 45.

Conservancy District (MRGCD) instead of pumping groundwater.[87] Interstate water trading reduced the total economic losses from drought by one-third.[88] Urban water use in Albuquerque and El Paso remain virtually unchanged.[89] The researchers pointed out, however, that there would be additional transaction costs associated with establishing and expanding water markets and for designing policy instruments to address third-party damages from transfers.[90] They also note existing institutional and legal impediments to trading water across state lines.[91] Even so, the studies suggest that water markets may be a valuable adaptation strategy for climate change.

The flexibility provided by water transfers would also depend on future investment in complementary infrastructure. Such investments to store and convey water could reduce negative effects of dry warming. Results from the Harou et al. study suggested California would greatly benefit from improving and expanding conveyance infrastructure to move water.[92] The study also found that under the most severe drought scenarios, the value of additional surface-water storage capacity falls to zero.[93] Similarly, under the driest warming scenarios in the Tanaka et al. study, expansion of storage infrastructure yielded few benefits, but expansion of conveyance systems yielded benefits in every year and, in some cases, every month of the year.[94] This is because, under dry warming scenarios, there would be less water stored in reservoirs.[95] In Southern California, the capacity of conveyance systems limits the extent to which the region can import more water. Thus, Southern California may also need to turn to further conservation, reuse, and desalination.[96] The Medellín-Azuara et al. study further indicated that the statewide water system could be better managed if California changed its rules for water storage and conjunctive management of surface and groundwater.[97] Based on model simulations, the study found that the storage rules would have to change significantly from historic operating patterns under climate change in order to minimize costs of water scarcity.[98] In-

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[87] *Id.* at 8–9.

[88] *Id.*

[89] *Id.* at 7, Table 2.

[90] *Id.* at 10.

[91] *Id.* at 3.

[92] Harou et al., *supra* note 28, at 8.

[93] *Id.* at 6.

[94] Tanaka et al., *supra* note 38, at 369–70.

[95] *Id.* at 375.

[96] *Id.*

[97] Medellín-Azuara et. al., *supra* note 34, at S87–88.

[98] *Id.* at S87–88.

frastructure, and accompanying management, will have to support new water transportation as water use shifts.

Conversely, irrigators may also need infrastructure if climate change increases precipitation and potential water supplies. A study conducted by Elbakidze examined potential impacts of climate change on agriculture by 2030 in the Truckee Carson Irrigation District of Nevada's Great Basin.[99] He considered two types of scenarios: one that projected warmer temperatures but wetter conditions and increased streamflow,[100] and another that experienced reduced streamflow.[101] In this study, agricultural returns increased with increased streamflow and decreased with decreased streamflow, but the changes were asymmetric: economic losses under reduced streamflow conditions were much larger than gains realized under increased streamflow conditions.[102] The model assumed existing infrastructure was sufficient to handle increased streamflow.[103] The results highlight that climate change scenarios affect returns to investment on infrastructure that captures and stores water. Under wetter scenarios, potential returns to such infrastructure are higher.

These hydro-economic studies varied in many dimensions: period, geographic scope, crop coverage, hydrologic detail, and assumed climate/water shock. Taken together, however, one can draw some general lessons from their results. Agriculture will most likely suffer the greatest water losses, absorbing much of the impact for urban users. Water costs will rise not only because of climate change, but also because of additional environmental regulations, especially those that protect endangered aquatic species. Still, agriculture need not merely rely on fallowing land, but could instead pursue other strategies that lower the cost of water loss. Beyond changes in growing practices, additional strategies for adaptation include investments in infrastructure to store and convey water, and water transfers.

As discussed later in this article, many of these studies assumed institutional barriers would be eliminated to achieve the most efficient results. Results from the Howitt et al. study assumed that between now

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[99] Levan Elbakidze, *Potential Economic Impacts of Changes in Water Availability on Agriculture in the Truckee and Carson River Basins, Nevada*, 42 USA. J. AMER. WATER RESOURCES ASSOC. 841 (2006).

[100] *Id.* at 844–45 (The wetter scenarios were based on two general circulation models, the Canadian and Hadley GCMs).

[101] *Id.* at 845–46 (Streamflow scenarios were examined both in isolation and combined with assumed yield increases or yield increases accompanied by price decreases. The crops included alfalfa, other hay, and irrigated pasture).

[102] *Id.* at 846.

[103] *Id.* at 848.

and 2050, California will have a more economical means of transferring water from Northern to Southern California.[104] In the Medellín-Azuara et al. study, institutional barriers to water transfers were not modeled. Although the hydro-economic studies did not specifically evaluate the role of institutions in supporting climate change adaptation, they identified potential solutions, which if implemented, could help everyone adapt to climate change.

IV. CLIMATE CHANGE ADAPTATION THROUGH ON-FARM WATER MANAGEMENT

Agriculture accounts for 79 percent of water withdrawals in the Southwest. Because of this, as the previous section highlighted, agriculture will likely play a central role in regional water reallocations in the face of climate change. We turn now to farm-level strategies to conserve water as an adaptation to climate change.[105] Local conservation strategies implemented by water managers and agricultural users tend to be more economical than new infrastructure projects that could capture and store new water supplies.[106] Options for managing demand may include addressing water pricing and markets, as discussed above, as well as improving practices on the ground by setting allocation limits, improving water-use efficiency, providing public and private incentives to adopt water-saving irrigation technology, reusing tailwater (excess surface water draining from an irrigated field), shifting to less water-intensive crops, and fallowing.[107]

One way to adapt to climate-change-induced water shortages is to shift the mix of crops grown. Table 1 shows ranges in water application rates by crop, state, and irrigation technology in acre-feet per acre.[108] Crops in warmer Arizona tend to have higher application rates, while those in Colorado tend to have the lowest. Crops irrigated by sprinkler

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[104] Howitt et al. (2009), *supra* note 33, at 14.

[105] Several studies note the importance of on-farm water conservation as a climate change adaptation strategy. *See* Hervé Lévite et al., *Testing Water Demand Management Scenarios in a Water-Stressed Basin in South Africa: Application of the WEAP Model*, 28 PHYSICS AND CHEMISTRY OF THE EARTH 779 (2003); Brian Joyce et al., *Integrated Scenario Analysis for the 2009 California Water Plan Update*, Sacramento, CAL. DEP'T OF WATER RES. (2010); Brian Joyce et al., *Climate Change Impacts on Water for Agriculture in California: A Case Study in the Sacramento Valley*, Sacramento, CAL. CLIMATE CHANGE CENTER (2006).

[106] Michael Kiparsky & Peter H. Gleick, PAC. INST. FOR STUDIES IN DEV., ENV'T, AND SEC., CLIMATE CHANGE AND CALIFORNIA WATER RESOURCES: A SURVEY AND SUMMARY OF THE LITERATURE (2003).

[107] *See* Tanaka et al., *supra* note 38.

[108] An acre-foot is the amount of water required to cover one acre of water one foot deep. Frisvold et al., *supra* note 4, at 223.

irrigation systems (also referred to as pressurized systems) have lower application rates than those irrigated by gravity systems, which rely on flooding fields.[109] Table 1 illustrates that the amount of water needed for agricultural production in the Southwest will be highly sensitive to decisions about which crops are grown, where they are grown, and how they are irrigated.

Table 1. Ranges of water application rates (acre-feet of water applied per acre) by state and irrigation technology for different crops grown in Southwestern states[110]

Orchards, Vineyards, Nuts	0.3 (Colorado/Drip)	6.5 (Arizona/Gravity)
Alfalfa	1.6 (Colorado/Sprinkler)	6.4 (Arizona/Gravity)
Sugar Beets	3.7 (Colorado/Sprinkler)	5.3 (Colorado/Gravity)
Cotton	2.2 (New Mexico/Sprinkler)	4.8 (Arizona/Gravity)
Corn/silage	1.4 (Colorado/Sprinkler)	4.7 (Arizona/Gravity)
Corn/grain	1.5 (New Mexico/Gravity)	4.2 (Arizona/Gravity)
Other Hay	1.3 (Colorado/Sprinkler)	4.2 (Arizona/Gravity)
Rice	4.1 (California/Gravity)	4.1 (California/Gravity)
Wheat	1.3 (Colorado/Sprinkler)	3.6 (Arizona/Gravity)
Barley	1.2 (Utah/Sprinkler)	3.6 (Arizona/Gravity)
Vegetables	1.7 (Colorado/Sprinkler)	3.5 (Arizona/Sprinkler)
Sorghum	0.6 (Colorado/Sprinkler)	3.5 (Arizona/Gravity)
Irrigated Pasture	1.5 (New Mexico/Sprinkler)	3.0 (Arizona/Gravity)

A recent study by the Pacific Institute argues that simply shifting to less water-intensive crops could significantly reduce agricultural water use.[111] Alfalfa—used primarily by dairies—is among the most water intensive crops. Other animal feeds and forage crops (hay, corn silage) are relatively water intensive (Table 1). In the Lower Colorado Basin, animal feed and forage crops account for 60 percent of total irrigated acreage and consume 5 million acre-feet of water per year.[112] This means that about one-third of the Colorado River's average annual flows are devoted to producing feed for livestock.[113] Therefore, there is a basis

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[109] Cynthia Kallenbach et al., *Cover Cropping Affects Soil N2O and CO2 Emissions Differently Depending on Type of Irrigation*, 137 AGRIC. ECOSYS. & ENV'T. 51 (2010). Sprinkler irrigation includes center-pivot, mechanical-move, hand-move, and non-moving systems (non-moving systems are used mostly for perennial crops). Rather than using gravity, these systems rely on mechanically generated pressure to pump water to crops. *See* Frisvold et al., *supra* note 4, at 224.

[110] U.S. DEP'T OF AGRIC., *supra* note 18.

[111] COHEN ET AL., *supra* note 64.

[112] *Id.* at 56.

[113] *Id.*

for reducing water demand requirements by “simply” shifting alfalfa production to other crop production.[114]

Irrigators also could adapt to climate variability by increasing use of readily available water management information. For example, the California Irrigation Management Information System (CIMIS), a weather information network for irrigation management developed and operated by the California Department of Water Resources, has proved highly valuable to the California agriculture industry.[115] The crop evapotranspiration (ET) data provided by CIMIS allows farmers to better match irrigation water applications to crop needs. Growers benefit from higher yields and lower water costs. Improved water management also increases fruit size, reduces mold, and enhances product appearance, all of which can fetch higher crop prices. Use of CIMIS reduces California’s annual agricultural water applications by an estimated 107,300 acre-feet.[116] Drought in 1989 appeared to significantly increase the number of growers and crop consultants who use CIMIS. CIMIS generated $64.7 million in benefits from higher yields and lower water costs, at an annual cost to the state of less than $1 million.[117] CIMIS has also improved pest control and promoted integrated pest management techniques, which can reduce costs and improve worker safety by reducing pesticide applications. CIMIS demonstrates enormous benefits and potential of information services for water management that growers can incorporate into their production systems.

Other southwestern states also provide on-line databases and support tools for water management. For example, the Arizona Meteorological Network (AZMET) provides online, downloadable weather data and information for Arizona agriculture.[118] Data include temperature (air and soil), humidity, solar radiation, wind (speed and direction), and precipitation as well as computed variables such as heat units (degree days), chill hours, and crop evapotranspiration. AZMET also provides ready-to-use summaries and special reports that interpret weather data such as Weekly Cotton Advisories. In Yuma County, Arizona, the Lettuce Ice Forecast Program provides temperature forecasts for the vegetable pro-

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[114] *Id.* at viii. This may be simple in technical terms, but more challenging economically. The Pacific Institute study also notes that costs of substitution from alfalfa to cotton and wheat would cost (in terms of foregone profits) 36 dollars per acre-foot of water saved.

[115] Douglas Parker et al., *Publicly Funded Weather Database Benefits Users Statewide*, 54 CALIF. AGRIC. 21 (2000).

[116] *Id.* at 23.

[117] *Id.* at 21.

[118] Bruce Russell, *The Arizona Meteorological Network: A Brief Overview*, CLIMAS SOUTHWEST CLIMATE OUTLOOK (Mar. 2004), http://www.climas.arizona.edu/sites/default/files/pdf2004marazmet.pdf.

duction. The Colorado Agricultural Meteorological Network (CoAgMet) provides daily crop water use or evapotranspiration reports that can improve irrigation scheduling.[119] In addition to providing raw data, the Colorado system allows users to generate customized, location-specific crop water use reports. While these and other services are developing innovative ways to provide information on water management, this information will only aid climate change adaptation if growers are able to make use of it.

Sparse Internet access can limit the utility of online databases. In 1996, the National Weather Service (NWS) offices discontinued issuing local agricultural weather forecasts in response to budget cuts and to avoid competing with privately supplied forecasts.[120] The expense of privately provided forecasts may pose a barrier to some agricultural information users.[121] For many southwestern farmers and ranchers, access to high-speed Internet service remains problematic. As of 2007, there were twenty-nine southwestern counties where fewer than 30 percent of agricultural producers have such access.[122] Access is particularly low in the Four Corners region of Arizona, Utah, and New Mexico, which has a relatively large population of Native American farmers and ranchers. Data from the more recent, 2012 Census of Agriculture reveals that while 71 percent of non-American Indian farm operations in Arizona and New Mexico had internet access, only 16 percent of American Indian operators had such access.[123] Across all operations and all six states, 30 percent of operations did not have internet access. Public and private entities can more effectively deliver information or develop tools for decision making for climate-change adaptation if they consider constraints faced by the intended users.[124]

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[119] A.A. Andales et al., *The Colorado Agricultural Meteorological Network (CoAgMet) and Crop ET Reports, Fact Sheet No. 4.723.* COLO. STATE UNIV. (2009), http://www.ext.colostate.edu/pubs/crops/04723.pdf.

[120] Jeanne Schneider & John Wiener, *Progress toward filling the weather and climate forecast needs of agricultural and natural resource management*, 64 SOIL WATER CONSERVATION J. 3, at 100A (2009).

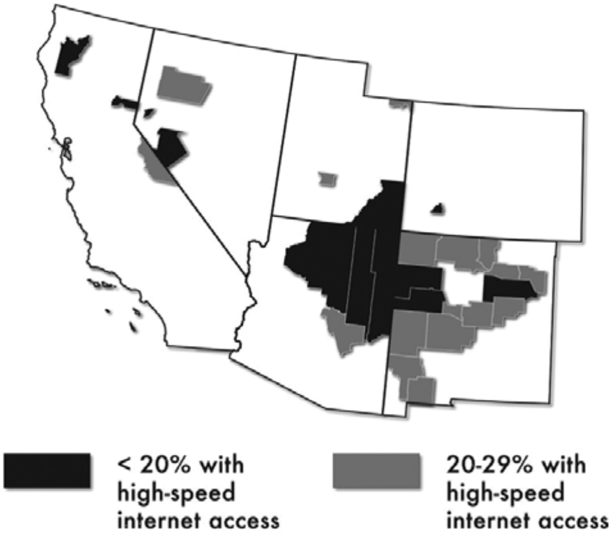
[121] *Id.* There is evidence that smaller scale irrigators are less likely to make use of private sources of water management information. *See* George Frisvold & Shailaja Deva, *Farm Size, Irrigation Practices, and Conservation Program Participation in the U.S. Southwest*, 61 IRRIGATION & DRAINAGE 569 (2012).

[122] U.S. DEP'T OF AGRIC., *supra* note 18.

[123] USDA uses the definition "American Indian" in reporting farm characteristics by race. U.S. U.S. DEP'T OF AGRIC., *supra* note 18; U.S. DEP'T OF AGRIC., NEW MEXICO STATE AND COUNTY DATA, 1 Geographic Area Series 31, 56, *available at* http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_State_Level/New_Mexico/nmv1.pdf.

[124] *See* Frisvold et al., *supra* note 4, at 219–20.

Figure 4. Southwest counties where farmers and ranchers have limited access to high-speed internet service[125]



In rural areas, radio, and television are still widely used for weather information.[126] Frisvold and Murugesan found that access to satellite television was a better predictor of weather information use by agricultural producers than access to the Internet.[127] Efforts to encourage commercial weather information providers may limit access through these popular media.[128] Recent institutional attempts to support water management information may not fully account for farmer and rancher preferences and constraints in using information. In June 2013, the U.S. Department of Agriculture (USDA) announced the selection of Regional Hubs for Risk Adaptation and Mitigation to Climate Change as part of the Obama Administration's Climate Action Plan.[129] Seven hubs and three supporting sub-hubs were established nationwide, with three of

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[125] *Id.* at 226.

[126] Jeanne Schneider & John Wiener, *Progress Toward Filling the Weather and Climate Forecast Needs of Agricultural and Natural Resource Management*, 64 J. Soil & Water Conservation 100A (2009).

[127] George Frisvold & Anand Murugesan, *Use of Weather Information for Agricultural Decision Making*, 5 Weather, Climate, & Society 1, 55 (Jan. 2013).

[128] Schneider & Wiener, *supra* note 126, at 100A.

[129] Office of communication, USDA, News Release No. 0016.14, Secretary Vilsack Announces Regional Hubs to Help Agriculture, Forestry Mitigate the Impacts of a Changing Climate (2014); The Office of the Press Secretary, Executive Office of the President, The President's Climate Action Plan (2013).

these ten facilities set in the Southwest Region.[130] The purpose of the hubs is to deliver information to agricultural producers to help them adapt to climate change and weather variability and offer "tools, strategies and management options for climate change response."[131] While USDA will work with University Cooperative Extension programs to deliver adaptation information face-to-face to growers, it is also anticipated that a large portion of climate change adaptation information and support tools will be disseminated via web portals. These web portals may have less success in regions with limited internet access. The Four Corners area of the Southwest has been characterized by "low-low" clusters of "counties with low crop productivity surrounded by counties with low wireless connectivity."[132] This raises the question of how such delivery mechanisms are to reach these populations on the wrong side of the "digital divide."[133]

Despite challenges with disseminating information, experts frequently cite efforts to improve irrigation efficiency as a promising response to climate change or water scarcity in general.[134] Improved efficiency can allow individual irrigators to save on water costs and improve yields, thus increasing profits. The evidence supporting the widely held belief that simply improving on-farm irrigation efficiency conserves water is weak, however.[135] Increased on-farm application efficiency

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[130] The hubs are in Fort Collins, Colorado and Las Cruces, New Mexico and a sub-hub in Davis, California. *See* SECRETARY VILSACK ANNOUNCES REGIONAL HUBS TO HELP AGRICULTURE, FORESTRY MITIGATE THE IMPACTS OF A CHANGING CLIMATE, *supra* note 127.

[131] OFFICE OF THE CHIEF ECONOMIST, USDA FACT SHEET MARCH 9, 2014, USDA REGIONAL HUBS FOR RISK ADAPTATION AND MITIGATION TO CLIMATE CHANGE (2014).

[132] Brian E. Whitacre et al., *How Connected Are Our Farms?*, 3d Quarter CHOICES 29(3) at 1, 7 (2014).

[133] *See* PIPPA NORRIS, DIGITAL DIVIDE: CIVIC ENGAGEMENT, INFORMATION POVERTY, AND THE INTERNET WORLDWIDE 3 (Cambridge University Press, 2001).

[134] J.S. Wallace, *Increasing Agricultural Water Use Efficiency to Meet Future Food Production*, 82 AGRIC., ECOSYSTEMS & ENV'T 105 (2000); Martin Parry et al., *Adapting to the Inevitable*, 395 NATURE 741, 741 (1998); Ragab Ragab & Chrystel Prudhomme, *Climate Change and Water Resources Management in Arid and Semi-Arid Regions: Prospective and Challenges for the 21st Century*, 81 BIOSYSTEMS ENGINEERING 3, 32 (2002); William Jury & Henry Vaux, *The Role of Science in Solving the World's Emerging Water Problems*, 102 PROC. NAT'L ACAD. SCI. 15715, 15717 (2006); Robert Mendelsohn & Ariel Dinar, *Climate, Water, and Agriculture*, 79 LAND ECON. 328, 339 (2003); Johan Rockstrom, *Increasing Water Productivity Through Deficit Irrigation: Evidence from the Indus Plains of Pakistan*, 104 PROC. NAT'L ACAD. SCI. 6253 (2007).

[135] Margriet F. Caswell & David Zilberman, *The Effects of Well Depth and Land Quality on the Choice of Irrigation Technology*, 68 AM. J. AGRIC. ECON. 798, 811 (1986); George Frisvold & K. Emerick, *Rural-Urban Water Transfers with Applications to the U.S.-Mexico Border Region*, *in* GAME THEORY AND POLICY MAKING IN NATURAL RESOURCES AND THE ENVIRONMENT, 155–80 (Ariel Dinar et al. eds., 2008); Jeffrey Peterson & Ya Ding, *Economic Adjustments to Groundwater Depletion in the High Plains: Do Water-Saving Irrigation Systems Save Water?*, 87 AM. J. AGRIC. ECON. 147 (2005); Frank Ward & Manuel Pulido-Velazquez, *Water Conservation in*

means that the crop—rather than its surrounding soil— takes up a greater share of the water that is applied. This means, however, that less water may return to the system as a whole (in the form of groundwater recharge or surface-water return flow). Other water users often count on this return flow or recharge for their water supplies. Reducing the water lost through the conveyance system means more of the water diverted reaches a crop, but also results in lower return flows or recharge that is no longer available to other irrigators, urban water users, or ecosystems.[136] While fisheries and aquatic habitat depend on return flows, these "uses" typically do not hold legally recognized water rights that can contest harm from water transfers.[137] Many riparian systems now depend on these return flows, which may decrease in managed hydrological systems that more efficiently accommodate human water uses.[138] In some cases, the Clean Water Act and Endangered Species Act establish minimum flow requirements.[139] However, implementation of these requirements has been contentious with mixed results.[140] Policies to increase irrigation efficiency with the hope of freeing up water for other uses may fail to conserve water. Thus, what may seem a rational response to water scarcity by irrigators at the farm level may exacerbate water scarcity problems at the basin scale.

While evidence that improving on-farm irrigation efficiency conserves water remains mixed, the USDA has pursued and expanded programs to subsidize technology adoption with just this aim. USDA has operated technical assistance and subsidy programs to promote resource-conserving technologies since the New Deal. Since 1936, USDA has administered the Conservation Technical Assistance Program, providing extension-type assistance to encourage farmers to adopt soil and

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Agriculture Can Increase Water Use, 105 PROC. NAT'L ACAD. SCI. 18215 (2008); Ray Huffaker & Norm Whittlesey, *A Theoretical Analysis of Economic Incentive Policies Encouraging Agricultural Water Conservation*, 19 INT'L J. WATER RES. Dev. 37 (2003).

[136] *See, e.g.*, Osvel Hinojosa-Huerta et al., *Andrade Mesa Wetlands of the All-American Canal*, 42 NAT. RESOURCES J. 899 (2002) (discussing negative environmental impacts of canal lining and citing other articles discussing the same topic).

[137] Howard Chong & David Sunding, *Water Markets and Trading*, 31 ANN. REV. ENV'T & RES. 239 (2006).

[138] John Wiener et al., *Riparian Ecosystem Consequences of Water Redistribution Along the Colorado Front Range*, 10 WATER RESOURCES IMPACT May 18 (2008).

[139] For analysis on additional costs of maintaining minimum flow requirements, see Ward, *supra* note 49; Richard Howitt et al., *Economic Impacts of Reductions in Delta Exports on Central Valley Agriculture*, 12 AGRIC. & RESOURCE ECON. UPDATE 1 (2009).

[140] Michael Moore et al., *Water Allocation in the American West: Endangered Fish Versus Irrigated Agriculture*, 36 NAT. RESOURCES J. 319, 320 (1996); Reed D. Benson, *So Much Conflict, Yet So Much in Common: Considering the Similarities Between Western Water Law and the Endangered Species Act*, 44 Nat. RESOURCES J. 29, 29 (2004).

water conservation and water pollution-control practices. The Agricultural Conservation Program (ACP), also initiated in 1936, provided partial subsidies, or "cost sharing," to encourage adoption of resource-conserving technologies and practices. Technology adoption programs were often aimed at curbing water pollution, but they also provided subsidies to improve irrigation efficiency. The 1996 Farm Bill—the FAIR Act—folded the ACP and other regional programs into a single Environmental Quality Incentive Program (EQIP). EQIP would pay up to 75 percent of the cost of adopting practices to conserve water or control water pollution. The EQIP program has been highlighted as means of climate change adaptation through water conservation.[141] Yet, despite ambitious goals for expansion, the evidence that the program has encouraged water conservation at a broad regional level remains in doubt.

The 2002 Farm Bill—the Farm Security and Rural Investment (FSRI) Act—significantly increased technology adoption subsidies and set forth some ambitious water conservation and reallocation goals. EQIP payments were budgeted to encourage water conservation on nearly 25 million acres (primarily in the western half of the United States), with projected reductions in agricultural water applications of 5.41 inches per acre.[142] According to USDA's Natural Resource Conservation Service (NRCS), "any water saved would be available for alternative uses such as by municipalities, utility generation, and wildlife habitat enhancement."[143] Assuming 20 percent loss in storage and transmission, the program was projected to free 8.9 million acre feet (MAF) of water per year over ten years.[144] This is a sizable amount of water considering total off-stream water withdrawals for domestic and commercial use in the entire United States equals about 50 to 55 MAF per year.[145] Subsequent USDA cost-benefit analyses of EQIP did not evaluate whether the expansion of EQIP had its projected impact on water conservation. Some subsequent studies have simply projected that the program will continue to reduce water applications 5.41 inches per acre or not discussed the issue.[146] Based on data from USDA's own Farm and Ranch Irrigation

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[141] INTERAGENCY CLIMATE CHANGE ADAPTATION TASK FORCE, FEDERAL ACTIONS FOR A CLIMATE RESILIENT NATION 19 (2011), *available at* https://www.whitehouse.gov/sites/default/files/microsites/ceq/2011_adaptation_progress_report.pdf.

[142] NATURAL RES. CONSERVATION SERV., U.S. DEP'T OF AGRIC., BENEFIT COST ANALYSIS: FINAL REPORT 56 (2003).

[143] *Id.*

[144] George B. Frisvold, *How Federal Farm Programs Affect Water Use, Quality, and Allocation Among Sectors*, 40 WATER RES. RESEARCH, 12, 13 (2004).

[145] *Id.*

[146] The new analysis repeats the projected conservation numbers without reporting on any analysis since 2003 to actually estimate the program's effect on water conservation. *See,*

Survey, however, there does not appear to be any noticeable trend to agricultural water conservation.[147] Between 2003 and 2008, absolute water use and applications both increased over the Lower Colorado Basin, Upper Colorado Basin, Pacific Northwest and the Great Basin.[148] Absolute water use did decline in California, but this was entirely due to a reduction in irrigated acreage. Instead of conserving absolute use of water, applications per acre actually increased.[149] Recent analysis by USDA economists has found (preliminarily) that EQIP may not have conserved any water during its expansion period from 2003 to 2008.[150]

Both hydro-economic modeling, discussed in Part II, and recent experience, discussed in Part III, inform potential solutions for agriculture to best adapt to climate change. Agriculture will have less available water, but changes to farming techniques can help farmers use that water more productively. However, challenges remain. Some strategies require constant information updates that may be difficult to disseminate. Water conservation may limit return flow for other users or the environment. Although agricultural water conservation, via changes in production practices, adoption of irrigation technology, and use of information, is seen as a key to regional climate adaptation, true agricultural water conservation also requires support from institutions, policies, and economic incentives.

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e.g., NATURAL RES. CONSERVATION SERV., U.S. DEP'T OF AGRIC., BENEFIT-COST ANALYSIS FOR THE ENVIRONMENTAL QUALITY INCENTIVES PROGRAM (EQIP) 24 (2009). A later report does not provide specific water conservation estimates, but regarding irrigation water use says, "Given the existing limitation and lack of data, NRCS will investigate ways to quantify the incremental benefits obtained from this program." *See* NATURAL RES. CONSERVATION SERV., U.S. DEP'T OF AGRIC., REGULATORY IMPACT ANALYSIS (RIA) FOR THE ENVIRONMENTAL QUALITY INCENTIVES PROGRAM (EQIP) at 23 (2014).

[147] *See* U.S. DEP'T OF AGRIC., *supra* note 12.

[148] *See id.* at Table 8.

[149] *See id.* at Table 8.

[150] *See* Steven Wallander & Michael S. Hand, *Measuring the Impact of the Environmental Quality Incentives Program (EQIP) on Irrigation Efficiency and Water Conservation*, No. 103269, 2011 Annual Meeting, Agricultural and Applied Economics Association, Pittsburgh, Pa. (July 24–26, 2011). The authors found, "EQIP payments may have reduced water application rates but also may have increased total water use and led to an expansion in irrigated acreage." *Id.* at 1. A more recent study found that the subsidized conversion from traditional center pivot irrigation systems to higher efficiency dropped-nozzle center pivot systems in western Kansas actually increased groundwater extraction, in part from shifting crop patterns. Lisa Pfeiffer & C. Y. C Lin, *Does efficient irrigation technology lead to reduced groundwater extraction? Empirical Evidence*, 67(2) J. ENVTL. ECON. & MGMT. 189 (2014).

V. DISASTER RELIEF, CROP INSURANCE, AND CLIMATE ADAPTATION

Agricultural producers may take a variety of actions to reduce risks from drought, flood, and other weather-related events. They can diversify the mix of the crops they grow, adopt irrigation and pest control practices to protect yields, enter into forward or futures contracts,[151] or make use of weather or other data to time operations to reduce risk.[152] Increasingly, farmers have diversified their household incomes by relying on both farm and non-farm jobs.[153] Farmers also rely on disaster relief programs to insure against losses.

Disaster relief programs affect producer incentives for managing risks because they alter the costs and benefits of these and other risk-reducing measures. Congress traditionally provided regular disaster payments to growers on an ad hoc basis in response to natural disasters and weather extremes that lowered crop yields or forage production.[154] Ad hoc payments, however, are expensive and maintain economic incentives to continue production in areas susceptible to agronomic risks.[155]

The Federal Crop Insurance Act of 1980[156] and subsequent legislation attempted to establish crop insurance, rather than disaster payments, as the main vehicle for managing farm risk.[157] Private insurers provide crop insurance, but the federal government heavily subsidizes this insurance. Farmers pay premiums half of actuarially fair rates.[158] Insurers also receive direct subsidies; so, for every dollar a farmer receives in insurance payments, the agricultural insurance industry receives

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[151] Steven Blank & Jeffrey McDonald, *How California Agricultural Producers Manage Risk*, 49(2) CAL. AGRIC. 9 (1995); E. Hart Bise Barham et al., *Mitigating Cotton Revenue Risk Through Irrigation, Insurance, and Hedging*, 43(4) J. AGRIC. & APPLIED ECON. 529 (2011); Timothy Dalton et al., *Risk Management Strategies In Humid Production Regions: A Comparison Of Supplemental Irrigation And Crop Insurance*, 33(2) AGRIC. & RES. ECON. REV. 220 (2004).

[152] Frisvold & Murugesan, *supra* note 127.

[153] Vincent H. Smith & Joseph W. Glauber, *Agricultural Insurance in Developed Countries: Where Have We Been and Where Are We Going?*, 34 APPLIED ECON. PERSP. & POL'Y 363, 373 (2012).

[154] Joseph W. Glauber, *Crop Insurance Reconsidered*, 86 AM. J. OF AGRIC. ECON. 1179, 1180 (2004).

[155] Gardner *supra* note 8, at 495; Randall A. Kramer, *Federal Crop Insurance 1938-1982,* 57 AGRIC. HIST. 181, 197–98 (1983).

[156] Federal Crop Insurance Program, Pub.L. No. 96-365 (1980).

[157] Joseph W. Glauber, Keith J. Collins & Peter J. Barry, *Crop Insurance, Disaster Assistance, and the Role of the Federal Government in Providing Catastrophic Risk Protection,* 62 AGRIC. FIN. REVIEW 81, 81 (2002).

[158] This means that insurance indemnity payments for losses are roughly double the premiums growers pay. In short, growers are earning net profits from their insurance policies. *See* Wright, *supra* note 9.

$1.44.[159] A USDA-commissioned study calculated private carriers' average rate of return on investment for 1989–2008 at 17 percent, but estimated the average "reasonable rate of return" for this period based on the private market would have been less than 13 percent.[160] While the number of producers covered under federally subsidized crop insurance has risen, ad hoc disaster payments continue, averaging about $1 billion annually.[161]

Subsidized crop insurance, combined with disaster payments, creates disincentives for agricultural climate adaptation. The programs reduce grower incentives to limit climate-related yield losses and encourage production in high-risk areas.[162] Premium subsidies provide an incentive for growers not to take protective measures against crop failure commensurate with the level of weather-related risk.[163] From 1985–2005, 28 percent of agricultural disaster payments went to farmers who received payments at least once out of three years.[164] Worse, farmers can receive insurance payments *and* disaster assistance for the same losses.[165]

The 2008 Farm Bill established the Supplemental Revenue Assistance Payments Program (SURE) as a permanent disaster fund.[166] SURE compensates producers for a portion of their losses not eligible for payments under crop-insurance policies.[167] Producers become eligible for payments if a disaster is declared in their county or a neighboring one.[168]

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[159] Barry K. Goodwin & Vincent H. Smith, *What Harm Is Done By Subsidizing Crop Insurance?*, 95(2) AM. JOURNAL OF AGRIC. ECON. 489, 489 (2013).

[160] MILIMAN, INC. ET AL., HISTORICAL RATE OF RETURN ANALYSIS (2009), *available at* http://www.rma.usda.gov/pubs/2009/millimanhistoricalrate.pdf.

[161] MYLES WATTS & ANTON BEKKERMAN, AGRICULTURAL DISASTER AID PROGRAMS: A SURE INVITATION TO WASTEFUL SPENDING (2011), *available at* http://www.aei.org/wp-content/uploads/2011/11/-agricultural-disaster-aid-programs-a-sure-invitation-to-wasteful-spending_152350984526.pdf.

[162] Joseph W. Glauber & Keith J. Collins, *Risk Management and the Role of the Federal Government*, *in* 23 A Comprehensive Assessment of the Role of Risk in U.S. Agriculture Natural Resource Management and POLICY 469 (2002).

[163] Goodwin, *supra* note 159.

[164] K. Cook & C. Campbell, *A Disaster Waiting to Happen*, Washington, D.C.: Environmental Working Group (2007).

[165] Joseph W. Glauber, DOUBLE INDEMNITY: CROP INSURANCE AND THE FAILURE OF U.S. AGRICULTURAL DISASTER POLICY (2007); *see also* BRUCE L. GARDNER & DANIEL A. SUMNER, THE 2007 FARM BILL AND BEYOND (2007).

[166] Dennis A. Shields et al., FARM SAFETY NET PROGRAMS: ISSUES FOR THE NEXT FARM BILL. CONGRESSIONAL RESEARCH SERVICE, 7-5700 R41317 at 16; Jim Monke, SUPPLEMENTAL APPROPRIATIONS FOR AGRICULTURE CONGRESSIONAL RESEARCH SERVICE, 7-5700 R41255 at 3.

[167] DENNIS A. SHIELDS, A WHOLE-FARM CROP DISASTER PROGRAM: SUPPLEMENTAL REVENUE ASSISTANCE PAYMENTS (SURE), 1(2010).

[168] *Id.* at 12.

Ninety percent of counties qualified for payments in either 2008 or 2009.[169] Most counties qualified both years. Eligible producers need show only a 10 percent yield loss on one crop to qualify for payments.[170] Outside designated counties, producers must show a 50 percent loss of a crop.[171] Low crop yields trigger payment eligibility even for farmers not growing the affected crop.[172] Some farmers can receive higher returns by allowing poor crop yields instead of acting to reduce crop losses.[173] Although the government estimated that SURE would cost $425 million annually, it actually cost $2 billion in 2008, twice the amount of previous ad hoc payment levels.[174]

Some researchers raise concerns that the program encourages riskier behavior by producers.[175] Small changes in yield, even one bushel per acre, can mean the difference between receiving large payments or no payments. This makes it difficult for administrators to gauge whether producers are actively trying to avoid yield losses. Payments are more likely if producers raise a single crop in a county that has high yield risk than if they grow a more diversified mix of crops.[176] In some cases, producers may receive higher revenues by simply allowing their crops to fail.[177] In the Southwest, 14 counties, primarily in dryland wheat producing areas of Colorado (and to a lesser extent, northern New Mexico), account for most of the payments.[178] Most are high-risk counties with payments triggered every year.[179]

The program appears to create a moral hazard by providing perverse incentives that reward crop failure.[180] SURE, by providing payments not covered under regular crop insurance, effectively reduces the deductible on crop insurance. The lower deductible reduces grower in-

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[169] WATTS, *supra* note 161, at 3.

[170] *Id.* at 2.

[171] *Id.* at 5.

[172] *Id.* at 15.

[173] *Id.* at 6.

[174] *Id.* at 2.

[175] G. SCHNITKEY, SURE WINDOW CLOSES SEPTEMBER 30, URBANA-CHAMPAIGN: UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN, DEPARTMENT OF AGRICULTURAL AND CONSUMER ECONOMICS (2008)*; see also*, G.A. Barnaby Jr., SURE CALCULATOR (NEW STANDING DISASTER AID 2008); SMITH & WATTS, *supra* note 8; SHIELDS *supra* note 167.

[176] DENNIS A. SHIELDS ET AL., CONGRESSIONAL RESEARCH SERVICE, FARM SAFETY NET PROGRAMS: ISSUES FOR THE NEXT FARM BILL, REPORT 7-5700, R41317, 11 (Cong. Research Serv. 2010).

[177] Smith & Watts, *supra* note 8.

[178] Frisvold et al., *supra* note 4, at 234.

[179] *Id.* at 248.

[180] GLAUBER ET AL., *supra* note 157, at 471 ("Moral hazard occurs when an insured producer can increase his or her expected indemnity by actions taken after buying insurance.").

centives to mitigate risk. Overall, the federal crop insurance program is likely to provide incentives to keep growing in marginal areas that are at highest risk from weather and climate-related events, and large quantities of crops that may not be suitable for local conditions, without sufficient regard for the risk. If the program does not change these incentives, they will tend to undermine resiliency to climate change impacts in the agricultural sector. As economist Brian Wright concludes:

> For those interested in the sustainability of U.S. agriculture and the environment, the crop insurance and disaster programs are themselves disastrous. The program reduces the incentive for farmers to manage farm risks and environmental problems, and reduces their motivation to adapt to a changing environment. Such adaptation will be all the more crucial for effectively competing on the world market as climate change progresses across the global agricultural sector.[181]

Growers currently receive about 60 cents in federal subsidies for each dollar spent on federally subsidized crop insurance.[182] Before the 2012 drought, many growers purchased “Cadillac” crop insurance policies providing extremely high levels of coverage.[183] They could afford to do so because of the generous subsidies. It has been estimated that growers in the Corn Belt could have been compensated for their actual losses at a cost of $6 billion rather than the actual $12 billion it cost under current crop insurance programs.[184] In sum, federal disaster and crop insurance programs encourage agricultural production in more marginal and ecologically fragile areas. In addition, they encourage riskier behavior—such as reduced production diversification and soil conservation—and create economic incentives for growers to simply let their yield fall in adverse circumstances. Further, it costs taxpayers far more than needed to provide growers with an adequate level of risk protection. For these reasons federal agricultural disaster and crop insurance programs have been roundly criticized from an interestingly diverse set of sources, from Fellows of the Agricultural and Applied Economics Association, to environmental groups such as the Environmental Working Group, to conservative think tanks such as the American Enterprise Institute.[185]

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[181] Wright, *supra* note 9.

[182] Smith & Glauber, *supra* note 153.

[183] BRUCE BABCOCK, ENVIRONMENTAL WORKING GROUP, TAXPAYERS, CROP INSURANCE AND THE DROUGHT 5 (Nils Bruzelius ed., 2012).

[184] *Id.* at 11.

[185] *See, e.g.*, Gardner, *supra* note 8; Wright, *supra* note 9; BABCOCK, *supra* note 183; Glauber, *supra* note 154; Cook & Campbell, *supra* note 164; Goodwin & Smith, *supra* note 159; Glauber, *supra* note 165; Glauber et al., *supra* note 157; Watts & Bekkerman, *supra* note 161.

Diverse minds agree that current crop insurance programs are not a cost-effective way to mitigate agricultural risks.

The 2014 Farm Bill continues highly subsidized crop insurance programs, establishes a new permanent disaster program and eliminates older price support and fixed income payment programs, replacing them with "shallow loss" insurance programs.[186] The shallow loss programs provide payments for yield or price risks not large enough to be covered by the regular, subsidized crop insurance programs.[187] It remains to be seen to what extent these shallow loss programs will serve as reduced deductibles for crop insurance and encourage growers to adopt riskier practices.

VI. CONCLUSIONS: IMPROVING INCENTIVES FOR AGRICULTURAL ADAPTATION TO CLIMATE CHANGE

This article began with the main conclusion shared by multiple hydro-economic studies cited in Part II: in response to future drought and climate change, significant adjustments are in store for Southwest agriculture. Some adaptations will be made *within* the agricultural sector. For example, one response may be relatively greater reductions in water use and production of field crops, while maintaining production of higher valued fruit, nut, and vegetable crops. Table 1 illustrated that water requirements vary widely by crop, state, and irrigation technology. So, in principle, the water requirements of southwestern farm acreage can be adjusted significantly simply by altering the relative mix of crops grown, where they are grown, and which irrigation technologies and methods are used.[188] Of course, water requirements and costs are only one part of irrigators' economic calculus, and cropping and technology choices will depend on crop, water, and other prices, grower experience, existing marketing chains, and infrastructure. Here, empirical work is needed to identify economic barriers to switching to less water-intensive crops and production patterns.

Some adaptations are already underway. First, agriculture-to-agriculture water transfers (often short-term leasing arrangements) allow irrigators to reduce problems of supply uncertainty and shift water from lower to higher valued uses. Agriculture-to-agriculture transactions

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[186] 186. Keith H. Coble, G.A. Barnaby & Rodney Jones, *Crop Insurance in the Agricultural Act of 2014*, 29(2) CHOICES (2014), *available at* http://www.choicesmagazine.org/choices-magazine/theme-articles/deciphering-key-provisions-of-the-agricultural-act-of-2014/crop-insurance-in-the-agricultural-act-of-2014; Wright *supra* note 9.

[187] 187. CARL ZULAUF & DAVID ORDEN, THE US AGRICULTURAL ACT OF 2014: OVERVIEW AND ANALYSIS vi (Dec. 2014) (Int'l Food Policy Research Inst. Discussion Paper 01393).

[188] 188. COHEN ET AL. *supra* note 64; Frisvold et al., *supra* note 4, at 2194.

made up 20 percent of the volume of water traded under the 1991 California Drought Water Bank.[189] In the Colorado-Big Thompson Project area, 26 percent of water share trading involved agriculture-to-agriculture trades.[190] Indeed, intra-agricultural transactions account for a significant share of voluntary water-transfer arrangement throughout the West.[191] Changes in agricultural policy have also made it easier for growers to shift between different crops, removing policy barriers. Starting with the 1985 Farm Bill, subsequent agricultural legislation has systematically removed planting restrictions and reduced the role of farm income support programs tied to the production of particular crops.[192] Before the reforms, growers often had a disincentive to shift out of a particular crop because they risked forfeiting eligibility to certain government payments.[193] Growers today face fewer institutional disincentives to switch between crops in the face of, for example, water scarcity or price increases.

Hydro-economic studies also suggest that agricultural adaptation will be critical to *regional* adjustment to climate change. As noted above, agriculture adjusts production patterns and water use so that M&I uses adjust very little. Two factors account for this. The first is simple math: agriculture accounts for such a large share of regional water use that small percentage reductions in agricultural use imply large percentage increases in water available from other, non-agricultural uses. The second is simple economics: other water users are willing to pay much more per-acre foot for water than water's current value in most agricultural activities. There are several barriers, however, physical, geographical, institutional, and economic, that will complicate large-scale shifts between agriculture across regions and from agriculture to other uses. These barriers are non-trivial and may substantially limit agricultural and regional adaptation to climate change. Below we will discuss the nature of these barriers and what types of research could help overcome them.

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[189] Richard E. Howitt, Nancy Y. Moore & Rodney T. Smith, A RETROSPECTIVE ON CALIFORNIA'S 1991 EMERGENCY DROUGHT WATER BANK (Calif. Dept. Water Res. 1992).

[190] Charles W. Howe & Christopher Goemans, *Water Transfers and Their Impacts: Lessons From Three Colorado Water Markets,* 39(5) J. Am. Water Res. Assoc.1055, 1058–60 (2003).

[191] From 1997 to 2005, agriculture-to-agriculture water leases were the most common type of water lease across 15 western states, with more than 6.5 maf of water exchanged over that time. *See* Jeddidiah Brewer et al., *2006 Presidential Address Water Markets in the West: Prices, Trading, and Contractual Forms,* 46(2) ECONOMIC INQUIRY 91, 104 (2008).

[192] Frisvold, *supra* note 144, at 3.

[193] George B. Frisvold, Paul N. Wilson & Robert Needham, *Implications of Federal Farm Policy and State Regulation on Agricultural Water Use, in* BONNIE G. COLBY & KATHARINE L JACOBS, ARIZONA WATER POLICY: MANAGEMENT INNOVATIONS IN AN URBANIZING, ARID REGION (ISSUES IN WATER RESOURCE POLICY) 137–56, 141 (Resources for the Future, 2007).

One challenge of climate change is that demands for water are often in different places from available supplies. For this reason, several studies highlight the need for future investments in water conveyance infrastructure.[194] Solutions to future water shortages will involve more than pouring more concrete, however. Large-scale water conveyance projects require substantial public investment, which make them public choices subject to public debate and approval. Conveyance projects will have environmental impacts that will require careful evaluation. Because they will likely involve federal funds and agencies, they will be subject to not only the National Environmental Protection Act process (often requiring Environmental Impact Statements), they will also have to consider implications for endangered species protection as well as conduct formal benefit-cost analyses. The public will have to identify priorities to best plan solutions for geographically disparate water supply and demand.

Questions will also arise about impacts of large-scale water transfers on water-exporting communities. Here, two types of analyses would be important for informing public debate. The first are empirical, positive analyses. For example, what have past large-scale transfers done to water-exporting communities? While larger regions may benefit from transfers, exporting regions can lose.[195] These losses may be short-lived, but that may depend on whether funds from transfers are reinvested in the local community or growers instead merely fallow acreage and discontinue agriculture, allowing "income flight" to other regions communities.[196] The second type of analysis is normative. For example, how *should* transfers be designed to limit losses and third-party damages in water exporting communities? Some possibilities involve compensation funds for agricultural labor and input suppliers, funds for community development, changes in state funding or taxation to account for reductions in county and municipal taxes and fees, and limits on the total volume of water that may be exported.[197] Support for public finance of projects, financed through taxes or bonds and approved by state legisla-

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[194] *See, e.g.*, Harou et al. *supra* note 28, at 8; Medellín-Azuara et al., supra note 34, at S87–S88.

[195] For a survey of such studies, see Chong et al., *supra* note 28, at 258.

[196] *See id.*

[197] *See id.*; Ellen Hanak, *Stopping the Drain: Third-Party Resistance to Water Marketing in California*, 23(1) CONTEMP. ECON. POLICY 59 (2005); Richard E. Howitt, *Empirical Analysis of Water Market Institutions: the 1991 California Water Market*, 16(4) RES. AND ENERGY ECON. 357 (1994); R. Howitt & E. Hanak, *Incremental water market development: The California water sector 1985-2004*, 30(1) CAN. WATER RES. J. 73 (2005); Bonnie G. Colby, Mark A. McGinnis & Ken Rait, *Procedural Aspects of State Water Law: Transferring Water Rights in the Western States*, 31 ARIZ. L. REV., 697 (1989).

tures or through referendums, will likely hinge on how well conveyance project proposals address both environmental impacts and effects on water-exporting communities.

Aside from physical and geographical barriers, there are also legal barriers to transferring water across basins and across state lines. While hydro-economic studies have demonstrated that allowing such transfers can greatly reduce costs of water shortages, the benefits of such trades (in the form of scarcity cost reductions) may be thought of as gross benefits. The economic value of relaxing supply constraints is easier to measure and model; consequently, benefits are easier to show in large-scale simulation models. Although studies often acknowledge the myriad legal, negotiation and other transaction costs in carrying out such trades, these costs are rarely modeled or measured. The same environmental and rural economic concerns that arise regarding conveyance projects will arise with inter-state water transfers. It would useful to have detailed case studies of past large-scale transfers. Such case studies could characterize the environmental and social disruptions of transfers and examine the extent to which they were mitigated. The case studies could also characterize transactions costs associated with the agreement and quantify the dollar value their magnitude. Quantifying environmental and social changes along with transactions costs in economic terms would provide better estimates of the *net* benefits of inter-basin or inter-state water trades.

Current water laws can create disincentives for agricultural water conservation. The salvaged water doctrine holds that any water conserved (and not used) by the holder of the water right becomes entitled to other senior water rights holders.[198] Under the beneficial use doctrine, the right to water conserved (and not used) may be deemed abandoned and forfeited.[199] Both these doctrines prevent irrigators from capturing any benefit from water conservation. Indeed, they may lose access to their water in the future. California provides one example of useful reform where conserved water can be treated as a beneficial use and not subject to forfeiture.[200] Allowing water trades from agriculture could provide irrigators with economic incentives to conserve water and sell sur-

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[198] Peter W. Culp, Robert J. Glennon & Gary Libecap, *Shopping for Water: How the Market Can Mitigate Water Shortages in the American West*, Discussion Paper 2014-05, THE HAMILTON PROJECT, 14–16 (2014). The salvaged water doctrine has been applied in Colorado. *Id.*; *see also* S.E. Colo. Water Conservancy Dist. v. Shelton Farms, Inc., 187 Colo. 181, 529 P.2d 1321 (1974).

[199] Culp et al., *supra* note 198, at 16.

[200] *Id.*; Chong *supra* note 137, at 244.

plus water.[201] Water, thus, can become just one more commodity that irrigators may sell or lease out, providing another source of income.

Current federal policy toward agricultural adaptation may be summarized as follows. The USDA is instituting policies to subsidize improved irrigation systems and greater use of state-of-the-art weather and climate information. It is trying to provide more tools for growers to better adapt to climate change. At the same time, however, it is providing farmers with generous insurance and disaster assistance payments that act more as transfer payments than risk reduction tools. In short, federal policies are attempting to provide farmers with better means to adapt to climate change and variability, but also providing generous payments when farmers do not adapt. The extent to which such payments undermine incentives for adaptation is an empirical question and the potential that federal agricultural policies are working athwart adaptation goals merits continued scrutiny.

Finally, informational barriers hamper agricultural adaptation to climate change. First, it is difficult to get current and consistent data on agricultural water use. The recent Pacific Institute study expresses the point well:

> State and federal agencies frequently report inconsistent irrigated land and water use information for areas within the Colorado River basin, obscuring key basin issues and hampering efforts to reconcile the basin's water supply and demand challenges.[202]

The USGS reports data on water withdrawals (water taken from ground or surface sources) at five year intervals, with the most recent surveys from 2005, 2000, 1995, and so on.[203] The USDA reports irrigation applications to fields from 2013, 2008, 2003 and so on.[204] Withdrawals and applications are not measured in the same way and neither directly measures consumptive use, which is the actual amount of water "used up" and lost to the hydrological system. For the purposes of measuring whether agricultural water conservation is truly occurring, consumptive use measures are critical. Yet, the last attempt to report consumptive use on a state and national scale was carried out by USGS 20 years ago, in

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[201] Culp et al., *supra* note 193, at 16; Chong & Sunding, *supra* note 137, at 244.

[202] COHEN ET AL., *supra* note 64, at vi.

[203] *See* U.S. GEOLOGICAL SURVEY, U.S. DEP'T. OF THE INTERIOR, WATER USE IN THE UNITED STATES (March 05, 2015), http://water .usgs.gov/watuse/ (past USGS survey reports).

[204] *See* U.S DEP'T. OF AGRIC., CENSUS OF AGRIC., 2012 CENSUS PUBL'N (Feb 20, 2015), http://www.agcensus.usda.gov/Publications/2012/ (past USDA Farm and Ranch Irrigation Survey Reports).

1995.[205] The Bureau of Reclamation reports consumptive use of water along the Lower Colorado River mainstem annually.[206] Yet, even these estimates are indirect measures based on water diversions and crop evapotransporation estimates.[207] Without good measures of consumptive use, it is difficult to estimate whether changes in on-farm irrigation efficiency are translating into actual water conservation.

As noted earlier, increased application efficiency does not necessarily conserve water at the irrigation district or watershed level. While the USDA's EQIP program has a stated goal of achieving substantial agricultural water conservation, the evidence to date of the programs effectiveness is not encouraging.[208] More empirical studies are needed that determine which constellation of economic, hydrological and institutional factors lead to system-wide water conservation.

Moreover, simply supplying information on websites and through web-based decision tools may not be enough. There are significant subpopulations in the Southwest that still have limited Internet access and do not use computers for many farm production decisions. This is especially true in the Four Corners area.[209] Aside from geography, smaller scale producers are less likely to use modern scientific methods to schedule irrigation or make other water management decisions.[210] Further, there is no one-stop shopping for water management information. Irrigators rely on multiple information sources and many do *not* rely on university extension or USDA specialists.[211] More research on *demand* for climate adaptation and water management information and barriers to information use would help design both climate adaptation portals and non-web resources that underserved farmers find useful.

Several analyses discussed here view agriculture-to-urban reallocation of water as a fundamental regional adaptation to climate change in the Southwest. Such reallocation, however, is often treated primarily as an engineering problem. Yet, many legal and institutional barriers exist to large-scale water transfers. Improved irrigation efficiency and climate information systems are also seen as keys to managing water

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[205] WAYNE B. SOLLEY, ROBERT R. PIERCE, & HOWARD A. PERLMAN, U.S. GEOLOGICAL SURVEY, U.S. DEP'T. OF THE INTERIOR, ESTIMATED USE OF WATER IN THE UNITED STATES IN 1995 (1998), *available at* http://pubs.usgs.gov/circ/1998/1200/report.

[206] Lower Colorado Region Boulder Canyon Operations Office, Bureau of Reclamation, U.S. Dep't. of the Interior, *Colorado River Accounting and Water Use Report: Arizona, California, and Nevada* (2013) (the most recent report).

[207] *Id.*

[208] *See* Wallander & Hand, *supra* note 150, at 5–6; Pfeiffer & Lin, *supra* note 150, at 15.

[209] Frisvold et. al., *supra* note 4, at 225.

[210] Frisvold & Deva, *supra* note 121, at 569.

[211] *Id.*

scarcity and adapting to climate change. While technology-based solutions can play a positive role, they have limits. Improved irrigation efficiency does not necessarily conserve water. Instead, it may reduce return flows and groundwater recharge, reducing the quantity of water available to others. Technology subsidies to improve on-farm irrigation efficiency may not have their intended water-saving outcomes. Water rights, irrigation district rules, and water pricing policies all play a role in whether improved efficiency translates into actual water conservation. Climate information systems have shown great promise in improving irrigation management and adaptation to climate variability. Yet web-based information systems may be little used by the many farmers who still have limited access to and facility with the Internet. Moreover, the 2014 Farm Bill replaced traditional commodity programs with expanded crop insurance and disaster assistance—programs that create disincentives to mitigate and adapt to climate risks. Federal programs to provide farmers with better technology and information to adapt to climate variability may prove ineffective if other federal programs simultaneously provide them with generous economic incentives not to adapt. Technological fixes to conserve agricultural water and transfer it to other uses will likely fail to facilitate climate adaptation unless these technological fixes are accompanied by changes in water management institutions, policies, and economic incentives.