CHOICES

a publication of AAEA Agricultural & Applied Economics Association

The Magazine of Food, Farm and Resource Issues

3rd Quarter 2010 | 25(3)

THEME OVERVIEW: THE CHANGING NATURE OF AGRICULTURAL WATER ALLOCATION

Richard Howitt

In all regions of the United States, with the exception of the North East, water is a critical resource for agricultural productivity, environmental viability, and urban development. Over the past 70 years the growing pressures of water demand have been satisfied by the development of additional infrastructure for storage and distribution. Much of this infrastructure was publically financed, often with implicit or explicit subsidies. This supply system gave rise to an allocation system based on engineering efficiency and political patronage, thinly masked by cost-benefit analysis.

The ability to develop new supplies of water has been severely curtailed over the last two decades in nearly all regions by the interaction of three factors, namely the recognition of the environmental costs of water development, the dwindling supply of suitable water development sites, and the diminished political support for publically financed water infrastructure. The rise of the environmental movement led to the recognition that water was a central vector for many indices of environmental quality. This recognition shifted the political perception of water development from a positive sum game to a zero or negative sum game. This is not a new phenomenon, in 1906 John Muir protested in vain against the construction of a dam across the Hetch Hetchy Valley in Yosemite National Park to supply water for San Francisco. In addition to environmental problems, water infrastructure developers select the cheapest and most promising sites first. Thus, even when measured in the strictly physical terms of the ratio of cubic yards of soil and rock moved per acre foot of water stored, the remaining potential water storage sites are about one third as efficient as the earlier developments. When the increasing real costs of infrastructure development are factored in, the real cost of water storage and conveyance has increased dramatically over the past 60 years.

The rapidly rising real scarcity cost of water has been matched by an increase in demands for urban and environmental water. This increasing competition for water long critical to agricultural productivity has changed the standard response to water demand imbalance, from supply augmentation to a reallocation of existing supplies. Essentially, water has gone from a resource that was allocated by engineering efficiency and political expediency to a public commodity that has significant public good externalities associated with its storage, distribution, and use. This shift in the demand response method means that water allocations now have an important behavioral component that interacts with the physical component. In addition to the growing demands from urban and environmental users, climate change will very likely diminish the potential supply of developed water and the reliability of water supplies will also be reduced by a wider variation in climate.

The five articles presented here have the common theme of showing how the recognition of the influence of economic behavior, when combined with technical hydrology, can lead to more predictable policy results. The topics range from the adoption of urban conservation in arid climates, to counter-intuitive outcomes of subsidized technology on extensive high plains agriculture. They also examine ground water use and irrigation feedback loops, ethanol production impacts on water use and quality, and the implications for California agriculture of adapting to potential climate change.

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3rd Quarter 2010 | 25(3)

THE ABC'S OF APPLES, BEES, AND CONNECTIONS HYDROLOGIC

Garth Taylor, Bryce Contor, and Joel Hamilton
JEL Classifications: Q25

Exploding municipal, energy, agricultural and environmental water demands are colliding with limited or declining supplies. New infrastructure to increase water supplies has become economically prohibitive and environmentally indefensible. Environmental issues and changing patterns of water use are forcing water managers to search for new ways to reduce demand and redistribute supply. Agriculture, being the least valued and largest water user—over 80% of water diversions in the West—is often viewed as the principal target of reallocation. While the prior-appropriation no-harm rule addresses many third-party impacts, there is no comprehensive methodology for addressing the economic and hydrologic connections that result from the changes in the form, place, and timing of water supply and demand that accompany water reallocation. The result exacerbates conflict in water reallocation, symptomatic of market failure.

Defining Hydro/Economic Externalities

Economic externalities occur when the activities of one entity affect the activities of another entity and no pecuniary remuneration occurs. The divergence between private and social benefit/cost resulting from externalities results in price/market institutions failing to sustain desirable activities or curtail undesirable activities (Bator, 1958). Using the classic example of apples and honey, Meade(1952) illustrated the concept of interrelated production functions and externalities. A bee-keeper whose bees obtain nectar from apple blossoms is the recipient of a one-way positive externality. However, the bees reciprocate by fertilizing the blossoms for an apple grower. Thus the apple grower also benefits from a reciprocal positive externality. In Meade's example, the effects are externalities because the interrelated production relationships are unpriced and uncompensated, that is, the property-rights are not assigned.

Similarly, surface/groundwater connections can result in either one way or reciprocal externalities. The surface water to groundwater hydrologic connection can recharge aquifers via canal seepage and/or in-field percolation. When the aquifer is nothydraulically connected to the water course—river, reservoir, or canal—water passively seeps through an unsaturated zone, providing water to groundwater pumpers. If the passive seepage is unpriced, the pumper is the recipient of a one-way positive externality. The interrelated function that defines this one-way externality is that demand for canal water, and therefore canal delivery quantities, partially determines the groundwater supply for the pumper.

When the aquifer intercepts the zone of saturation of the canal, surface water is hydraulically connected to groundwater. The interaction is no longer one-way, but two-way; lowering of the water table by groundwater pumping induces additional seepage from the canal. Noting the water temperature differential between canal and groundwater, these connected wells are aptly labeled “warm water wells” (Strauch, 2009). With a reciprocal externality, groundwater pumpers not only enjoy the positive externality of passive seepage which is independent of pumping, they reciprocate by inflicting induced additional canal seepage by pumping water from the aquifer. The interrelated functions that define this reciprocal externality are that demand for canal water partially determines the groundwater supply for the pumpers while demand for well water partially determines water supply to the canal water users. Reciprocal externalities exist upon specific reaches of canals and many riparian aquifers.

We should caution that a negative or positive hydrologic externality depends solely on the production function of the externality recipient not on the externality producer. When canal seepage raises the water table and pumping costs are reduced, the externality is positive. When the rise in water table saturates soil and damages crops, the externality is negative. As an historical note, construction of many canal projects throughout the West was soon followed by construction of extensive drain systems to alleviate the negative externality of water logging.

Aquifers created or sustained by incidental recharge from unlined canals extend over vast areas in every western state. In the mammoth aquifers of Idaho's Snake River Plain and California's Central Valley, the increased recharge is virtually all from "infiltration of irrigation water" (Alley, Healy, LaBaugh, and Reilly, 2002). And the principal source of recharge to the Snake River Plain Aquifer is from canal seepage. Similarly, aquifers in Nebraska's North Platte, Washington's Columbia River Basin, Idaho's Boise Valley and others are created and/or sustained by canal seepage.

A Market Failure Example—"Buy and Dry"

A classic case of market failure with a hydro/economic externality is illustrated in the "Buy and Dry" of agricultural to urban water markets. An irrigation district, supplied by a canal, sells its water right to a distant city; water deliveries through the canal decrease or cease and the aquifer sustained by canal seepage declines. The groundwater pumper, even though she holds an adjudicated right, is damaged. Whom does she sue—the farmers that sold the water, the city that purchased it, or the state that allowed the transaction?

Lacking legal recourse, the groundwater user could seek redress through a water market. Here the market fails. The amount of water conveyed down the canal is determined solely by the demand and adjudicated right of the surface water users. A market failure is defined as a wedge or disparity between social and private benefits. The private beneficiaries are the surface water users because the water supplied through the canal is priced. The groundwater users, the recipients of the positive externality of canal seepage, wishing to dodge paying for seepage water, do not have their values for water represented in the price mechanism of a market. The market fails in that the amount of water conveyed down the canal is less than the social optimum—the sum of both surface water and groundwater users.

The market failure is perpetuated when water is sold to the city. When the marginal benefit of groundwater pumpers are excluded from the calculus in the water sale, the quantity of water sold to the city will be greater and priced less than the social optimum. Inviting the groundwater users into the sale negotiations would correct the failure by internalization of groundwater user benefits. However, from the canal user's perspective, the groundwater pumpers have been the beneficiaries of free water since construction of the canal. The costs of canal operation and maintenance, the costs of canal and storage construction, purchase of water from various suppliers, and damages resulting from warm water wells have been borne entirely by the surface water users. Further, inclusion of the groundwater users would not be in the city's interest. With the groundwater users represented at the sale, the socially optimal amount of water sold to city will decrease and the price the city pays for water will increase. Groundwater users fall through cracks of a failed legal system and market that does not address hydrologic externalities.

Remedies for Hydrologic Externalities

There are four general policy responses to remedy externality caused market failures: (1) Pigouvian tax on a negative externality or subsidy on a positive externality, levied to align the market price with the social price; (2) technological elimination; (3) markets or internalization through pricing; (4) regulatory or administrative fiat.

Idaho's Eastern Snake River Plain Comprehensive Aquifer Management Plan (CAMP) included language to "recognize the value of incidental recharge [from surface-water irrigation]." To fund the reallocation through buyouts or other means and increase water supplies from aquifer recharge, increased storage, or other ways, CAMP proposed a fixed per-acre rate charge. The highest rate was set for groundwater users—a rudimentary fixed rate Pigouvian tax, to discourage pumping damage on surface water. Ironically, funding of CAMP was legislatively blocked by some of the very canal companies who might have become subsidy recipients.

Canal lining is a widespread prescription to conserve water by technologically eliminating seepage. The touted benefits are decreased diversions, with the assumption that the "saved" water will be dedicated to other uses. Benefits must be weighed against the explicit costs of construction and the foregone benefits of seepage to groundwater users. However, deliberations typically ignore the reduction of recharge and the resulting impact upon aquifer users. In Oregon for instance, a portion of “conserved” water can be used to expand irrigation or transferred to other consumptive uses. Economically sound analysis requires that benefits be weighed not only against construction costs but also against the foregone benefits to groundwater pumpers and spring users. However, the U.S. Bureau of Reclamation (BOR) mandate is to provide surface water and private canal companies are authorized to assess for deliveries of surface water. Since the benefits to groundwater users are external to the mission and/or revenues of decision makers, groundwater users’ benefits are likewise generally external to deliberations.

Internalization through pricing requires ownership and control of the priced commodity. In the Grant County Blacks Sands Irrigation District, Columbia Basin of Washington, the BOR is attempting to assert ownership of groundwater, where that water can be directly attributed to canal seepage (Family Farm Alliance, 2010). Internalization by ownership would pave the way for pricing the benefit generated by seepage. However, this potential remedy for externalities, contravenes a long standing principle of prior appropriations; once one loses physical control of water—whether through surface returns or percolation to aquifers- the water reverts to public ownership.

Following the legacy of the prior appropriation, regulatory fiat is perhaps the most often invoked mechanism to remedy externalities. Within each of the past three years in Idaho, junior groundwater pumpers in the Eastern Snake River Plain have been “called out”—subjected to prior-appropriation regulation. However, when calls are stayed by legal action, the market failure persists. Another example of attempting to address externalities by fiat is Oregon's practice of regulating groundwater pumping " in unconfined alluvium—sands and gravels—within 1/4 mile of the banks of a stream or water surface." (Oregon Department of Water Resources). As with any regulatory remedy, arbitrary set back regulations implicitly rank the damages of induced seepage incurred by surface water users as greater than the economic benefit of groundwater users within the setback band. An additional problem with regulatory fiat is the lack of comprehensive consideration of all externalities and hydrologic effects. In Idaho, for instance, aquifer calls and conjunctive management rules have attempted to address the externality that groundwater pumping imposes upon surface water, but the larger externality of recharge from surface water irrigation was ignored until CAMP.

Hydrologic Externalities Can No Longer Be Ignored

Areas where the ground water aquifer is created or sustained by surface water irrigation are global. While hydrologists have a thorough understanding of the surface and groundwater connection, laws and property rights, and water policy have lagged in recognizing that connection. Following the legacy of prior appropriation doctrine, current water policy approaches are largely regulatory. We are all aware of the horror stories, where the legal and regulatory enforcement or litigation costs exceed the value of the water. In the forthcoming seismic shifts in water use, continued reliance upon regulation of hydrologic externalities will only increase the potential for catastrophic market failures or inefficient water use that a water scare society can no longer afford. Having framed the surface to groundwater hydrologic connections as economic externalities, we offer the power of economics as remedies: (1) Pigouvian taxes on pumping or subsidies for canal conveyance, (2) internalization by pricing or markets, or (3) negotiated payments between pumpers and surface diverters. At the very least, we must identify and explicitly consider all the producers and recipients of hydrologic externalities.

For More Information

Alley, W.M., Healy, R.W., LaBaugh, J.W., and Reilly, T. E. . (2002). Flow and storage in groundwater systems. *Science* 296, 1985-1190.

Bator, F. (1958). The anatomy of market failure. *Quarterly Journal of Economics,* 782(3), 351-379.

Family Farm Alliance. (2010, August). Irrigators seek supreme court review in reclamation contract law case. *Water Review*. No. 83.

Meade, J. E. (1952). External economies and diseconomies in a competitive situation. *Econ. Journal* 62(9)

54-67.

Oregon Water Resources Department. (2010). Oregon Administrative Rule filed through May 14, 2010 for the Willamette Basin Program. Oregon Water Resources Department, Salem Ore. http://arcweb.sos.state.or.us/rules/OARS_690/690_502.html.

Strauch, D. (2009). Pathfinder irrigation district general manager. Mitchell, Neb. personal communication.

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IMPACTS OF BIOFUELS ON WATER SUPPLY: PROPOSED CURES MAY WORSEN THE DISEASE

Ray Huffaker
JEL Classifications: Q25, Q48

The Energy Independence and Security Act of 2007 set a target of 36 billion gallons of biofuel by 2022—a five-fold increase over 2007 production (The Act is located in 42 USCS §7545(o)(2)(B)(i)(I)). Fears are that an expansion of this magnitude could increasingly stress scarce natural resources—primarily arable land and water—and consequently increase the prices of food and feed which compete for the same resources (Doornbosh and Steenblik, 2007; The Economist, 2008; Monblot, 2008; The Wall Street Journal, 2007).

The National Academy of Sciences (NAS) recently issued a report investigating the potential impact of biofuel production on water availability, and identified "agricultural practices and technologies" to conserve water (National Academy of Sciences, 2007). The report reasoned that expanded ethanol production can increase water scarcity if biofuel crops are grown in dryer regions requiring new irrigation, or are substituted for crops requiring less irrigation. It proposed the adoption of improved irrigation technologies "that reduce the amount of water applied per unit of biomass produced" as "one of the most important ways to mitigate any effects that increased biofuels production may have on water resources." (p.28)

The NAS report also reasoned that the water demands of biorefineries could worsen water scarcities locally. Biorefineries producing corn ethanol consume 'process' water that evaporates from cooling towers and evaporators during distillation. For example, in Minnesota, biorefineries consume from 3.5 to 6 gallons of water per gallon of ethanol produced (Institute for Agriculture and Trade Policy, 2006). The NAS report proposed water recycling within biorefineries as a conservation measure designed to reduce the "consumptive use of water." (p. 5) Biorefineries can employ water treatment technologies to purify unconsumed process water so that it can be recycled within the plant or discharged to freshwater sources.

The cures proposed in the NAS report may worsen the disease. An in-depth look into the hydrologic impacts of adopting improved irrigation technologies in growing biofuel crops, and of recycling water in biorefineries, demonstrates that these mitigation measures may unintentionally increase water scarcity from biofuel production (Huffaker, 2009).

Adoption of Improved Irrigation Technologies

Consider the following hypothetical:

A traveler withdraws $100 from a non interest accruing bank account for cash to spend on a trip. She spends $60 on her trip and redeposits the unspent $40. Can she save money by reducing the withdrawal from $100 to $75 if she continues to spend $60 on her trip?

No, she cannot save money simply by reducing the withdrawal! In both cases, her bank account is reduced by the $60 she spends on her trip. The key is that she redeposits the unspent cash that she withdraws. If she wants to save money, she has to spend less on her trip. The only way she saves money by withdrawing less cash is if she always spends all of the cash on her trip. In such a case, she would save $25 = $100 -$75.

This hypothetical may seem overly simple to shed much light on the complex issue of whether adoption of improved irrigation technologies conserves water. Not so—the same principles apply! Surprisingly, water policy worldwide falls prey to the misconception that savings can always be measured by reductions in withdrawals.

Consider the above hypothetical recast in the context of irrigated agriculture:

An irrigator has water rights to withdraw 100 units of water from a river to grow a crop over a growing season. The crop consumes 60 units of the withdrawn water…

The rate at which crops consume water depends on crop size and atmospheric evaporative demand (*ET*)—the sum of evaporation from open-water or moist-soil surfaces and transpiration from plants. On-farm irrigation efficiency is defined as the ratio of *ET* to applied water. If an irrigation technology is 100% efficient, then every unit of applied water satisfies the crop's *ET* demand. However, in practice, only a fraction of applied water is converted to *ET*. For example, graded furrow surface irrigation is characterized by efficiencies ranging from 50% to 80%, depending on field characteristics and how well an irrigator regulates set times and stream sizes. The irrigation technology in this hypothetical is 60% efficient since the 100 units of withdrawn water are converted to 60 units of *ET*.

…the unconsumed 40 units of water return to the river system in a usable form…

One reason for an irrigation technology to be less than 100% efficient is that it does not apply water uniformly over the field. Some parts of the field are over-irrigated—plants are flooded, and others are under-irrigated—plants are water stressed. Water in excess of crop ET requirements can recharge the surrounding hydrologic system via surface runoff to a river or deep percolation through soil into an aquifer. Both types of recharge constitute 'irrigation return flow'. In this hypothetical, all 40 units of unconsumed water recharge the river system.

…Can the irrigator conserve water by increasing on-farm irrigation efficiency from 60% to 80%, if crops continue to demand 60 units of ET?

No, the irrigator does not save water simply by increasing irrigation efficiency! Although the water withdrawal required for 60 units of *ET* is reduced from 100 units to 75 (= 60/0.8) units, the overall water supply continues to be reduced by the full 60 units of *ET*. The key is that water not converted to *ET*—irrigation return flow—recharges the water supply in the broader hydrologic system. Conservation requires that the irrigator adopt technologies reducing the *ET* demand of crops. *ET* demand can be reduced, for example, by adopting irrigation technologies that reduce evaporation from open-water or moist soil surfaces, by irrigating fewer acres, by switching to crops requiring less water, or by irrigating crops at a deficit. When irrigation return flow is an insignificant component of water supply, then reductions in water withdrawals constitute conserved water.

The irrigator conserves water by reducing withdrawals only if none of the water returns to the hydrologic system in a usable form. In such a case, she would save 25 = 100 – 75 units. This is the hydrologic world implicitly assumed by the NAS report when it reasons that improved irrigation technologies "that reduce the amount of water applied per unit of biomass produced" would "mitigate any effects that increased biofuels production may have on water resources" (p. 28). The implication that irrigation return flow is negligible where biofuel crops are grown is unjustified. For example, irrigation return flow is estimated to constitute almost half of the water diverted in the Western United States (Pulver, 1988). Western water laws protect appropriators from changes in upstream water uses that would reduce return flow constituting part of their water supply.

More importantly, policy that ignores the role of irrigation return flow in touting improved irrigation efficiency as a fail-safe conservation measure can be counterproductive. Such policy can give the illusion of water conservation, and worse yet, mask unintentional reductions in water supplies if more efficient water application increases crop demand for *ET* (Allen, Willardson, and Frederiksen 1997). The 'cure' worsens the disease! For example, a policy of increased on-farm irrigation efficiency in the North China Plain reduced pumping rates by 50%—giving the illusion of conservation, but failed to stem the rapid decline of groundwater due to increases in *ET*—thereby reducing deep percolation of unconsumed irrigation water recharging the aquifer. The study generating this result recommended that China protect the aquifer by reducing irrigated acreage (Kendy et al., 2003).

Water Recycling in Biorefineries

Let's revisit a modified version of the original hypothetical:

The traveler withdraws $100 from a noninterest accruing bank account for cash to spend on two trips. She spends $60 on the first trip, $20 on the second trip, and redeposits the unspent $20. Has she saved money by 'recycling' the withdrawn cash through another trip?

The traveler has not saved money. She has done the opposite since her bank account is reduced by the additional $20 spent on the second trip.

Similarly, each time process water is recycled through the biorefinery, evaporative losses increase, return flow decreases, and the overall water supply is reduced to the detriment of other users. The NAS report misses this hydrologic causal chain by mistakenly assuming that recycling reduces the consumptive use of water. Conservation policies should promote the adoption of new processing technologies that reduce evaporative losses.

There are problems with generally relying on improved on-farm irrigation efficiency in growing biofuel crops and recycling of process water in biorefineries as water conservation measures in biofuels production. This does not imply that these measures can not convey substantial benefits in other applications. For example, both measures can mitigate the impacts of biofuels production on water quality by reducing the throughput of water into farm and biorefinery production. Moreover, improved on-farm irrigation efficiency can convey substantial benefits at the field level including improved salinity control, reduced water-logging, reduced soil erosion, and reduced leaching of fertilizers and other chemicals. Policymakers must understand the hydrologic implications of these measures so that they are well applied to achieve desired outcomes.

For More Information

Allen, R., Willardson, L., and Frederiksen, H. (1997). Water use definitions and their use for assessing the impacts of water conservation. Proceedings of the ICID Workshop on Sustainable Irrigation in Areas of Water Scarcity and Drought.

Doornbosch, R., and Steenblik, R. (2007). Biofuels: Is the cure worse than the disease? Round Table on Sustainable Development, OECD.

New reasons to be suspicious of ethanol. (2008, February 28). *The Economist*, p. 28.

Huffaker, R. (2009). Protecting water resources in biofuels production. *Water Policy*, 12, 129-34.

Institute for Agriculture and Trade Policy. (2006). Water use by ethanol plants. Minneapolis, Minn.

Kendy, E., Molden, A., Steenhuis, T., and Liu, C. (2003). Policies drain the North China Plain: agricultural policy and groundwater depletion in Luancheng County, 1949-2000. Research Report 71, International Water Management Institute, Colombo, Sri Lanka.

Monblot, G. (2008). An agricultural crime against humanity. *Conservation Magazine*, 9.

National Academy of Sciences. (2007). Water implications of biofuels production in the United States. National Academies Press.

Pulver, R. (1988). Liability rules as a solution to the problem of waste in western water law: An economic analysis. *California Law Review,* 76, 671-726.

Ethanol backlash. (2007, November 12). *The Wall Street Journal*, p. A-16.

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CHOICES

a publication of AAEA Agricultural & Applied Economics Association

The Magazine of Food, Farm and Resource Issues

3rd Quarter 2010 | 25(3)

WATER-CONSERVING ATTITUDES AND LANDSCAPE CHOICES IN NEW MEXICO

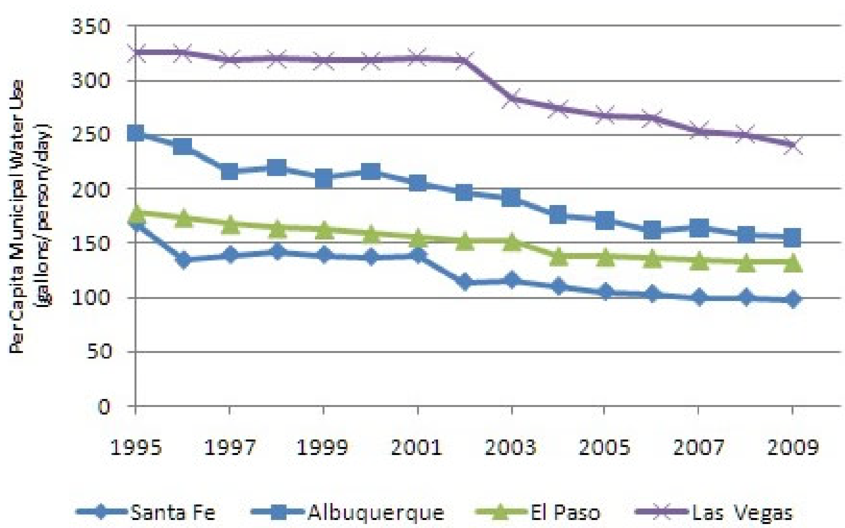
Brian H. Hurd
JEL Classifications: Q25, Q48

Communities throughout the arid western United States and in growing numbers in the relatively more water-abundant east are challenged by increasingly scarce water supplies, growing populations, and needed economic development. Communities desire secure, reliable water supplies, as well as a varied array of attractive public amenities including parks, open spaces, swimming and recreation facilities, public golf courses, and other water-intensive services. Water managers must balance these desires with the growing costs of system maintenance and expansion, all the while generating sufficient revenues to service these costs.

Municipal Waters and Household Choices

This balance is frequently achieved by community efforts to reduce per capita residential water use. Figure 1 shows successful reductions in several cities—a pattern that is repeated across the region. Economic incentives—such as increasing block rate structures where per unit water prices are higher for higher volumes consumed and rebates for water-saving appliances, fixtures, and landscapes—alone do not appear to explain the relative success that communities have achieved in reducing per capita water use. It appears likely that for many communities, water-use patterns have positively responded to noneconomic factors including heightened awareness and education, increased sense of duty, and responsibility to the community's resources and to neighbors.

Figure 1: Recent Trends in Per Capita Water Use for Selected Major Desert Cities

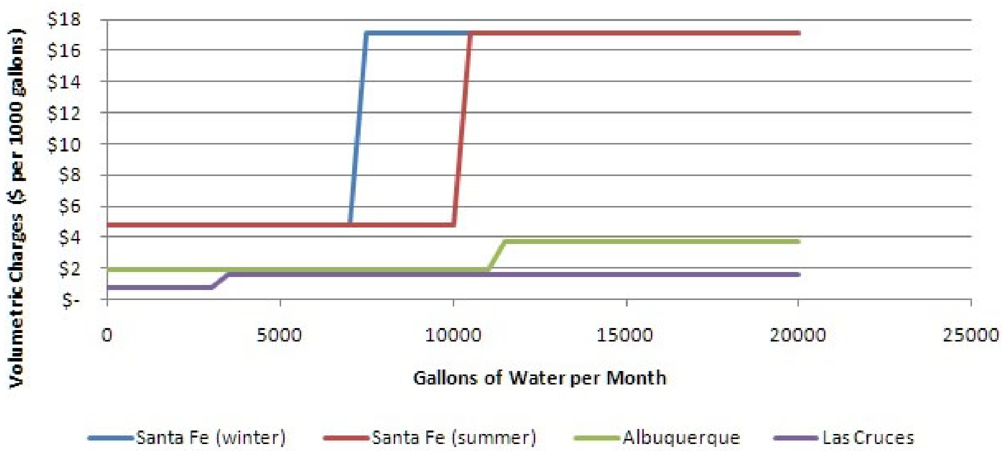


Municipal water conservation programs have found growing acceptance in communities throughout regions grappling with water scarcity and drought. Program elements often include economic incentives, such as rebate programs that reduce or replace turfgrass with water-wise landscapes and drought–tolerant vegetation and in some places provide credits for installing water-conserving fixtures and appliances. Communities are also encouraging conservation by replacing declining or flat rate pricing structures with increasing-block rates. However, in addition to public acceptability of rate changes, the utility must also meet its revenue requirements and avoid the ‘conservation trap’ in which reduced water use results in diminished revenues and hence the need to raise rates even further and risk the perception that water conservation success is being punished. This is a particular problem for systems where system-wide growth is leveling off and there are not sufficient numbers of new customers to offset revenue losses from conservation. That is an important and recognized problem that confronts successful water conservation and drought management programs. In fact, the city of Las Cruces’ water conservation ordinance explicitly addresses this problem and implements program monitoring and economic evaluation to ensure that the program will “remain revenue neutral on utility operations” (City of Las Cruces Water Conservation Program, page 15).

Resistance to higher water rates and limited program resources for financial incentives means greater reliance on noneconomic approaches and public appeals for wise–use and ‘correct’ behavior. As public resources are directed into such programs, concerns are raised about their effectiveness and performance. Assessments of public attitudes and the barriers to changing behavior can provide both quantitative and qualitative measures of conservation program impacts and effectiveness and are the subject of recent research in New Mexico (Spinti, St-Hilaire, and Van Leeuwen, 2004; Hurd and Smith, 2005; Hurd, 2006; Hurd, St-Hillaire, and White, 2006).

In New Mexico water conservation programs have been very actively developed in all of the urban areas, including the major cities of Santa Fe, Albuquerque, and Las Cruces. Each of these cities, for example, have revised their water rates structures, and all have an increasing-block structure to volumetric pricing in addition to fixed monthly charges. Figure 2 compares the current volumetric pricing for each of these cities, and shows that Santa Fe has the most aggressive volumetric pricing policy as well as the highest fixed charge of $14.54 per month—compared to $11.41 and $6.82 in Albuquerque and Las Cruces, respectively. This disparity is explained in part by Santa Fe’s recent acute shortages and heightened need for conservation as well as raising revenues for infrastructure expansion.

Figure 2: Volumetric Water Use Rates as of September 2010 for Selected New Mexico Cities



In addition to conservation pricing, additional incentive and rebate programs have been offered. For example, Albuquerque currently offers single-family residences a water bill credit of $0.75 for every square foot of lawn converted to Xeriscape up to 2,000 square feet, and has rebate programs for high-efficiency showerheads, toilets, washing machines, and hot water recirculation systems. Until July 2010, Santa Fe had a rebate program for washing machines, high efficiency toilets, and rain barrels; though successful it was discontinued due to limited funds. And Las Cruces, while not providing direct incentives or rebates, offers education and occasional workshops in residential landscape planning and implementation (Santa Fe Sangre de Cristo Water Division, 2010; Albuquerque Bernalillo County Water Use Authority, 2010; City of Las Cruces Utilities

Dept., 2010).

Household Perceptions of Water Importance and Personal Responsibility

Irrigating the urban residential landscape usually accounts for 40-70% of household water use. Additionally, residential landscapes receive 30 to 40% more water than typically required by the common types of plants and grass. Estimates of potential water savings range from 35% to 75% of current per capita water use based on a typical home with a traditional bluegrass type landscape (Sovocool, 2005). Improvements in the efficiency of landscape irrigation could yield significant water savings and is properly the focus of municipal water conservation programs.

In 2004, a mail survey was conducted of 1,216 households in Santa Fe, Albuquerque, and Las Cruces, New Mexico to gather data on household water conservation, preferences and attitudes toward landscapes using accepted protocols (e.g., Dillman, 2000). Survey findings from 423 completed responses were compared to 2000 Census data and, although the sample was higher than the general population in levels of both education and income, that is not too surprising given that the sample is based on home ownership, which is likely to correlate with higher levels of both income and education. The primary focus of the survey was to collect data on landscape preferences in order to model landscape choices and the important factors that affect a homeowner’s landscape decisions. Summary findings from selected survey questions are given below, however the technical details and results from the choice modeling are more completely provided in Hurd (2006).

Two key factors that determine how receptive a household might be to both economic and noneconomic efforts to change their water-use and landscape choices is the degree of perceived importance of water-stress within their community and the perception of personal responsibility toward water conservation in general. It is expected that residents who tend to consider water-stress within their community as important and that those who are more considerate of their own personal responsibility will more likely be influenced by water conservation programs. And this could indicate if there would be an increased likelihood of making actual changes in their landscape and water-use choices and behaviors. Key findings suggest that homeowner attitudes and perspectives regarding importance of water issues and personal responsibility for water conservation are generally strong.

Figure 3: Homeowner Perceptions of Relative Importance of Water—Stress in Their Community

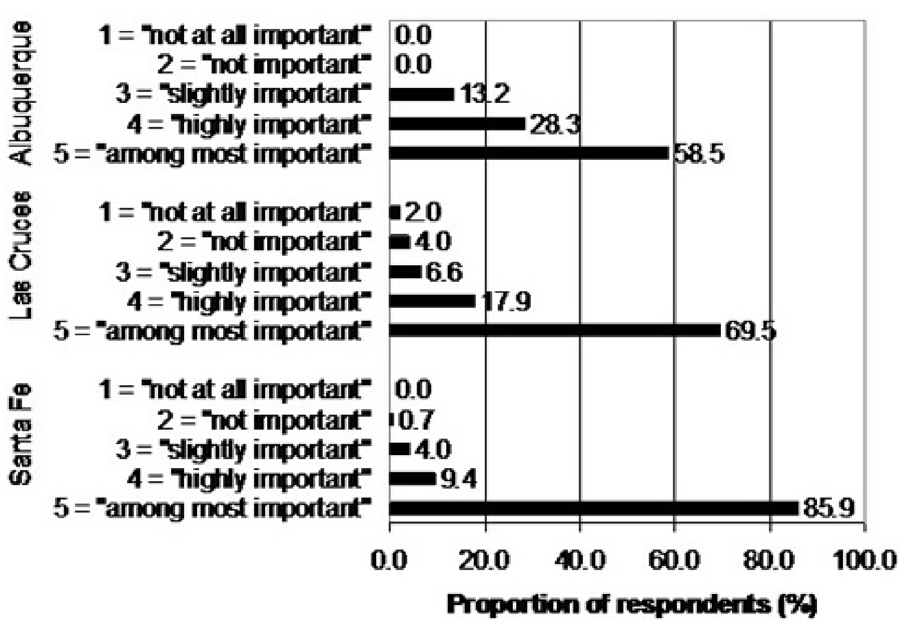
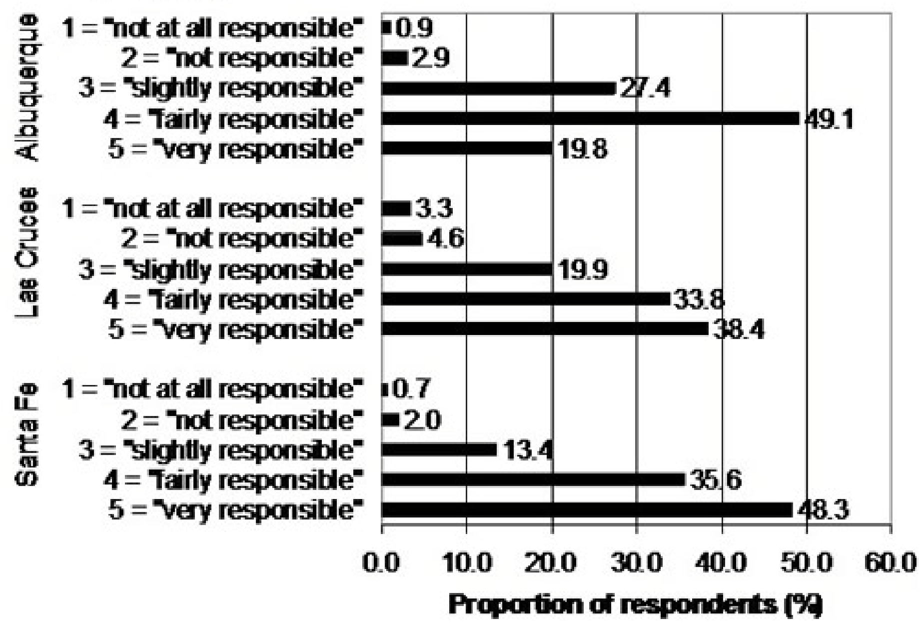


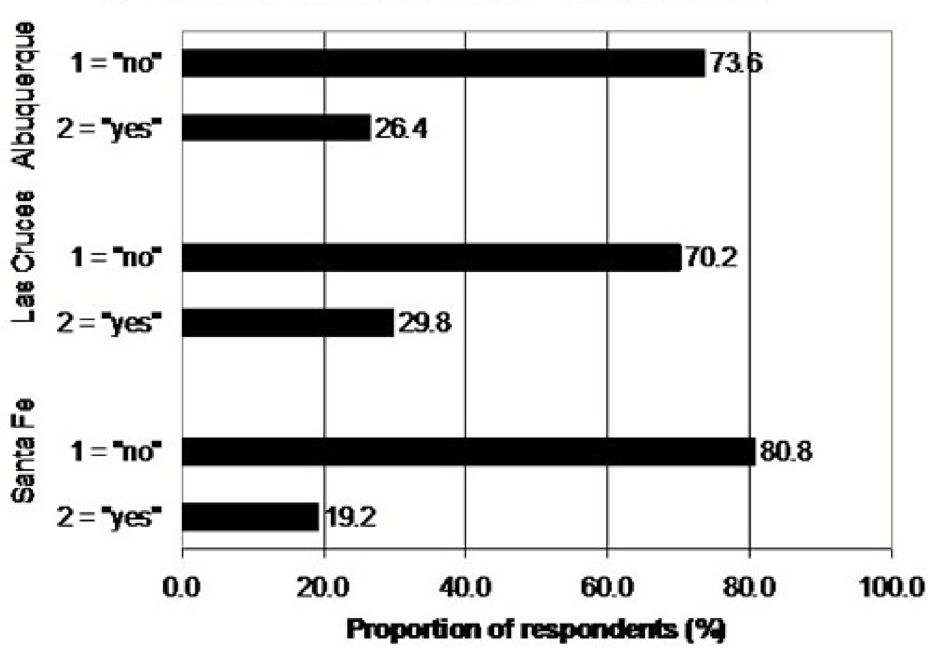
Figure 4: Perceived Degree of Household Responsibility for Water Conservation



Is Cost a Barrier in Landscape Choice?

Water-intensive lawn landscapes are increasingly giving way to more water efficient and climate appropriate landscapes. Acceptance of water-conserving, Xeriscape landscapes appears to be growing, though the rate of adoption seems to be lagging and suggests that significant barriers may well exist (Spinti, St-Hilaire, and Van Leeuwen, 2004). Effective municipal water conservation programs will better achieve significant per capita water savings by identifying and addressing key barriers and triggers that otherwise impede change.

Figure 5: Is Cost Perceived as a Barrier to Xeriscape Adoption?



Transitions toward water-conserving landscapes can be induced or hindered by desires of consistency with neighboring landscapes, cultural constraints—such as preconceptions of residential landscape or familiarity and comfort with traditional turfgrass lawns, and ultimately by access to and availability of sufficient time and money. Figure 5 shows how homeowners responded when asked if cost was a prohibitive factor in considering whether or not to adopt Xeriscape.

Additional findings suggest that:

1. The use of water-saving devices is quite widespread, with more than 90% of these households reporting at least one device such as a low-flow toilet, faucet or showerhead.
2. Santa Fe residents tend to identify strongly with relatively more natural and native landscapes. With less than 10% of landscape in lawn, 61% of Santa Fe residents report being content with their existing landscape, more than either Albuquerque (55%) or Las Cruces (56%). This suggests that there is a significant share of households, particularly in Albuquerque and Las Cruces that might consider landscape changes with improved outdoor water-use efficiency.
3. There is considerable interest by 15% of these homeowners in learning more about and seeking advice on landscaping. Perhaps this is a potential area for increased Extension and public education programs by local communities.
4. More than 80% of these homeowners indicated that water price is an important consideration in landscape decisions, even more than the 55% indicating the importance of community water-conservation programs.
5. There is broad support by nearly 95% of these households to use water-efficient landscapes around public buildings.

Moving Forward

Communities are realizing measurable success in reducing per capita water use, as residents alter their behavior and patterns of water use, adopt new high-efficiency systems, and adapt to more climate-appropriate landscapes in residential and public settings. Though changes in water rate schedules and limited availability of rebate programs have contributed to this success, something more profound appears to be motivating behavior than mere economics. The survey findings tend to confirm that water-use behavior can be affected by changing attitudes, awareness, and know-how. New Mexico's residents are, for the most part, mindful of water-conservation challenges and prepared to shoulder responsibility for stewarding the state's water resources. The findings further suggest that New Mexico residents are increasingly aware of the role of water in their communities and state. How households manage and use water to create desired landscapes and outdoor living spaces can be significant. For example, if residential outdoor water use could be cut by one-fourth in just the three communities profiled in this study, annual water savings could approach 6 billion gallons of treated, potable water—approximately 17,000 acre-feet. Conservatively valuing this saved water at a rate of $1 per thousand gallons yields, nearly $6 million savings would accrue to the residents of these communities.

Other water-stressed communities may find noneconomic factors attractive program elements in addition to changing water rates and rebate programs. However, it is probably short-sighted to consider these factors as replacements for incentive-based programs that are particularly helpful for achieving the lower levels of per capita water use.

For More Information

Albuquerque Bernalillo County Water Use Authority. (2010). Albuquerque water rate schedule. Available online: http://www.abcwua.org/content/view/220/408/, accessed: Sept. 9, 2010.

City of Las Cruces Utilities Department. (2010). Las Cruces water rates. Available online: http://www.las-cruces.org/financial_srvs/utility%20services.shtm, accessed: Sept. 9, 2010.

Dillman, D. A. (2000). *Mail and internet surveys: The tailored design method (2nd Edition)*. New York: John Wiley & Sons.

Hurd, B.H. and Smith, J. (2005). Landscape attitudes and choices: A survey of New Mexico homeowners. New Mexico State Univ., Las Cruces, N.M., Water Task Force Report 5. Available online: http://aces.nmsu.edu/pubs/taskforce/water/WTF_5.pdf.

Hurd, B.H. (2006). Water conservation and residential landscapes: Household preferences, household choices. *Journal of Agricultural and Resource Economics*, 31(2), 173-192.

Hurd, B.H., St-Hilaire, R. and White, J. (2006). Residential landscapes, homeowner attitudes and water-wise choices in New Mexico. *HortTechnology*, 16(2), 241-246.

Santa Fe Sange de Cristo Water Division. (2010). Santa Fe water rate schedule. Available online: http://www.santafenm.gov/index.aspx?NID=1773, accessed: Sept. 9, 2010.

Sovocool, K. A. (2005). Xeriscape conversion study: Final report. Las Vegas, Nevada, Southern Nevada Water Authority.

Spinti, J. E., St-Hilaire, R., and Van Leeuwen, D. (2004). Balancing landscape preferences and water conservation in a desert community. *HortTechnology*,14(1), 72-77.

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This study was funded by the New Mexico State University Agricultural Experiment Station and the Rio Grande Basin Initiative. Thanks also to Drs. Rolston St-Hilaire and John White for their collaboration and support, to Josh Smith for research assistance, and to the USDA Western Regional Project W2190 colleagues.

CHOICES
a publication of AAEA Agricultural & Applied Economics Association
The Magazine of Food, Farm and Resource Issues

3rd Quarter 2010 | 25(3)

CLIMATE CHANGE, MARKETS, AND TECHNOLOGY

Richard Howitt, Josué Medellín-Azuara, and Duncan MacEwan
JEL Classifications Q15, Q25, Q38

The impacts of climate change in arid areas will be mostly driven by changes in water scarcity. While regional rainfall changes are uncertain, the increase in temperature is forecast with much more confidence; temperature change is a strong driving force behind forecast reductions in irrigation water supplies. Even with relatively unchanged average rainfall, changes in the timing of precipitation will cause supply shortages.

Climate Change and Agriculture

Take the case of California as an example of the likely effect of climate change on agriculture in an arid region with a postindustrial economy. California agriculture is heavily dependent on irrigation so it may offer lessons for adaptation to climate change that can be applied to irrigated agriculture in other arid regions. Climate change will have negative effects on California's irrigated agriculture in terms of increased water scarcity, more variation in water supply, and lower yields due to heat stress. Parallel changes in technology and markets will partially or totally offset the negative effects.

Technological advances such as fertilizers, disease resistant crops, and mechanical improvements have increased crop yields in California by an average of 1.4% per year (Brunke, Sumner, and Howitt, 2004). While increased yields will help dampen the negative effect of a warm-dry climate, continued growth of 1.4% per year is likely not sustainable and is expected to level off in the future (Alston and Pardey, 2009). Even so, technological change will offset climate related yield reductions for some California crops.

The market for select California crops is expected to grow significantly in response to growth in income, population, and domestic and foreign demands. Irrigated production of crops in temperate regions is dominated by “commodity crops” such as corn, alfalfa, cotton, and rice that have an elastic market demand, and a negligible or negative income elasticity of demand. In contrast, the revenue from irrigated agricultural production in California and other arid areas is dominated by “middle class crops” such as fruits, nuts, and vegetables which have inelastic price and income elasticities of demand that are positive and quite significant. These elasticity differences greatly alter projections of climate impacts. The strong income elasticities of California specialty crops combined with growth in incomes in the United States and many Pacific Rim economies translates into a growing demand for these crops. In addition, the inelastic price response provides a revenue buffer against any downside production effects.

Another adjustment mechanism is the role of water markets, including both inter-sector, between agriculture and urban users, and intra-sector transfers. Water markets allow regions with low agricultural scarcity value of water to trade water to regions with high agricultural water scarcity values, in essence allowing water to flow to its highest value use. Regional differences in climate change effects could be offset by developing water markets.

Visualizing California Agriculture under Climate Change

In order to develop insights into the future of agricultural production in California we use a combined hydrologic-economic model of agricultural production in California (Howitt, Ward, and Msangi, 2001). To estimate water deliveries, and regional water constraints, under climate change, we use a larger hydrologic-economic model of the entire California water system (Draper, et al. 2003). Changes in water and crop yields due to climate change are explicitly included in the models in addition to technological change; we include an increasing urban footprint that reduces agricultural land area, population growth, and changing market conditions. Among the IPCC panel climate scenarios we consider the warm-dry scenario which yields a statewide-average 4.5°C temperature rise and an 18% reduction in precipitation by the end of the century (Cyan, et al. 2008).

We consider two future cases for California's Central Valley agriculture in the year 2050, under the IPCC warm-dry climate change scenario and under a scenario where climate remains unchanged. We contrast both of these cases with each other and a base year of 2005 and compare changes in agricultural production, water use, and revenues. To focus ideas we consider agriculture in the Central Valley of California, the main production region in the state. Agricultural commodities in California are collapsed into 12 representative crop groups: alfalfa, citrus, corn, cotton, field crops, grains, grapes, orchards, pasture, sugar beet, tomato, and truck crops.

California Agriculture from 2005 to 2050: Future Scenarios

Statewide, in 2005 California used 82 million acre-feet (maf) of water, of which 8.9 maf went to urban uses, 32 maf went to agriculture, and 41.1 maf went to other uses including habitat. In California's Central Valley in 2005 there was 8.3 million acres of irrigated agriculture which used 25.8 maf of water. The Central Valley is divided up into two regions for our analysis, the Sacramento and San-Joaquin Valley. These represent two distinct regions separated, loosely, by the Sacramento-San Joaquin Delta.

The status of Central Valley agriculture in 2050 depends on technological changes, market conditions, water availability, and climate change. Changes in yield will result from better technology, changes in markets will result from increasing population and income, and changes in water availability will result from an increasing urban footprint in the San Joaquin valley and other parts of the state, and the need to consider environmental habitat. All of these factors will be influenced by climate change, which we discuss in turn below.

Changes in Yield

Yield improving technological innovations for California crops are likely to grow at the historic rate of 1.4% per year until the year 2020. In 2020, physical photosynthetic limits and other factors will cause the rate of growth to plateau. Taking into account the average historical rate of growth until 2020, and capping the rate of growth thereafter, suggests an average increase in yield of 29% across all California crop groups by 2050. These yield increases are independent of climate change and thus offer a significant buffer against the yield reducing effects of warm-dry climate change.

The scientific consensus is that climate related crop yield changes are expected in California, and other regions, due to changes in precipitation and temperature. Changes in precipitation will lead to stress irrigation, where crops are irrigated at less than normal needs, with varying effects on yield depending on the specific crop. Similarly, temperature increases will change the timing of the growing season and have differential effects on yield across crops. Further complicating the story is that both changes in precipitation and temperature will vary significantly between regions under climate change. A handful of studies have been conducted which take these environmental conditions into account for California (Adams, Wu, and Houston, 2003; Bloom, 2006; Lee, De Gryze, and Six, 2009; Lobell, Cahill, and Field, 2007). Climate induced yield changes will vary across the two regions of the Central Valley. Table 1, below, summarizes the expected percent change in yield by 2050 under warm-dry climate change. The effect of climate change varies by both crop and region with crops like alfalfa expected to realize an increase in yields while vineyards are expected to realize a significant decrease.

Table 1

Expected Climate Related Yield Changes in California

Crop Group	Sacramento Region	San Joaquin Region
Alfalfa	4.90%	7.50%
Citrus	1.77%	-18.40%
Corn	-2.70%	-2.50%
Cotton	0.00%	-5.50%
Field	-1.90%	-3.70%
Grain	-4.80%	-1.40%
Orchards	-9.00%	-9.00%
Pasture	5.00%	5.00%
Grape	-6.00%	-6.00%
Rice	0.80%	-2.80%

Adapted from Howitt, Medellin-Azuara, & MacEwan, 2009

Changes in Market Forces

Market conditions for many "middle-class" California crops, including fruit, nuts, and vegetables, are characterized by inelastic demand and a positive income elasticity. In other words, consumers are not very responsive to changes in price and, additionally, are likely to buy more of these crops as incomes increase. Both of these effects are independent of climate change. Incomes in the U.S. and Pacific Rim economies are expected to grow significantly in the future, especially as China and other economies come online. At the same time, global population is expected to increase which will also lead to an increased demand for many California crops. Increasing population, income, and a muted response to increases in price suggests that California "middle-class" crops will be more profitable in the future. Additionally, this provides an incentive for growers of other crops, including rice, corn, and grains, to shift production into these more profitable specialty crops. The net effect is another revenue buffer against the effects of climate change.

In general, most crops prices are expected to increase by 2015 in real terms with a drop following afterwards. Thus rice, corn, and grain, "commodity crops," might experience price drops of 1.45%, 0.67% and 1.58%, respectively. This translates into demand shifts of -1.4% for rice, -17% for corn and -19.9% for grain, indicating that production shifts away from California. In contrast, for fruit, nuts, and vegetables, the so-called "middle-class" crops for which California has market power, population and income growth will increase demand. A U.S. population increase of 43% and income increasing by 2.5 times by 2050 translate into increases in U.S. demand for "middle-class" crops ranging from 3.44% for some field crops to 45% for vegetable truck crops (Howitt, Medellin-Azuara, and MacEwan, 2009).

Changes in Water Availability

Arguably the most important, and most popular in the media, effect of climate change is changes in water availability. In California's Central Valley, water is scarce and warm-dry climate change will put stress on water deliveries to agricultural locations as well as urban and habitat uses. For California under the climate scenario hypothesized in this paper, a reduction in precipitation of 27%, a reduction in inflows of 28%, and an increase of 15% in reservoir evaporation are expected (Medellin-Azauara, et al. 2008). In the Central Valley, groundwater inflows may be reduced by nearly 10% under this climate scenario. The expected reduction in water availability for urban and agricultural uses is summarized in table 2, below. In total, a 14% reduction in water is expected statewide, with a 21% reduction for agriculture and a much more modest 0.7% reduction for urban users.

Table 2

Expected Climate Related Reduction in Water Availability

Region	Agriculture	Urban	Total
California Statewide Total	21%	0.70%	14%

Adapted from Medellin-Azuara, Connell, Madani, Lund, & Howitt, 2008

California Agriculture under Climate Change

By 2050, climate change will have effects on water availability and on crop yields which vary significantly by region and crop. Under the same time frame, and unrelated to climate change, yields will increase due to technological innovations and the market for "middle-class" crops will grow significantly with growth in income and population. Changes in yield alter crop profitability, changes in water availability change the types of crops grown and the extent of the land area they use, and changes in market conditions impact the relative profitability of crops. Taking all of these considerations into account, what is the net effect on Central Valley agriculture and, by way of extension, agriculture in other arid regions? The net effect of climate change on agriculture can be summarized in terms of change in total irrigated crop land, water use, and agricultural revenues.

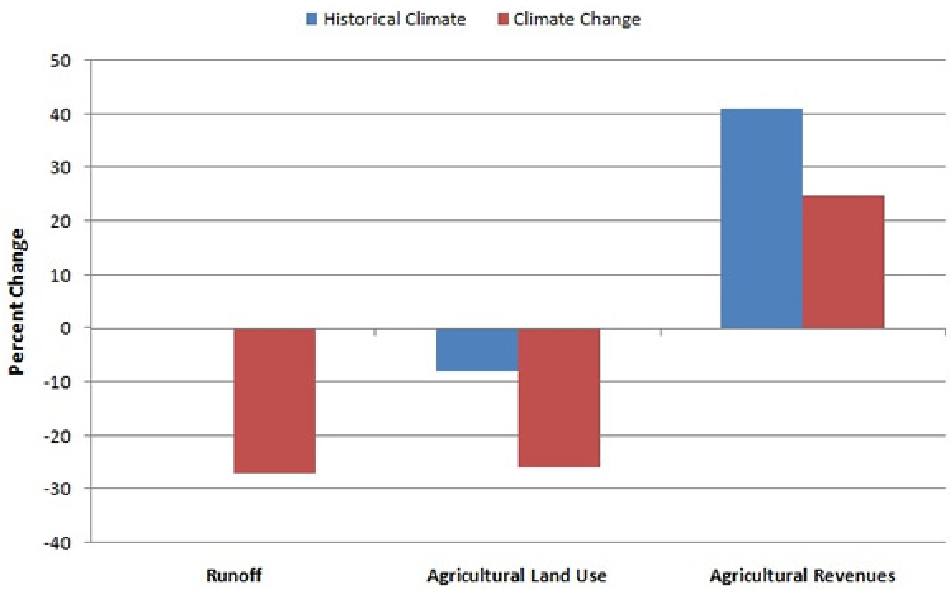
Without climate change, agricultural land use is expected to decrease by 7.3% in California's Central Valley by 2050. This is mostly driven by an increasing urban footprint as urban areas continue to expand into agricultural land. Under climate change, agricultural land use would be reduced by another 18.7%, for a total combined reduction of 26%. The additional decrease in land use is largely due to a reduction in water availability. Reduced water availability pushes marginal agricultural land out of production. So, in the future, California will have a smaller agricultural sector, in terms of total land use, both due to expanding urban footprint and reduced water availability.

Without climate change, total agricultural water use, applied water, will decrease by about 7% by 2050 to 23.9 maf by 2050. This is the result of a contraction in total irrigated land area and a shifting mix of crops in response to evolving markets. Under climate change however, total agricultural water use is expected to fall by an additional 19.3%, for a total reduction of 26.3% by 2050. The additional decrease in water use under climate change is due to several factors in response to a decrease in water availability. Adaptation of agricultural production to climate drives cropping patterns to more profitable and less water intensive crops making total water use reduce more than total land use in agriculture.

The combined effect of a change in total land use, water use, and shifting cropping pattern translates into changes in total agricultural revenues. Without climate change, agricultural revenues in the Central Valley are expected to increase from $20 billion in 2005 to $28.4 billion in 2050, an increase of 42%. Under climate change, agricultural revenues in the Central Valley are expected to increase from $20 billion in 2005 to $25.2 billion in 2050, a lesser increase of 26%. In short, climate change by year 2050 is likely to reduce agricultural revenues relative to a case of no climate change, such as the historical climate pattern. However, revenues will increase from the base year of 2005, as adjustments are made, including the more profitable and less water intensive crops that make up the 2050 future crop mix.

Figure 1 summarizes the percent change in water availability, agricultural land use, and agricultural revenues between 2005 and 2050 under the case of climate change and the case of no climate change, the historical climate.

Figure 1: Water Use, Land Use, and Agricultural Revenues under Historical Climate and Climate Change Adapted from Medellin-Azuara, Howitt, MacEwan, and Lund, 2010 In Review.



In isolation, the effects of climate change will have detrimental effects on agricultural production and revenues. However, the revenue losses are partially compensated by higher crop prices, technology, and adaptation to less water intensive crops. Figure 1 succinctly summarizes the future of agriculture in California's Central Valley under climate change. Water deliveries will be significantly decreased since water shortages for crops are expected to be a major outcome of climate change. Land use decreases mirror changes in water availability, and reflect the need to accommodate the 2050 urban footprint as well as a shifting of cropping patterns into higher valued crops on less land. This unused cropland with minimal water supplies will pose a challenge for conversion to environmental habitat.

Concluding Observations

The take-home message is that a contracting total area in agricultural production and decreases in water availability and yields due to climate change are offset by increased yields due to technological change, and increasing prices of select crops. The shift in agricultural production still results in an increase of agricultural revenues relative to 2005, although relatively less than the increase in revenues under a no climate change scenario. California's Central Valley becomes a smaller, but still more profitable, agricultural production region by 2050.

For More Information

Adams, R. M., Wu, J., and Houston, L. L. (2003). Climate Change and California, Appendix IX: The effects of climate change on yields and water use of major California crops. Sacramento, CA: California Energy Commission Public Interest Energy Research.

Alston, J., and Pardey, P. (2009). Theme Overview: Agricultural productivity and Food Security in the Long run. *Choices, 24*.

Bloom, A. J. (2006). Rising carbon dioxide concentrations and the future of crop production. *Journal of the Science of Food and Agriculture, 86*(9), 1289-1291.

Brunke, H., Sumner, D., and Howitt, R. E. (2004). *Future Food Production and Consumptionin California Under Alternative Scenarios*. Davis, CA: Agricultural Issues Center, University of California.

Cayan, D. R., Maurer, E. P., Dettinger, M. D., Tyree, M., and Hayhoe, K. (2008). Climate change scenarios for the California region. *Climatic Change, 87*, S21-S42.

Draper, A. J., Jenkins, M. W., Kirby, K. W., Lund, J. R., and Howitt, R. E. (2003). Economic-engineering optimization for California water management. *Journal Of Water Resources Planning And Management, 129*(3), 155-164.

Howitt, R. E., Medellin-Azuara, J., and MacEwan, D. (2009). *Estimating Economic Impacts of Agricultural Yield Related Changes*. Sacramento, CA: California Energy Commission Public Interest Energy Research.

Howitt, R. E., Ward, K. B., and Msangi, S. (2001). *Statewide Agricultural Production Model (SWAP)* (Appendix A). Davis, California: Department of Agricultural and Resource Economics. University of California.

Lee, J., De Gryze, S., and Six, J. (2009). *Effect of Climate Change on Field Crop Production in the Central Valley of California*. Sacramento, California: California Energy Commission Public Interest Energy Research.

Lobell, D. B., Cahill, K. N., and Field, C. B. (2007). Historical effects of temperature and precipitation on California crop yields. *Climatic Change, 81*(2), 187-203.

Medellin-Azuara, J., Connell, C. R., Madani, K., Lund, J. R. and Howitt, R. E. (2008). *Water Management Adaptation with Climate Change*. Sacramento, CA: California Energy Commission Public Interest Energy Research.

Medellin-Azuara, J., Howitt, R. E., MacEwan, D., and Lund, J.R., (2010). Economic Impacts of Climate Change on Agriculture in California. *Climatic Change. Under Review.*

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