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Theme Overview: Water Scarcity, Food Production, and Environmental Sustainability-Can Policy Make Sense?

Ariel Dinar

JEL Classifications: O13, O33, Q16, Q18
Keywords: Climate Change, Food Production, Institution, Policy, Water Scarcity and Quality

On May 27, 2016 in an election rally in Fresno, California, the heart of the agricultural production region of the San Joaquin Valley—which faces severe water problems—Donald Trump vowed to fix the California water crises. According to the Associated Press (Colvin and Knickmeyer, 2016) he declared that “there is no drought,” and that the California water problem is created because the water is sent out to the sea "to protect a certain kind of three-inch fish." Whether or not these statements are election rhetoric, they do reflect the confusion about water scarcity and social tradeoff in water allocation. As suggested by Rijsberman (2006), looking globally, it is difficult to determine whether water is indeed scarce in the physical sense or “whether it is available but should be used better.” Therefore, it is legitimate to be confused about whether or not water is indeed scarce and whether or not drought prevails.

Articles in this Theme

Dealing with Water Scarcity: Need for Economy-Wide Considerations and Institutions

Adaptation, Climate Change, Agriculture, and Water

Cost-Effective Conservation Programs for Sustaining Environmental Quality

Enhancing Water Productivity in Irrigated Agriculture in the Face of Water Scarcity

Role of Institutions, Infrastructures, and Technologies in Meeting Global Agricultural Water Challenge

Confusion exists about water scarcity, but much more confusion and disagreement prevails about policies and the means to address water scarcity. In an article published at the beginning of the millennium, Glieck (2003) compares 20th century water policies and those needed for the 21st century. Policies developed in the previous century were based on development of physical means, such as pipes and reservoirs. But the fact that many unsolved water problems, including in particular scarcity, remain or even worsened calls for a paradigm shift. Glieck’s term “soft path” calls for development and adoption of policies with non-structural means to allow for complementing of physical infrastructure with lower cost management systems, decentralized and transparent decision-making, use of pricing and water markets for water allocation, development and use of technological means, and incorporation of incentives for environmental protection considerations.

While the list of possible routes for a policy reform that addresses water scarcity and its implications is quite long, there have been attempts to follow it, some with more success and some with less success. The five articles in this special theme issue of *Choices* represent a subset of the issues at stake:

- The role of economy-wide policies, policies that consider all types of water, and investment in technological vs. non-structural research;
- Adaptation of the agricultural and water sectors to climate change;
- Incorporation of environmental consideration in cost-effective conservation policies;
- Challenges of agricultural water productivity for coping with scarcity; and
- Role of water institutions

In the opening article of the special theme issue, Ariel Dinar reviews the spatial water scarcity situation across continents and a few countries, using one of several available indices for water scarcity. He argues that there is enough evidence that natural processes, such as population growth, and water mismanagement are by themselves drivers of increased water scarcity in many countries and regions around the world. Fresh water resources are becoming a constraint to economic development and food production. Because water is part of various sectors' well-being, and because different sectors are involved in ”producing” and “consuming” various types of the water spectrum, they can be interlinked. The article suggests that a comprehensive approach—the economy-wide approach—can better address the water needs of and impact on a multi-sectoral economy and provide a better tool for assessing water policy interventions. Since a “soft path” is suggested for policies of the 21st century, social investment in research and development should not focus only on technical research leading to technologies, but also on institutions that have to be in place in order to allow such technologies to operate and decision makers to perform better.

Robert Mendelsohn focuses on adaptation as a strategy to allow the agriculture and water sectors to keep future climate change impacts at a modest level. Mendelsohn argues that since irrigated agriculture withdraws the lion’s share of available water resources, the growing scarcity of water is likely to have significant impacts on farmers, especially in semi-arid regions. Therefore, he calls upon both water managers and the farming sector to adapt to new scarcity circumstances that will even exacerbate with climate change, by introducing several institutional reforms, establishing the legal framework to allow water trade, providing incentives to switch to higher valued crops, improving the water application methods, and recycling water.

Roger Claassen and Marc Ribaudo review features of conservation programs for maintaining environmental quality under the impact of climate change and agricultural production. The article reviews several conservation programs administered by USDA including financial and technical assistance that are aimed at reducing these damages. However, the article identifies the cost-effectiveness of these programs as a challenge for their success. In particular, the authors suggest that the incentive system for farmers to adopt conservation practices through participation in the program may not be effective and needs to be better understood and improved.

The article by Susanne Scheierling and David Treguer addresses challenges related to enhancing water productivity in irrigated agriculture as a coping mechanism with water scarcity. The authors review several metrics that measure water use efficiency in irrigated agriculture. Obviously, they find that the term irrigation water use efficiency has as many definitions as the disciplines that calculate it. While this could not pose any problem in using irrigation water use efficiency for academic purposes, depending on the discipline, it may lead to major discrepancies when designing, implementing and assessing policy interventions to enhance water productivity in irrigated agriculture. The article provides some examples of how the estimation approaches used for calculation of irrigation water use efficiency may affect the policy recommendation. Omitted considerations may include (1) the scale of the calculation, that is, whether or not at the farm level or at the basin level and if all water involved (including return flows) is considered; (2) the physical and institutional constrains in the locality or region under investigation and the technological, legal, and institutional options. And, (3) whether or not the conserved water can be retained in the system, or will it be used by the water right holder that saved it to increase irrigated area (the expansion effect).

And last but not least, the article by Rathinasamy Maria Saleth, Nitin Bassi and Dinesh Kumar provides an overall institutional framework to deal with possible changes to the system that regulates scarce water resources in countries with large irrigated agricultural sectors. The authors argue that water challenges facing many agricultural countries can be addressed by acknowledging the institutional, infrastructural, and technological aspects—existing and proposed—of the system. The article establishes a framework for institutional linkages and impact pathways of water demand management that allows for the testing of policy interventions. It provides examples and evidences from different countries, and sketches a water demand management strategy that, the authors believe, can resolve water challenges, including scarcity and climate change impacts both within and beyond agriculture.

The special theme focused on a small list of policy issues associated with climate change and water scarcity in their interaction with agriculture and the environment. The "For More Information" section at the end of each article provides a list of references with more detailed analysis and discussion on this very complicated issue that traps many, including professional analysts, policy makers, and politicians.

For More Information

Colvin, J. and E. Knickmeyer. 2016. “Trump Vows to Solve California's Water Crisis” Associated Press, May 27. Available online: http://bigstory.ap.org/article/fea527c86dfe42c78609619c5ce7fd59/trump-vows-solve-californias-water-crisis.

Gleick, P. H. 2003. “Global Freshwater Resources: Soft-Path Solutions for the 21st Century.” *Science*, 302:1524-1528.

Rijsberman, F. R. 2006. “Water Scarcity: Fact or Fiction.” *Agricultural Water Management,* 80:5–22.

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Dealing with Water Scarcity: Need for Economy-Wide Considerations and Institutions

Ariel Dinar

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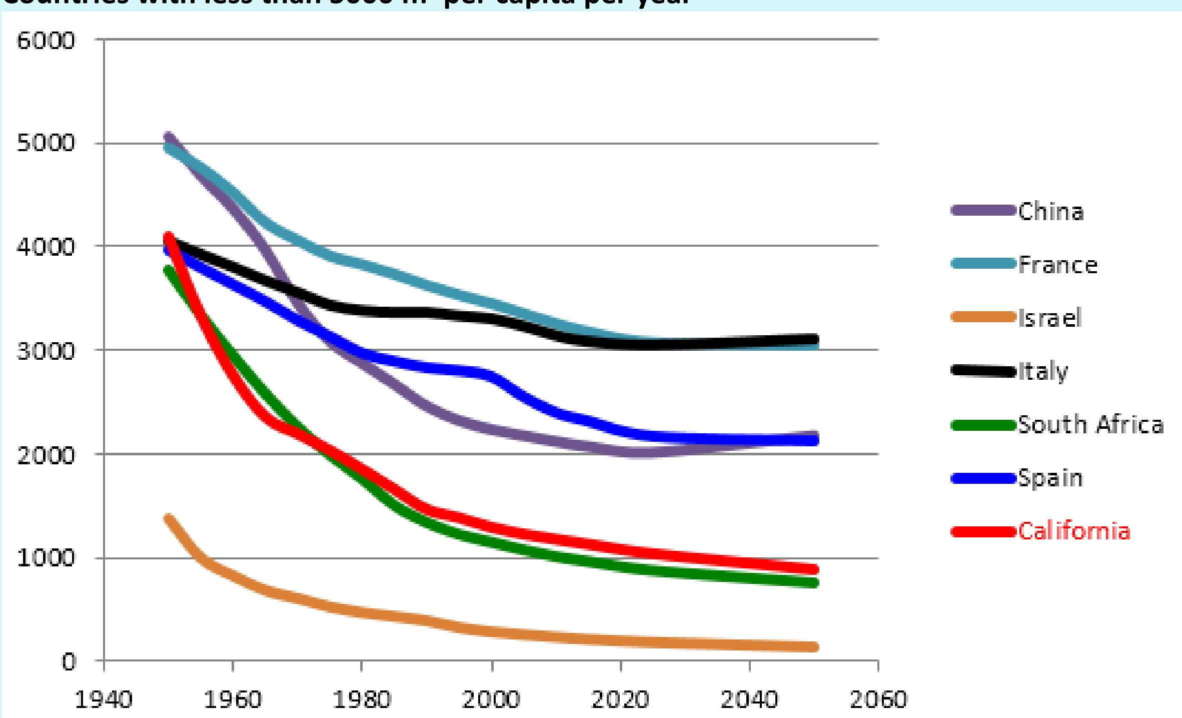
Keywords: Water Institutions, Water Policy, Water Pollution, Water Research, Water Scarcity

Much has been said on the state of water in the world. The starting point for the discussion about water scarcity is a simple arithmetic: The amount of water in circulation is more or less fixed and the world population increases over time. These two facts are by themselves sufficient to describe the inter-temporal and cross-sectional trends

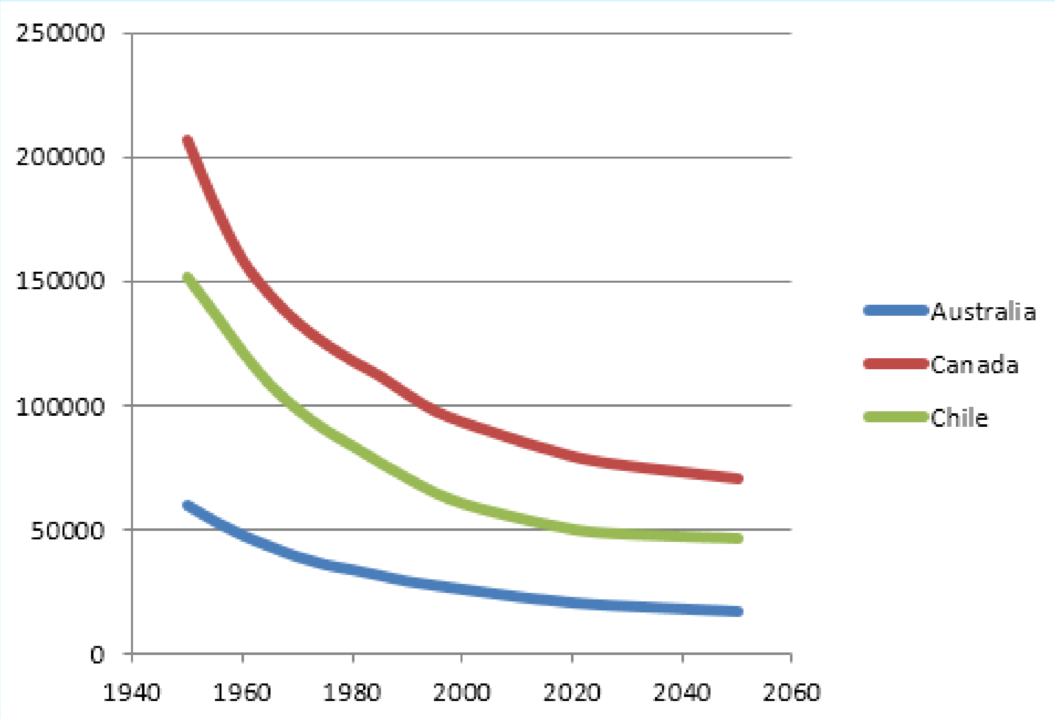
Figure 1a: Total Renewable Water Resources, Selected Countries and California, 1950-2050 (m^3 per capita)
Countries with less than 5000 m^3 per capita per year



Sources: U.S. CIA, 2015; USCB, 2016; Hanak et al., 2011; California Department of Finance, 2016
Notes: 1 acrefoot = 1,235 m^3.

that explain changes in scarcity of water. Figure 1 demonstrates such trends in selected countries around the world.

Figure 1b: Total Renewable Water Resources, Selected Countries and California, 1950-2050 (m^3 per capita)
Countries with 50,000-200,000 m^3 per capita per year



Sources: U.S. CIA, 2015; USCB, 2016; Hanak et al., 2011; California Department of Finance, 2016
Notes: 1 acrefoot = 1,235 m^3.

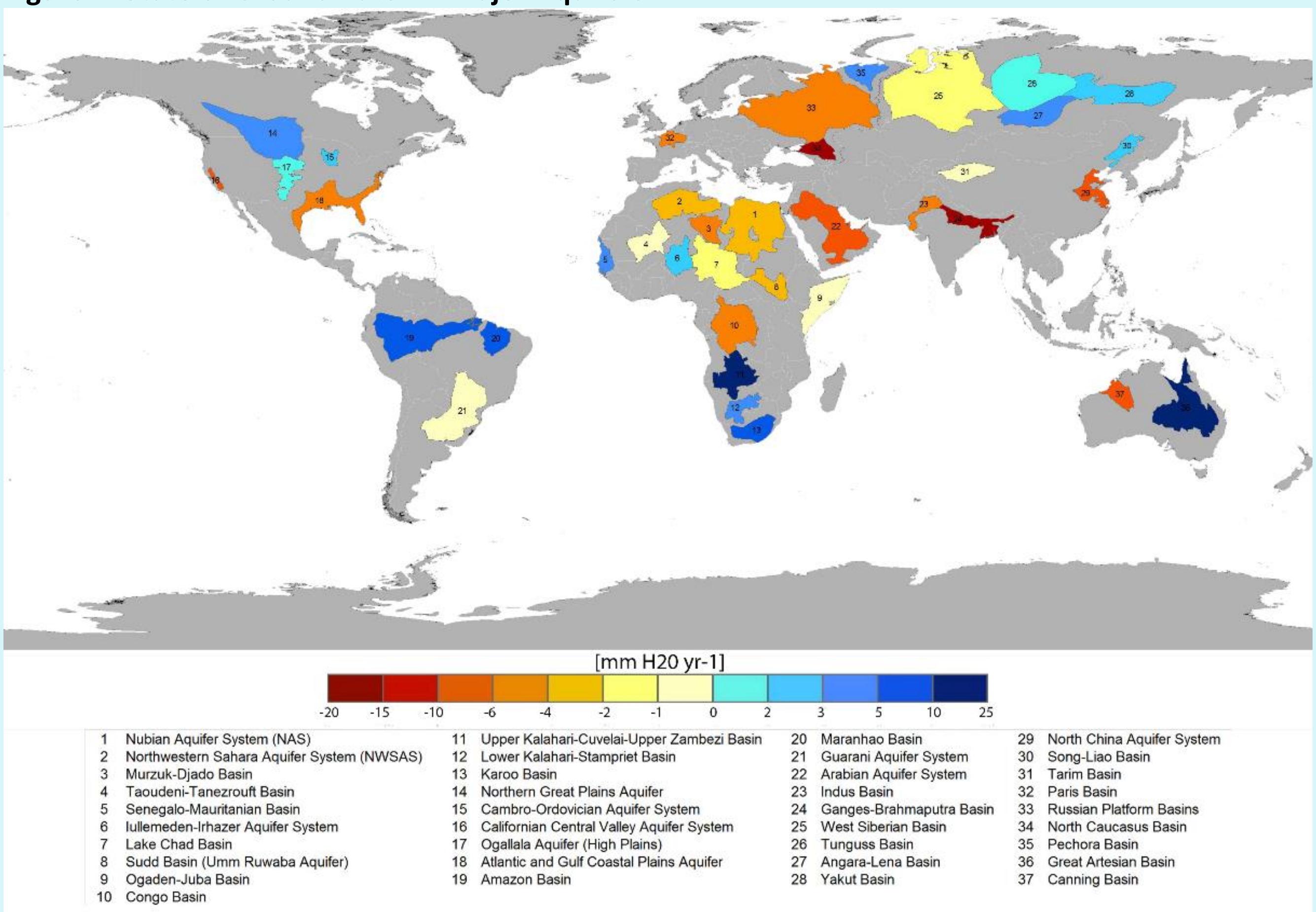
A simple metric of water scarcity is the water availability per capita. We calculate it for both water-endowed and water-short countries. Under ideal conditions of water resource management and with no external shocks, such as climate change, both affecting the availability and variability, respectively, over time and across landscape, our world faces increased scarcity of water. This scarcity under 'ideal conditions' is by itself devastating. Different regions and countries lost 50-75% of the available water per capita in the past 100 years. Add to that the loss due to mismanagement and external climate change shocks, and we face a catastrophic situation, especially in some parts of the world.

The substantial reduction in the available renewable water resources, on the one hand, and the increase in the water-consuming economic activities—for example for food production, increases in standards of living—on the other hand, lead to a widening gap between the water quantities supplied and demanded. Usually, such a gap is bridged in the short run by increasing the overdraft of available water stocks—namely groundwater aquifers. Indeed, 21 of the world's 37 largest aquifers around the world extracted more water than was recharged during a recent 10-year study period ending in 2014 (Ritchey et al., 2015) (Figure 2).

Such a gap between supply and demand is the result not only of the reduction in the available quantity, but also a consequence of the deteriorated quality of water resources, making them inadequate for consumption.

According to the International Food Policy and Research Institute (IFPRI) and VEOLIA (2015) human activities contribute significant amounts of Biochemical Oxygen Demand (BOD), Nitrogen (N) and Phosphorus (P), which make their way into water bodies around the world and risk various water sources. By 2050, with a predicted drier climate scenario with medium levels of income and population growth projections it is expected that one in three people will be at risk of nitrogen pollution—an increase of 173% compared to 2015—and phosphorous pollution—an increase of 129%; and 1 in 5 people will be at risk of water pollution from BOD—an increase of 144%.

Figure 2: State of Groundwater in Major Aquifers



Source: Richey et al., 2015

The above scenarios indicate a desperate need for effective policy interventions. Useful policies will address economy-wide considerations, consideration of all water types, and inclusion of support of public research in water resources and their management. Can the gap between the availability of water and the demand for water be closed? Is it indeed a catastrophic situation? We know that water is an essential input to many economic activities. We also know that to manage water effectively we need well-performing technologies and institutions, and these are put into play by enabling policies. Rather than the traditional delineation on sectoral supply-side policies and demand-side policies, given the central role of water in the economy, an effective policy intervention design has to be based on an economy-wide, rather than sectoral, basis. Further, given the interactive role of water and other natural mediums in which it is applied and moves, a system-wide rather than a local dimension approach would be more effective.

Because water is so scarce, can we afford using only part of the water resources, or to put it differently, can we afford using water only once without recycling it? And finally, would a change in focus of water research be useful to address water scarcity and improved water use efficiency?

Water and Economy-Wide Considerations

Because of its major role in the economy, water resources are the focus of many intervention policies that affect both demand- and supply-side regulations. Water policies are multi-objective in nature, aiming to achieve benefit equity, food security, and environmental and resource sustainability. With the lion's share of consumption—70–90%—of annual renewable fresh water resources, agriculture is the focus of many policy efforts for improved performance of scarce water use. But, while focusing on policies that target irrigated agriculture may lead to an immediate improvement in irrigation water use, still, other implications may negatively affect other water-using sectors, and indirectly also the agricultural sector. This system of cause and effect holds also for the urban water sector, as well as for the industrial and environmental sectors (Dinar, 2014).

Therefore, water plays a central role as an inter-sectoral mechanism and has to be considered at the economy-wide level when being allocated among competing uses or regulated in one or more sectors. Water allocation has significant impacts on overall economic efficiency, particularly with growing physical scarcity in certain regions. Water also has become a strategic resource, involving conflicts among those who may be affected differently by various policies. As an example, recent economy-wide analysis in Mexico highlights the dilemma associated with policies aimed to reduce support to the irrigation sector—including water allocation, and subsidies for crops or inputs, such as electricity for pumping groundwater—which is seen as a major reason for aquifer depletion in the country. The Mexico case is similar to many other cases in both developed and developing countries, facing similar dilemmas. On the one hand such policy interventions affect farmers' behavior, but on the other hand they lead to negative impacts on lower strata population in the agricultural regions who lose their jobs. In a similar way, removal of subsidies to certain crops and/or to certain inputs may have an indirect effect on the economy due to the blanket policy administered. A conclusion that is reached suggests that localized policies seem appropriate in addressing impacts of water availability that vary across regions, households, and producers (Yunez-Naude and Rojas Castro, 2008).

Integrating the Waters and the Mediums for Water Impacts

Most of us think about water in terms of diversions from streams that are stored behind dams or in storages. However, both the sites for developing new water supplies, mainly reservoirs, and the opportunity cost of such water become very prohibitive. Of the more or less available freshwater on earth, about 35 million cubic kilometers (km^3), about one third is stored as groundwater. In addition, oceans contain 1,365 km^3 of saltwater that could be available for consumption after a relatively costly desalination process (Shiklomanov, 1998; Clark and King, 2004).

Ten percent of the total available freshwater, or 3.5 million km^3, is consumed by households. Of this amount, about 330 km^3 are generated globally as municipal wastewater (Hernandez-Sancho et al., 2015). For example, of the 32 billion gallons—or 121 million cubic meters (m^3)—of municipal wastewater discharged nationwide in the United States each day, approximately 45.5 million m^3 are discharged to an ocean or estuary—an amount equivalent to 6% of total water use in the United States. Reusing this water would directly augment the nation's total water supply (NAS, 2012).

Reuse of treated wastewater in irrigated agriculture may serve several purposes, subject to quality regulations. First, it may reduce the need for development of new, expensive fresh water resources—such as, new dams, transfer of water from remote locations, and over-pumping of ground water aquifers. Second, by treating and reusing wastewater in irrigated agriculture environmental pollution is controlled or eliminated. So irrigated agriculture serves as 'environmental guard' in this respect. With the ongoing expansion of the urban sector, more fresh water will probably move from irrigated agriculture to the urban sector.

Certain sources of water and certain types of soils that were taboo in the past are considered now appropriate for use in irrigated agriculture (Qadir et al., 2014; Assouline et al., 2015). Both treated wastewater and naturally occurring saline water can be used now for a wide range of soils and crops, mainly due to recent development in management practices and crop genetic developments, and with little harm to environment if properly implemented.

Another non-conventional source of water is desalination of seawater. The practically infinite amount of seawater and the fact that many major urban centers are located next to the coast, coupled with the recently-developed desalinization technologies, make desalinated seawater a feasible next available technology to produce necessary water supplies in many locations. Table 1 describes the various sources of water and the receiving sectors.

Table 1: Interaction Between Water Sources and Water Using Sectors

Water type	Ag.	Urban	Env.	GW
Freshwater	↑	↑		↑
Groundwater	↑	↑	↑	
Wastewater	↑	←	↑	↑
Desalinated Water		↑		

Source: Author's elaboration

Paradigm Shift Needed for Sacred Research

Fortunately, researchers have produced technological innovations which allow for more efficient use of water. This is true for conservation, use of marginal water and creation of new water—for example, recycled wastewater and desalinated water. However, are technological innovations the limiting factor facing our water scarcity now? Do we need more technologies, or rather more effective institutions to manage water resources?

For example, the 2017 President's Water Innovation Budget (Environmental Leader, 2016) is expected to fund research and development in water conservation and new water supply technologies (Table 2). Scrutiny of the items in the table suggests that of the nearly $260 million budgeted, all goes to technologies and none to improved institutions and new water management arrangements to enable these technologies.

Table 2: The 2016 President's Water Innovation Budget Distribution

Budget ($ millions)	Purpose
98.6	Promotion of water conservation initiatives and technologies
4	Near real-time assessment of water use during drought
28.6	Water technology solutions for next-generation water-treatment technologies
25	Energy-Water Desalination Hub for developing technologies to reduce the cost
15	Agricultural production and practices that conserve water
88	Technologies that increase the US water supply, drinking water quality, and water for use in agriculture and industry processes or cooling
259.2	Total Budget for Technological Water Innovations

Source: Adapted from Environmental Leader, 2016

While technical solutions to the water crisis are important, these are not the limiting factors in reaching sustainable water use. Given the present situation of extreme scarcity, one has to realize the fact that about 30% of the available water resources, such as groundwater, are common pool resources that require the development of joint management practices; and that cross-sectional differences in water scarcity could be overcome if trade in water takes place. The potential for cooperative arrangements among users (CFBF, 2015), new and improved water institutions, and self-enforced regulations by user groups (Harter, 2015) have been recognized already by water users and state and Federal agencies, but there is still not sufficient support realized via funding of studies and research on non-structural interventions and institutions for water regulation.

Policy Recommendations

The water situation in our world is dire and worsens over time due to natural trends and human impacts. The serious trends in water availability and level of production in many parts of the world can be halted, or even stopped, if we manage to introduce several paradigm shift in policies we employ in water and other water-related issues:

- All water-using sectors including consumptive and non-consumptive ones should be included in any analysis of policy design and interventions.
- All water types, including good and low quality, cheap and expensive, have to be part of the resources considered for use by all sectors in all locations.
- Public spending on water-related research needs to be more balanced and include, not only technical aspects of water conservation and technology, but also improved institutions to manage water and water allocation.

For More Information

Assouline, S., D. Russo, A. Silver, and D. Or. 2015. "Balancing Water Scarcity and Quality for Sustainable Irrigated Agriculture." Water Resources Research, 51:3419-3436, DOI:10.1002/2015WR017071.

California Department of Finance. 2016. "Report P-1: Summary Population Projections by Race/Ethnicity and by Major Age Groups." Available online: http://www.dof.ca.gov/research/demographic/reports/projections/P-1/

California Farm Bureau Federation (CFBF). 2015. "Cooperation among Farmers Essential." Available online: http://www.cfbf.com/CFBF/CFBFNews/NewsRelease/2015/Cooperation_among_farmers_will_be_essential_for_future__farm_leader_says.

Clark, R. and J. King. 2004. "The Atlas of Water." London: Eartscan.

Dinar, A. 2014. "Water and Economy-wide Policy Interventions, Foundations and Trends in Microeconomic." 10(2):1-84.

Environmental Leader. 2016. "Obama's Spending Plan Pumps $260M into Water Technology R&D." Available online: http://www.environmentalleader.com/2016/02/10/obamas-spending-plan-pumps-260-into-water-technology-rd/#ixzz46j4oPKtl

Hanak, E., J. Lund, A. Dinar, B. Gray, R. Howitt, J. Mount, P. Moyle, and B. Thompson. 2011. "Managing California's Water: From Conflict to Reconciliation." San Francisco: PPIC.

Harter, T. 2015. "California's Agricultural Regions Gear Up to Actively Manage Groundwater Use and Protection." California Agriculture, 69(3):193-201.

Hernandez-Sancho, F., B. Lamizana-Diallo, J. Mateo-Sagasta, and M. Qadeer. 2015. "Economic Valuation of Wastewater –The Cost of Action and the Cost of No Action." Nairobi: United Nations Environment Programme.

International Food Policy Research Institute (IFPRI) and VEOLIA. 2015. "The Murky Future of Global Water Quality: New Global Study Projects Rapid Deterioration in Water Quality." Washington, D.C. and Chicago, IL: International Food Policy Research Institute and Veolia Water North America.

National Academy of Science (NAS). 2012. "Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Wastewater." Washington DC: National Academies of Science.

Richey, A. S., B. F. Thomas, M.-H. Lo, J. T. Reager, J. S. Famiglietti, K. Voss, S. Swenson, and M. Rodell. 2015. Quantifying Renewable Groundwater Stress with GRACE, Water Resources Research, 51, 5217–5238, doi:10.1002/2015WR017349.

Shiklomanov, I. A. 1998. World Water Resources: An Appraisal for the 21st Centura. IHP Report. Paris: UNESCO.

United States, Census Bureau (USCB). 2016. International Programs. International Data Base. Available online: https://www.census.gov/population/international/data/idb/worldpopgraph.php

United States, Central Intelligence Agency (CIA). 2014. The CIA World Factbook 2015. Available online: https://www.cia.gov/library/publications/the-world-factbook/

Yunez-Naude, Y. and L. G. Rojas Castro. 2008. "Perspectivas de la agricultura ante Reducciones en la Disponibilidad de Agua para Riego: Un Enfoque Equilibrio General." El Agua en México: Consecuencias de las Políticas de Intervención en el Sector. El Trimestre Económico Lecturas 100:183-211. Fondo del Cultura Económica, México.

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Adaptation, Climate Change, Agriculture, and Water

Robert Mendelsohn

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Water already has scarcity value in many watersheds. Seventeen countries currently withdraw more than half of their available renewable water supply (FAO, 2016). Continued population and GDP growth will only increase future water demand and raise the scarcity value of water. Managing water more efficiently is already a pressing issue in semi-arid regions and will be ever more important in the future. Climate change is likely to make this problem worse. Higher future temperatures will increase evaporation lowering water supply and also increase the demand for water for irrigation, cooling, and other uses (IPCC, 2014). If society fails to adapt to this challenge, some analysts argue that there will be large damages from future water scarcity (Titus, 1992).

What can society do to adapt to water scarcity? Society can make adjustments in both the water and agriculture sectors in order to avoid large damages. The water sector can use the available water more carefully. The sector can use water over again by carefully cleaning water for specific uses. This will expand effective supply. The sector can learn how to manage demand. Water can be moved from low- to high-valued uses. The agriculture sector is the largest current user of water. Agriculture is responsible for 70% of water withdrawals worldwide (FAO, 2016). In Africa, the fraction of water withdrawn for agriculture is 83% and in Asia, it is 80%. Although the agriculture sector might want to continue their current rate of water withdrawal, the urban, industrial, and mining sectors may need growing shares of future water. Urban and industrial users account for only about 30% of current withdrawals globally, but they tend to place a very high value on the water they use. Although most users have some low-valued uses of water, farmers are likely responsible for most of the world's low-valued uses. A couple prominent examples of low-valued uses of irrigation water are when: water is used to grow low-valued, but water intensive crops, and when irrigation water never reaches target crops. The agriculture sector can learn how to do more with less water. They, of course, can move from irrigated to rain-fed farming. But irrigation provides very high yields and it helps farmers cope with arid conditions and high long run temperatures. There may be better alternatives for farmers. Farmers can weigh whether the scarcity value of water justifies water-intensive and low-valued crops. They can also weigh whether capital can be substituted for water by relying on more expensive irrigation methods.

Water Sector

Water management has historically dealt with rising water demand by finding new supplies of water. Dams, canals, and wells have tapped into new water resources. In water abundant regions, water authorities have the option of exploiting more of the untapped water sources in their watersheds. In semi-arid locations, unexplored water supplies are growing rarer. Users in many watersheds are exploiting all their water resources already. Ground water is being rapidly depleted leaving future water consumers to depend solely on limited surface water. At least in most of the world's semi-arid areas, water is already scarce and likely to become scarcer in the future. This has led to conflict as water users fight for more water. Water management in these regions need more tools to cope with this growing scarcity of water. Watersheds in semi-arid regions are therefore in a very different situation compared to water abundant watersheds. The semi-arid regions are a part of the world that will face the highest potential risks to their water sector.

One way to expand the supply of water is to use it over and over. Only a small fraction of water withdrawals are consumed, that is, evaporated or absorbed into products. Most water withdrawals run off. They either travel through pipes, the surface, or in shallow aquifers. Some of this water is already used more than once by neighbors or downriver cities. But invariably, the quality of water falls with each use as it becomes more polluted, limiting its reuse.

One strategy for expanding water supply is to treat water so that it can be used again. Treating wastewater so that it can be used for drinking is very expensive and would only be warranted for household and limited industrial use. But several watersheds are exploring using municipal wastewater for irrigation. Because of the microbes in municipal wastewater, the reuse of this water for irrigation was largely banned in many countries. However, limited treatment to remove microbes is sufficient to convert wastewater into a suitable source of irrigation water (Dreschel et al., 2010). Treating wastewater solely to eliminate microbes is relatively inexpensive. In fact, the remaining nitrogen and phosphorous left in lightly treated wastewater is beneficial for irrigation (Dreschel et al., 2010). Consequently, there is renewed enthusiasm for converting municipal wastewater into irrigation water in semi-arid countries.

An alternative strategy for coping with scarcity is to rely on demand management (Booker and Young, 1994). By moving water from low- to high-valued uses, demand management can increase the value obtained from what water is available. By shifting the available water to high-valued uses, only low-valued uses of water are lost. The water will be efficiently allocated and the aggregate value of the water is maximized. This is a good policy in times and places where water is scarce. As the scarcity value of water increases, maximizing its value will be ever more important.

There are several mechanisms that can lead to efficient water allocation. A central authority can determine the value of water in each use and simply allocate the water to the highest valued use. The government could auction the water each year to the highest bidder. Alternatively, the rights to the water could be assigned to historic users who would then be permitted to trade the water.

A top-down reallocation of water places the burden of allocation on the water governing body. This central authority would have to determine the marginal value of water to each user. Although it is likely that such an authority can distinguish between the highest and the lowest valued users, it takes a great deal of information about all users to allocate the water perfectly efficiently. It is unlikely that a centralized authority could efficiently distribute water across all users. The centralized authority would also have to be comfortable with taking water away from low-valued users. At least in most political contexts, the low-valued users will do what they can to prevent this reallocation. Finally, most water users have many uses which range from high to low. Although an authority may be able to determine how much water to allocate to each user, they cannot easily control how that water is used. Asking water authorities to manage what a user does with their water allocation is both intrusive and likely to be expensive.

The auction and trading approaches place the burden of allocation on the user. Both approaches are effective market mechanisms to allocate a scarce resource. They will both lead to a market price for water which equilibrates demand and supply. If this market price is the same for everyone, it will lead to an efficient outcome that maximizes the value of the water. The information burden is more realistic than the central planning case as each user evaluates their own marginal value of water and decides whether a use is worth the price. They would buy the water only if their marginal value exceeds the price. In the trading situation, they would sell water for a specific use only if they valued their own use less than the price.

The principal difference between the auction and the trading mechanism is the implicit property right to the water. The auction assumes that the government owns the water and users must pay to obtain water. The highest bidders get the water. The trading mechanism gives the water property rights to the historic user. The property owner of the water is free to sell as much of their water as they want and to buy more from another property owner. The trades would be voluntary so that no one is worse off. Which property rights system is preferable is not an economics question but rather a question for the law.

The process of using markets to allocate water across users gives flexibility to water allocation. In times of drought, water would temporarily be diverted from low-valued uses. High-valued uses would retain their water. From a social or aggregate perspective, the system would withstand droughts with much lower losses.

This short term flexibility is even more important in the long term. As water becomes permanently scarce, low-valued users can permanently reassign water to high-valued users. Expanding high-valued users can buy additional water from the lowest valued users. By reallocating water across users, the system can make important allocation changes that reflect both changing demand and supply.

This flexibility is particularly important with climate change. Climate change will increase demand and possibly reduce supply. If no adaptations are undertaken, there would be large damages in the water sector as high valued uses would lose water (Titus, 1992). However, if water is reallocated to higher uses, climate damage falls sharply in this sector (Hurd et al., 2004; Lund et al., 2006). Reallocation entails moving water to activities with higher value such as municipal and industrial uses (Hurd et al., 1999 and 2004) and moving water to more productive places such as more fertile agricultural zones (Lund et al., 2006). Reallocation can also imply reducing withdrawals above hydroelectricity dams to protect flows through the dam (Hurd et al., 1999). This research reveals that by reallocating water to its highest valued use, the supply reductions caused by climate change lead to only modest damage. Aggregate damages are modest because all that society loses is relatively low-valued uses. Specifically, the largest reduction is in low-valued irrigated farming such as growing fodder for livestock animals. However, if water reallocation is not done, many high valued uses are lost instead to municipal, industrial, and high-valued agricultural users. This leads to a lot more damage.

Critics of water markets and efficient allocations in general claim that this flexibility is dangerous because high-income households and profitable firms could enjoy all the water they want, leaving low-income households to die of thirst. Would this happen if water was allocated by a market? Drinking is one of the highest valued uses of water in the entire market. A market for water is going to place a very high priority on getting people drinking water precisely because it is a high-valued use. In the absence of markets for water in many developing countries, poor people currently pay the highest price for water in the country (WUP, 2003). Rich households and firms enjoy low cost water from their utility connections, but poor households must pay much higher prices for water from tankers. Markets for water would even out these price differences and likely reduce the price of drinking water for the poor. Higher prices may be a burden for the poor and they may cause the poor to use less water. But it is not inevitable that markets would prevent people from having access to drinking water.

A more serious concern with reallocating water is that there are often incidental beneficiaries of water withdrawals. When a farmer exercises his right to withdraw water, a great deal of that water flows off the farmer's land into neighbors lands either over the surface or in shallow aquifers. The neighbors get access to water from the primary farmer's withdrawal. If the primary farmer sells the right to withdraw his water to a distant user, the neighbors will no longer get this incidental benefit. The neighbors therefore have a stake in preventing the primary farmer from selling. The water market would benefit from effective ways to grant part of the proceeds from a water sale to the neighboring users of existing withdrawals.

One final concern with water trading is that current institutions make trading difficult (Libecap, 2011; Olmstead, 2014). Current water institutions define who has priority to withdraw water but they do not weigh where the water is of highest use. In fact, current institutions often discourage efficient adaptation (Libecap, 2011). But as climate change increases the scarcity value of water, the pressure to update these water governing institutions will increase (Libecap, 2011).

Agriculture

The analysis of the water sector suggests that water will move from low- to high-valued users as it becomes scarce. Although there are high-valued uses of water in agriculture, the sector is responsible for the bulk of low-valued uses in many watersheds. For it to adapt to a water scarce future, the agricultural sector may be forced to learn how to get more value out of their water withdrawals.

Additional water supplies are very valuable to farms without sufficient rainfall. Unfortunately, irrigation tends to be costly. So generally, the farm has to be very productive to warrant irrigation. Irrigation tends to be more profitable on more fertile lands and where the cost of obtaining water is low. As water scarcity increases, marginal farms are likely to move towards rain-fed agriculture or livestock. One response by farmers will be to lower the acreage of irrigated land.

The returns from irrigation also depend on the amount of water that each crop needs and the value of that crop per hectare. As water becomes scarcer, low-valued and water-intensive crops become less desirable. Another response by farmers will be to switch crops. Farmers using irrigation will switch to crops with high value per unit of water. For example, in California, as water becomes scarcer, an efficient response would reduce acreage in field crops (such as, irrigated wheat and corn), fodder (such as, alfalfa, hay, pasture), and rice, maintain acreage in cotton, and increase acreage of high-value irrigation for truck crops, subtropical crops, grapes, fruits, and nuts (Howitt and Pienaar, 2006).

Another adaptation that farmers will adopt is more water efficient methods. The farmers can substitute capital for water. The amount of water required to irrigate a crop falls as one shifts from gravity fed, to sprinkler, to drip irrigation. For example, in California, fruits and nuts need 4.32 acre feet/acre of water with gravity fed systems, but only 4.11 with sprinklers, and 3.66 with drip irrigation (Mendelsohn and Dinar, 2003). With vegetables, they need 1.56 acre feet/acre for gravity fed, 1.52 for sprinklers, and 1.35 for drip irrigation (Mendelsohn and Dinar, 2003). These savings in water require much higher expenditures on the equipment. For example, with vegetables, the cost of irrigation averages $51/acre for gravity fed, $220 for sprinklers, and $645 for drip irrigation (Mendelsohn and Dinar, 2003). For even greater water savings, farms can monitor the soil moisture for each row of plants and administer more water through drip only as needed. Each of these methods requires ever higher investments in pipes and monitoring equipment but the amount of water per hectare used falls dramatically.

Adaptations by Water and Agriculture Sector Can Keep Climate Change Impacts Modest

Since climate change will likely exacerbate water scarcity by reducing the supply and increasing the demand for water, the water sector is going to need to adapt by moving water from low- to high-valued uses. This in turn will likely mean that agriculture must persist with less water. The broad adaptations of the water and the agriculture sector are considered are listed in Table 1.

Table 1: Adaptation to Future Climate Change

Sector	Change	Advantages	Disadvantages
Water	Tap New Sources	Increase supply	Only in water abundant regions
Water	Treat Wastewater for Specific Reuses	Expand effective supply Clean to desired water quality	Vulnerable to toxics
Water	Move water from low to high valued uses	Increase aggregate value of water Increase flexibility of system Least expensive alternative	Can have winners and losers Needs institutional reform
Agriculture	Less irrigated land	Concentrate water on most fertile farms	Irrigated farms can be high valued
Agriculture	Switch to high-valued crops that use less water	Increases value of agriculture	Lose specific crops
Agriculture	Water saving irrigation methods	Grow more irrigated crops on more land	More expensive Lose low-intensity irrigated farms

In the water sector, the historic choice has been to tap new sources of water. This is still possible in water abundant regions and is likely the first choice in these places. However, there is a growing number of semi-arid locations that no longer have this choice and so they need alternatives. One option is to use water more than once. Many withdrawals of water consume only a small fraction of the water. But each use reduces water quality. Waste treatment systems can clean water for another use. However, it is expensive to bring water to a very clean level. The key to making this an attractive adaptation is to target how clean the water needs to be for a specific use. Urban areas may need the water to be a high quality to make it suitable for drinking. But irrigation does not require drinking water quality. Less expensive waste treatment focused on only removing pathogens may be sufficient to reuse municipal wastewater for irrigation. Targeted wastewater treatment can expand the effective supply of water.

An urgent adaptation for almost the entire world, however, is to engage in demand management of water. As water becomes scarcer in the future, the value of demand management increases. In principle, demand management entails moving water from low- to high-valued uses. The result is that society gets more value from its water. Although it sounds very simple, it is difficult to implement because it requires the allocator to know just how valuable different uses are and that the allocator has the power to choose just the most valuable uses. This is a daunting task for a central authority. The authority would have to know how to rank every single use and it would have to force each user to just implement the most high-valued use. Although governments are adept at managing the supply, there is not a single government or water authority that is informed enough, nimble enough, or powerful enough to manage demand efficiently.

The only way to manage water demand effectively is to create water markets. Water markets leave each user to decide how to allocate water across their alternative uses and how much total water they need given the price of water. The user sets their marginal value for each use to the price. The price of water becomes the marginal value of water. With a market, the marginal value becomes the same for all users and the available water is efficiently allocated. As demand and supply conditions change, the market adjusts the price and the system remains efficient.

There are two prominent ways one can establish a market for water. The government can auction the water and sell the water to the highest bidder. Or the government can grant water rights to historic users and then allow them to trade their water. Both approaches require institutional reform in the water sector. Both approaches make the system more flexible and adept at coping with both temporary and long term fluctuations in water. The difference between the two methods is a matter of property rights. With the auction, the government owns the water and all users must purchase it. With historic rights, historic users own the water and users who want more water must purchase it from users who are willing to sell. But in both cases, the market would help all users carefully calibrate the marginal value they place on water with the scarcity value of that water.

Because farmers withdraw most of the world's water and they tend to have many low-valued uses of water, when water gets scarce, farmers will likely get less water. Farmers will have to adapt. One way farmers might adapt is to reduce irrigated acreage. Secondly, they may switch crops and move to crops that yield higher returns and use less water. Thirdly, they may spend more money on irrigation equipment and move from flood irrigation to water saving methods such as sprinklers and drip irrigation. As water becomes scarcer, the agricultural sector will adapt by getting more out of the water they can still use.

If the water sector can increase its internal efficiency, the damage from climate change and droughts will be dramatically reduced (Hurd et al., 1999 and 2004; Lund et al., 2006). Adaptation can make a huge difference in the outcomes in this sector. Agriculture can also adapt and limit the damage from lost water by dropping their lowest valued uses of water (Howitt and Pienaar, 2006). These adaptations together will keep the net impacts of climate change to a modest level in both the water and agriculture sectors over the next century.

For More Information

Booker, J.F., and R.A. Young. 1994. Modeling Intrastate and Interstate Markets for Colorado River Water-resources. *Journal of Environmental Economics and Management* 26 (1): 66–87.

Cline, W. R. 1992. *The Economics of Global Warming*. Peterson Institute.

Drechsel, P., C.A. Scott, L. Raschid-Sally, M. Redwood, and A. Bahri (eds.). 2010 *Wastewater Irrigation and Health Assessing and Mitigating Risk in Low-Income Countries.* International Water Management Institute. Earthscan, London.

Food and Agriculture Organization (FAO). 2016. *AQUASTAT, FAO's Global Water Information System*. Website accessed on January 6, 2014.

Howitt, R., and E. Pienaar. 2006. "Agricultural Impacts." Mendelsohn R. & Smith J. B. (eds) *The Impact of Climate Change on Regional Systems: A Comprehensive Analysis of California*, pp. 188–207. Edward Elgar Publishing: Northampton, MA.

Hurd, B., J. Callaway, J.B. Smith, and P. Kirshen. 1999. "Economics Effects of Climate Change on U.S. Water Resources." R. Mendelsohn and J.B. Smith (eds). *The Impact of Climate Change on the United States Economy*, pp. 133–77. Cambridge University Press: Cambridge, United Kingdom.

Hurd, B., M. Callaway, J. Smith, and P. Kirshen. 2004. "Climatic Change and U.S. Water Resources: From Modeled Watershed Impacts to National Estimates." *JAWRA Journal of the American Water Resources Association*, 40(1): 129–48.

Intergovernmental Panel on Climate Change (IPCC). 2014. *Climate Change 2014: Impacts, Adaptation, and Vulnerability.* Cambridge University Press: Cambridge, UK, and New York, NY, USA.

Libecap, G. D. 2011. "Institutional Path Dependence in Climate Adaptation: Coman's 'Some Unsettled Problems of Irrigation'." *American Economic Review* 101(1): 64–80.

Lund, J. R., X. Cai, and G.W. Characklis. 2006. "Economic Engineering of Environmental and Water Resource Systems." *Journal of Water Resources Planning and Management* 132(6): 399–402.

Mendelsohn, R. and A. Dinar. 2003. "Climate, Water, and Agriculture", *Land Economics* 79: 328-341.

Olmstead, S.M. 2014. "Climate Change Adaptation and Water Resource Management: A Review of the Literature." *Energy Economics* 46: 500–9.

Titus, J.G. 1992. 'The Costs of Climate Change to the United States', in S. K. Majumdar, L.S. Kalkstein, B.M. Yarnal, E.W. Miller and L.M. Rosenfeld (eds.). *Global Climate Change: Implications, Challenges and Mitigation Measures*. Easton: Pennsylvania Academy of Science, pp. 384–409.

Water Utility Partnership for Capacity Building Africa (WUP). 2003. *Better Water and Sanitation for the Urban Poor*. European Communities and Water Utility Partnership.

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Cost-Effective Conservation Programs for Sustaining Environmental Quality

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The interface between agriculture and the environment is critical. Maintaining and increasing the productivity of agriculture depends on the quality of ecosystems that provide healthy soil, favorable climate, pollination, and water for irrigation. However, agricultural production can also damage ecosystems by contributing to climatic change through greenhouse gases emissions; by degrading the soil through erosion and loss of soil carbon; by polluting surface and groundwater with sediment, nutrients, and pesticides; and by contributing to the loss of wildlife habitat and biodiversity.

Evidence suggests that climate change and more intensive use of natural resources are increasing the risk of environmental damage. Although the exact effect of climate change on weather patterns is uncertain and will vary across the United States, climate change will increase the frequency and severity of extreme weather events, including intense rain storms, periods of extreme heat stress, and drought (Walthall et al., 2013; USCCSP, 2008). More intense rainfall, in particular, poses a significant challenge for conservation, especially intense storms that occur during the non-growing season or when the soil is bare. Rainfall rates that exceed the capacity of the soil to absorb and hold water will increase runoff that carries sediment, nutrients, pesticides, and other pollutants from fields to surface and ground water (SWCS, 2003; Nearing, Pruski, and O'Neill, 2004; Hatfield and Prueger, 2004).

In the Great Lakes basin, for example, evidence suggests that increased frequency of intense rain storms in the winter and spring are a key driver of elevated dissolved phosphorous loads into Lake Erie (Scavia et al., 2014; Daloglu, Cho, and Scavia, 2012; Michalak et al., 2013). Conservation practices or conservation systems—that is, groups of practices that work together—that are not designed for more frequent, higher intensity storms may not be fully effective in controlling nutrient runoff produced by them (Bosch et al. 2014). For example, filter strips may be inundated by the high-intensity storm events (Bosch et al., 2014). The application of other structural practices such as water and sediment basins or terraces may be needed to reduce or eliminate these negative impacts.

Climate change may also prompt farmers to change crops and production practices. These changes could have positive, negative, or mixed effects on the environment. Although there has not been extensive research in this area, some examples are instructive. Conservation tillage and no-till, for example, are often adopted as a soil moisture conservation strategy and are more often adopted in warmer regions (Ding, Schoengold, and Tadesse, 2009). To the extent that weather becomes warmer or drier in the future, conservation tillage and no-till adoption may increase. Changes in cropping patterns are also likely. O'Neill et al. (2005) argue that warmer, wetter weather in the Upper Midwest would make it profitable for farmers to switch acreage from wheat, a high residue crop, to soybeans, a low residue crop, potentially increasing soil erosion and nutrient runoff. Irrigation may also be used as an adaption strategy, putting further strain on water supplies. However, recent research suggests that U.S.

irrigated acreage could actually decline after 2020 due to limited water supplies and heat stress which reduces the relative profitability of irrigated production (Marshall et al., 2015). Although the exact mix of future climate change adaptations cannot be predicted and will vary, environmentally positive and negative adaptations are clearly possible.

While climate change is important in every part of United States and global agriculture, we focus on the U.S. crops sector.Conservation practices used in crop production can play important roles in mitigating the risks of climate change, limiting any increase in adverse environmental effects, and helping farmers increase resilience to increased production risks that may be associated with climate change. Climate mitigation efforts can include changes in land use, tillage, nutrient and manure management, and other practices that reduce greenhouse gas emissions or sequester carbon. Conservation practices can also help limit environmental damage—for example, sediment, nutrient, and pesticide runoff—that could be intensified due to climate change. On-going, periodic review of U. S. Department of Agriculture (USDA) conservation practice standards helps ensure that newly adopted or installed practices, if designed to USDA standards, will be effective even through weather patterns have changed.Some practices could provide multiple services. Practices that build soil health, for example, could provide climate mitigation (soil carbon sequestration), environmental protection (higher rainfall infiltration rates that reduce runoff and the loss of sediment and nutrients to the environment), and producer risk reduction (higher soil water holding capacity could reduce yield loss due to drought).

The increasing need for conservation practices could place greater demands on programs supporting conservation practice adoption.The USDA, through programs administered by the Natural Resources Conservation Service (NRCS) and the Farm Service Agency (FSA), has a long history of supporting conservation practice adoption through voluntary programs that provide both financial and technical assistance to producers. (See Box). Even as the need for conservation practices is rising, however, funding for USDA conservation programs has leveled off, at least for now. After substantial increases in conservation funding in the early years of the 2002 and 2008 Farm Acts, funding in the first years of 2014 Farm Act (2014 and 2015) were lower than levels in 2013—the last year when the 2008 farm bill was in force.

USDA Conservation Programs

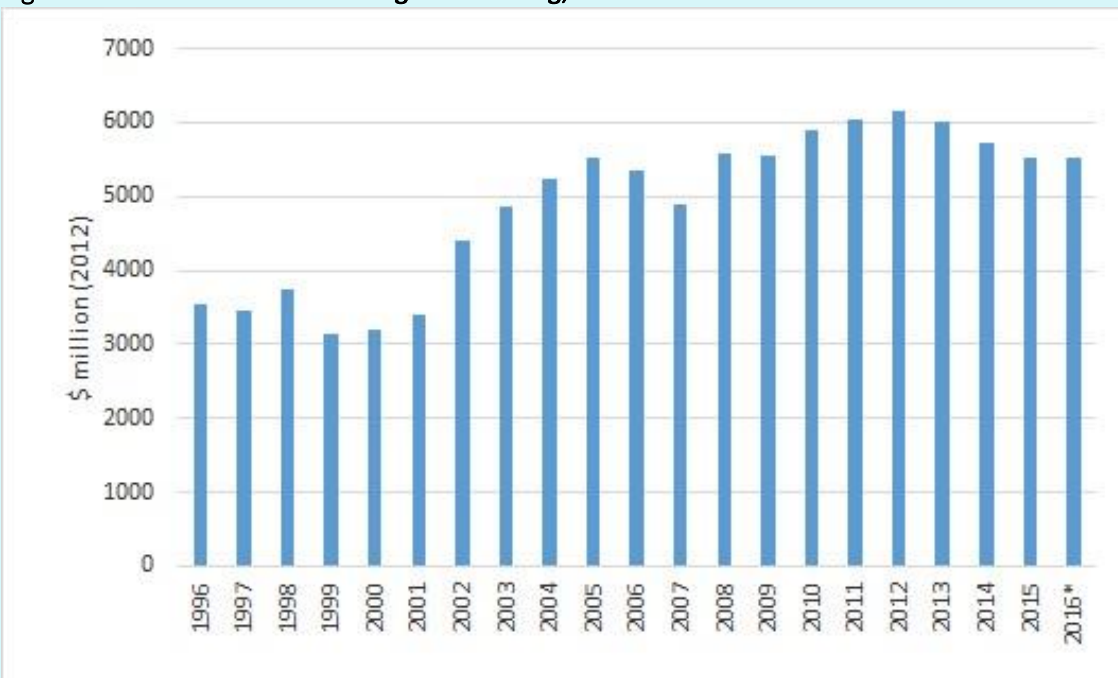
The U.S. Department of Agriculture administers a number of voluntary conservations programs. The Conservation Reserve Program (CRP), Environmental Quality Incentives Program (EQIP), the Conservation Security Program (CSP) and Conservation Technical Assistance (CTA) are the largest of these programs.

Program participation is voluntary. Producers receive financial and technical assistance in exchange for land retirement, through CRP, or adoption of conservation practices on working agricultural land, through EQIP and CSP. Payments are generally limited to participation costs, including direct costs of practice adoption and income foregone, or some portion of costs, although details vary across programs. Technical assistance can be provided without financial assistance (CTA).

Benefit-cost targeting is a feature of all major conservation programs and is generally implemented by ranking conservation program applications using a benefit-cost index. The best-known is the Environmental Benefits Index (EBI) used to rank applications in the general signup portion of the CRP (USDA-FSA, 2013). While most programs use some type ranking mechanism, details vary widely across programs.

Conservation effort is also targeted to specific regions and resources. The Regional Conservation Partners Program (RCPP) is designed to coordinate conservation program assistance with partners to solve problems on a regional or watershed scale. Financial assistance is coordinated through RCPP but provided to producers largely through other conservation programs. The Conservation Reserve Enhancement Program (CREP) forges Federal-state partnerships to focus conservation effort on specific resources—for example, water quality and wildlife habitat along a river corridor.

Figure 1: **USDA Conservation Program Funding, 1996-2016**



Source: USDA, Economic Research Service analysis of Office of Budget and Policy Analysis (OBPA) data on actual funding for 1996-2015 and OBPA estimates for 2016.
Notes: Includes the Conservation Reserve Program, Conservation Stewardship Program, Environmental Quality Incentives Program, Agricultural Conservation Easement program, Resource Conservation Partnerhsip Program, Conservation Technical Assistance and processor programs. Spending is adjusted to 2012 dollars.

Regardless of future conservation program budgets, cost-effectiveness will be an important determinant of how much conservation programs actually accomplish. As the increasing frequency of extreme weather events increases the need for conservation practices, the importance of cost-effectiveness will also increase. A program is cost-effective when payments go to farmers to support practices that deliver the largest environmental gain relative to adoption and maintenance cost. Given that USDA conservation programs are subject to budget constraints, the environmental gain that can be leveraged by a program is maximized when payments to individual program participants are just large enough to encourage adoption. Previous research suggests that the “devil is in the detail”—the cost-effectiveness of conservation programs can vary widely depending on how much is paid to which farmers for taking what actions (Shortle et al., 2012).

Cost-Effective Conservation is a Major Challenge

Achieving cost-effectiveness may be very difficult because the interface between agriculture and the environment is extensive and heterogeneous (Nowak, Bowen, and Cabot 2006). Thousands of farmers and ranchers, individual natural resources, including rivers and streams, wetlands, lakes, estuaries, groundwater, many types of wildlife habitat, and air quality can be affected by agricultural production. The benefits associated with increasing the supply of ecosystem services vary widely. Even when focusing on a specific resource, the environmental effect of individual farms—even individual fields—may vary widely depending on the mix of crop and livestock commodities produced, topography, soils, landscape position, and the specific production and conservation practices already in use. In many cases, the confluence of vulnerable resources and production practices that do not address these vulnerabilities produce situations where a large share of pollution originates on relatively small number of farms and fields (Nowak, Bowen, and Cabot, 2006). For example, consider a field with slopes that encourage rapid runoff of storm water, located near a river or lake, where granular fertilizer is applied to the soil surface without incorporating it into the soil. While nutrient loss to water is very likely, application of basic nutrient management techniques—for example, injecting fertilizer below the soil surface—could reduce nutrient runoff at a modest cost. For fields that are less prone to runoff or located at a greater distance from water, the environmental benefit of applying the same nutrient management practices is likely to be lower.

A large body of research suggests that program features like pay-for-performance (basing payment rates on the amount of ecosystem services produced) and benefit-cost targeting (targeting practices to landscapes or fields where they have the greatest effect per dollar of cost) can deliver environmental benefits at a lower cost than programs that do not account for heterogeneity across landscapes, farms, and fields (Babcock et al., 1997; Feather and Hellerstein, 1997; Cattaneo et al., 2005; Ribaudo, Savage, and Aillery, 2014). Some studies suggest that gains could be large. Feather et al. (1999) show that the likely increase in environmental benefits due to targeting introduced in the Conservation Reserve Program (CRP) in the early 1990s was equal to 25% of program costs without increasing program cost. In theory, more dramatic gains in cost-effectiveness could be obtained with extensive information on producer's willingness to adopt conservation practices and the relationship between conservation practice adoption and ecosystem services (Ribaudo, Savage, and Aillery, 2014).

When designing and implementing an actual conservation program, however, information needed to identify and enroll the farms and fields that would provide the most cost-effective environmental gain is difficult and costly to obtain. Because agricultural emissions—such as, nutrient runoff—cannot be directly observed, it can be very difficult to identify the farms and fields where large environmental gain, relative the cost of conservation practices, could be obtained.On-going research is expanding knowledge of the agriculture-environment interface. For example, the NRCS, through the Conservation Effects Assessment Program (CEAP), has made significant progress toward understanding the effect of conservation practices on soil erosion, nutrient runoff, and many other environmental effects. Nonetheless, our understanding is still far from complete. Incorporating new knowledge into program delivery can also be difficult because it requires the development of inexpensive and effective tools for measuring or estimating field level impacts on ecosystem services. That is, practical tools for program implementation must be effective without extensive and costly data collection and modeling efforts that are typical of research programs (for example, CEAP).

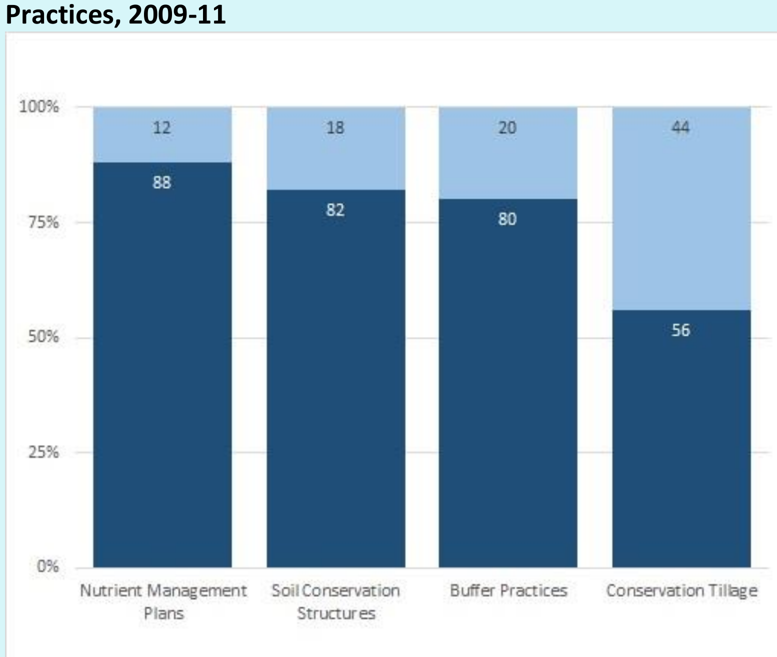
For voluntary conservation programs, producer participation is also critical. Cost-effectiveness may be limited when farmers don't participate in conservation programs (non-participation), when farmers receive payments for practices that they would have adopted without a payment (non-additionality), and when farmers stop using practices after a conservation program contract ends or the life of the practice ends (dis-adoption).

Producer willingness to adopt conservation practices and participate in conservation programs is difficult to anticipate. At any given point in time, some farmers adopt some conservation practices without financial assistance while others need substantial payments to adopt the same practices. In addition, technical assistance is often needed, even if financial assistance is not. A farmer will adopt conservation practices when the on-farm benefit from reduced input cost and preservation of soil productivity exceeds the cost of adoption within his or her planning horizon. Many conservation practices yield both on-farm and environmental, off-farm benefits. Individual farmers may be uncertain about the on-farm benefits and costs of implementing a given practice and may change their assessment of individual practices over time in response to successful application by neighbors, technical change that makes the practice easier to use, or a more complete understanding of on-farm benefits. Evidence also suggests that some farmers are willing to relinquish some return in exchange for protecting the environment (Chouinard et al., 2008). Because adoption cost, on-farm benefits, and environmental attitudes vary, the minimum level of payment needed to induce adoption—the farmer's "willingness to accept" or WTA—also varies in ways that are difficult to observe.

Non-participation by farmers who could produce large environmental gains relative to cost could limit cost-effectiveness. Farmers will participate in a voluntary conservation program only if the payment offered exceeds their WTA. Relatively high WTA could reflect high practice adoption costs or low on-farm benefits, but there are other issues. Data from the 2012 Agricultural Resources Management Survey (ARMS) shows a portion of conservation program non-participants believe that government conservation practice standards make practices more costly than necessary (34%) and that the cost of program application (29%) and documenting compliance (31%) are too high.Only 20% indicated that they believe practice-specific payments are too low (McCann and Claassen, 2016).

Non-additionality occurs when farmers participate in a conservation payment program even though they would have adopted conservation practices without receiving a payment. Payments may be made to these producers because program administrators do not know what level of payment they would be willing to accept. For conservation programs with fixed budgets, payments for practices that are non-additional—that would have been adopted even without the payment—use programs' resources but do not yield any environmental gain. Anecdotal evidence suggests that some farmers request financial assistance to access technical assistance that is provided by NRCS at no cost—any farmer may request technical assistance but priority is given to farmers who receive financial assistance.

Figure 2: **Additionality in Adoption of Common Conservation Practices, 2009-11**



Source: USDA, Economic Research Service, Economic Research Report, ERR-170

Existing estimates of additionality in voluntary conservation payment programs generally indicate that additionality is high for practices that have high initial costs or provide on-farm benefits that are small or realized only in the distant future. Using national data, Claassen et al., (2014) show that soil conservation structures (such as, terraces) and buffer practices (such as, grass waterways, filter strips) are additional about 80% of the time. Additionality is lower for practices that are more likely to be profitable in the short run. Conservation tillage practices—including no-till—are estimated to be additional roughly 50% of the time. High additionality on nutrient management plans means that farmers are unlikely to have a written plan without a payment. The result provides no information about plan application. Mezzatesta, Newburn, and Woodward (2013), using data from 25 Ohio counties, find additionality exceeding 80% for practices that have high costs or low on-farm benefits—for example, field-edge filter strips—but less than 25% for conservation tillage. Low additionality means that only a portion of benefits can be attributed to the program. If additionality in conservation tillage is actually 50%, for example, only half of the benefits from conservation tillage adopted with financial assistance can be attributed to the program.

Dis-adoption occurs when a producer participates in a conservation program but decides not to continue using the supported practice when the contract expires or life of conservation practices ends. Conservation payments provide a financial cushion to farmers for a limited time, helping them resolve uncertainty about practice costs and benefits or, perhaps, cover some one-time costs of transitioning to new practices. Beyond the end of the contract or the formal life of a practice, conservation practice use is likely to be sustained only when farmers believe that on-farm benefits exceed costs.

To date, there has been very little research on sustained adoption of conservation practices on working land. In a single watershed in Utah, Jackson-Smith et al. (2010) identified practices funded by USDA through the Little Bear River Watershed project between 1992 and 2006—mostly in the 1990s—and conducted follow-up interviews with producers to determine what proportion of practices had been maintained over time. Of practices actually implemented, they found that 78% were still in use, including 86% of structural practices (for example., more efficient irrigation systems) but only 66% of management practices (for example, conservation crop rotation). We note that roughly 30% of discontinued practices were dropped because individuals had quit farming or sold land for development While these data do not represent the entire United States, they suggest that follow up on practice use could provide valuable information on the effect of agricultural conservation programs.

Some Specifics (because the Devil Really is in the Detail)

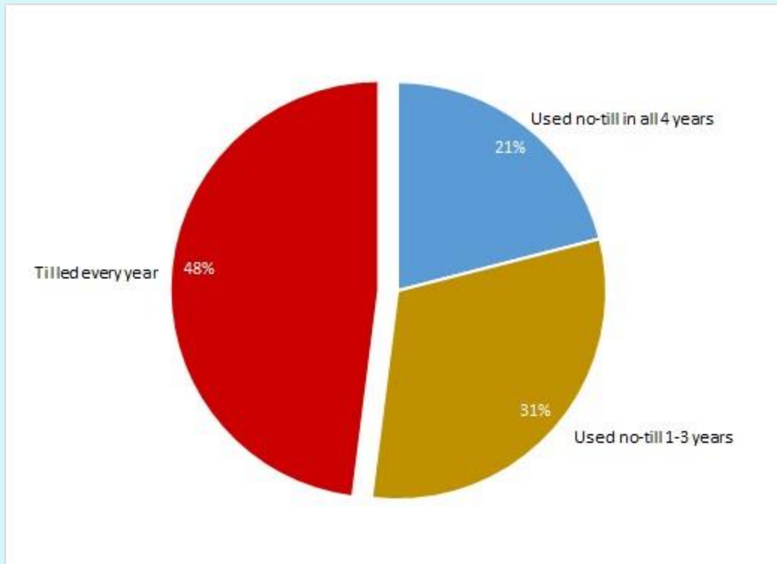
Building soil health is increasingly viewed as a way to improve environmental quality and productivity because healthy soils have greater capacity to buffer extreme weather events. On the environmental side, for example, healthier soils with improved aggregate stability and more organic matter can increase rainfall infiltration rates and soil water holding capacity, thereby reducing sediment, nutrient, and pesticide runoff, and associated environmental damages. In terms of productivity, healthier soils can increase drought resilience by capturing and retaining moisture in the soil and making it available for plant growth.

An extensive review of the agronomic literature (USDA-NRCS, 2014) suggests that soil health can be improved under a wide range of soil and climatic conditions, but only through the consistent application of a suite of practices over a period of years. Soil health can be built through long-term and continuous use of no-till, cover crops, double cropping, mulching, and rotation with permanent grass, such as pasture or hay. For example, continuous no-till used in conjunction with high residue/cover crops can have a positive effect on key soil properties including soil organic matter, soil aggregate size and stability, water infiltration, and water-holding capacity. Science-based nutrient management is needed to maintain soil fertility for robust plant growth while minimizing the loss of nutrients to the environment.

According to the 2012 Census of Agriculture, cover crops were used on 10 million acres—about 3.2% of harvested cropland. Some farmers are concerned that cover crops will delay corn planting and about the cost of using cover crops (Reimer, Weinkauf, and Prokopy, 2012; Singer and Nusser, 2007). Preliminary results from an Indiana study indicate that on-farm benefits are less than the cost of cover crop adoption but that total social benefits including improved environmental quality are larger than adoption cost (Tyner, 2015). To the extent that annual costs of cover crops exceed on-farm benefits, concern about non-additionality is minimal. The potential for non-participation and dis-adoption, however, are high.

In Maryland, for example, it took annual, ongoing payments of $30-$55 per acre per year to effect a large increase in the use of cover crops as part of the effort to reduce nutrient losses to the Chesapeake Bay (Maryland Department of Agriculture, 2016a). For the 2015-16 cover crops season, Maryland farmers planted nearly 500,000 acres of cover crops (Maryland Department of Agriculture, 2016b), covering roughly 35% of the 1.4 million acres of cropland in Maryland (NASS, 2012). We do not know how many farmers would continue using cover crops if payments were ended.

Figure 3: **No-till Use Over a 4-Year Period for Corn, Soybean, and Wheat fields, 2009-2012**



Source: USDA, Economic Research Service and National Agricultural Statistics Service, field level data from Agricultural Resources Management Surveys, 2009, 2010, and 2012.
Notes: Surveyed fields grew wheat in 2009, corn in 2010, or soybeans in 2012, but could have been planted to other crops during any of the 3 years preceding the survey year

Unlike cover crops, no-till and strip-till are already widely adopted and largely without financial assistance, at least in some regions. Of farmers who reported some form of conservation tillage in the 2009, 2010, and 2011 field-level ARMS, only 10% reported ever receiving a payment for conservation tillage (Claassen et al., 2014). As already noted, the risk of non-additionality in conservation tillage practices is high. And, while the risk of complete dis-adoption is likely to be low, intermittent adoption may be limiting the soil health benefits of adoption no-till. Survey data also suggests that no-till and strip-till are used only intermittently on many farms. In 2010-11, for example, roughly 40% of four major crops—corn, soy, wheat, and cotton—were grown using no-till or strip-till but only about 23% of these crops were on farms that use no-till or strip-till on all crops (Wade, Claassen, and Wallander, 2015). Field-level ARMS survey data also show that farmers often rotate no-till with other tillage practices.

Farmers growing wheat in 2009, corn in 2010, and soybeans in 2012 were asked about no-till used in the survey year and the three previous years. No-till was used at least once on more than half of surveyed acres but was used continuously over the four-year period on only 21% of these acres (Claassen and

Wade, 2015). Evidence suggests that producers often rotate tillage practices along with crops. For example, no-till is more common on soybeans than corn (Wade, Claassen, and Wallander, 2015). These findings suggest that incentives may be needed to ensure continuous adoption of no-till/strip-till.

Understanding the Economics of Sustained Adoption is Major Challenge

Climate change is already intensifying the potential for environmental damage from agricultural production. Increasingly, extreme weather events threaten to overwhelm the capacity of existing conservation systems to absorb runoff from intense storms and sustain crop production through more severe periods of heat and drought stress. Conservation practices can help reduce risk to the environmental damage and limit the vulnerability of agricultural production to extreme weather events. Demand for financial and technical assistance from conservation programs is likely to increase. A higher level of program funding could help meet that demand. Working to improve program cost-effectiveness could also help increase the level of environmental protection derived from each dollar of conservation expenditure.

Increasing cost-effectiveness in conservation programs depends on identifying and engaging farmers who could deliver large environmental gains relative to the cost of achieving those gains. A key difficulty in achieving these gains is the complexity of the agriculture-environmental interface and the cost of obtaining information needed to identify these producers. The key question is whether greater cost-effectiveness—more environmental gain per dollar of cost—that could be achieved with more accurate targeting are large enough to justify the expense of identifying the producers that can deliver these gains. Even if these producers can be effectively identified, farmers and ranchers cannot be required to participate in voluntary conservation programs. Larger incentive payments could increase participation, but may not be the only issue limiting participation. Non-additionality and dis-adoption may also be issues. At this time, however, there have been only a handful of studies on these topics.

A more complete understanding of conservation practice adoption is needed. To date, most studies of conservation practice adoption have defined adoption within the scope of a single field and a single year. Understanding the economics of sustained adoption is a major challenge. Increasingly, producer surveys are eliciting information that could help improve adoption estimates. The CEAP survey, for example, asks producers for a wide range of information on a single field for a three-year period. The field-level portion of the ARMS asks for information on a limited set of practices, including crop history, cover crops, and no-till/strip-till, over a four-year period. At this time, however, there is very little data on how farmers use practices once conservation program contracts expire or conservation practice life ends. And, there is very little information on the frequency of dis-adoption or the frequency with which adoption is subsequently expanded to other parts of the farm. Developing data is a critical first step. For some practices, including no-till, remote sensing is likely to be a viable option. Increasing follow up on the effect of financial assistance for conservation management practices could also provide valuable information.

For More Information

Babcock, B.A., P.G. Lakshminarayan, J. Wu, and D. Zilberman. 1997. "Targeting Tools for the Purchase of Environmental Amenities." *Land Economics* 73, 325–339.

Bosch, N.S., M.A. Evans, D. Scavia, and J.D. Allan.2014."Interacting Effects of Climate Change and Agricultural BMPs on Nutrient Runoff Entering Lake Erie." *Journal of Great Lakes Research* 40:581-589.

Cattaneo, A., R. Claassen, R. Johansson, and M. Weinberg. 2005. "Flexible Conservation Measures on Working Land: What Challenges Lie Ahead?" Economic Research Report, vol. 5. U.S. Department of Agriculture, Economic Research Service, Washington, D.C. 52 pp

Chouinard, H.H., T. Paterson, P.R. Wandschneider, and A.M. Ohler.2008. "Will Farmers Trade Profits for Stewardship? Heterogeneous Motivations for Farm Practice Selection." Land Economics 84:66-82.

Claassen, R., J. Horowitz, E. Duquette, and K. Ueda. 2014. "Additionality in U.S. Agricultural Conservation and Regulatory Offset Programs." USDA, Economic Research Service, ERR-170. Available online: http://www.ers.usda.gov/publications/err-economic-research-report/err170.aspx

Claassen, R. and T. Wade. 2015."No-Till/Strip-Till and Cover Crop Adoption:New Data from ARMS." Presented at Economics of Soil Health, Washington, D.C., September 2015,Available online: http://www.farmfoundation.org/webcontent/Economics-of-Soil-Health-1904.aspx

Daloglu, I., K.H. Cho, and D. Scavia.2012."Evaluating Causes of Trends in Long-term Dissolved Reactive Phosphorus loads to Lake Erie." Environmental Science & Technology. 46:10660-10666.

Ding, Y., K. Schoengold, and T. Tadesse. 2009. "The Impact of Weather Extremes on Agricultural Production Methods: Does Drought Increase Adoption of Conservation Tillage Practices?" *Journal of Agricultural and Resource Economics* 34(3):395-411.

Feather, P., and D. Hellerstein. 1997. "Calibrating Benefit Function Transfer to Assess the Conservation Reserve Program". *American Journal of Agricultural Economics* 79 (1), 151–162

Feather, P. D. Hellerstein, and L. Hansen. 1999."Economic Valuation of Environmental Benefits and the Targeting of Conservation Programs: The Case of the CRP USDA, Agricultural Economics Report." AER-778. Available online: http://www.ers.usda.gov/publications/aer-agricultural-economic-report/aer778.aspx

Hatfield, J. and J. Prueger. 2004."Impacts of Changing Precipitation Patterns on Water Quality."*Journal of Soil and Water Conservation* 59(1): 51-58.

Jackson-Smith, D., M Hailing, E. de la Hoz, J. McEvoy, and J. Horsburgh.2010."Measuring Conservation Program Best Management Practice Implementation and Maintenance at the Watershed Scale." *Journal of Soil and Water Conservation*. 65(6): 413-423.

Marshall, E., M. Aillery, S. Malcolm, and R. Williams. 2015. "Climate Change, Water Scarcity, and Adaptation in the U.S. Field Crop Sector." USDA, Economic Research Service, ERR-201. Available online: http://www.ers.usda.gov/publications/err-economic-research-report/err201.aspx

Maryland Department of Agriculture, 2016a. "Maryland Farmers Shatter Cover Crop Planting Record: Approach 500,000 Acre Milestone." Available online: http://news.maryland.gov/mda/press-release/2016/01/20/maryland-farmers-shatter-cover-crop-planting-record-approach-500000-acre-milestone/

Maryland Department of Agriculture., 2016b."Maryland's 2015-2016 Cover Crop Program." Available online: http://mda.maryland.gov/resource_conservation/counties/WELCOMEWEB.pdf

McCann, L. and R. Claassen.2016."Farmer Transaction Costs of Participating in Federal Conservation Programs:Magnitude and Determinants." *Land Economics* 92(2): 256-272.

Mezzatesta, M., D. Newburn, and R. Woodward. 2013. "Additionality and the Adoption of Farm Conservation Practices." Land Economics, 89(4): 722-42.

Michalak, A.M., E. Anderson, D. Beletsky, S. Boland, N.S. Bosch, T.B. Bridgemanf, J.D. Chaffinf, K.Chog, R. Confesorh, I. Daloğlug, J.V. DePintoi, M.A.Evansg, G.L. Fahnenstiel, L. Hek, J.C. Hol, L. Jenkinsg, T.H. Johengen, K.C. Kuod, E. LaPorten, X. Liud, M.R. McWilliams, M.R. Mooreg, D.J. Posseltd, R.P. Richardsh, D. Scaviag, A.L. Steinerd, E.Verhammei, D.M. Wright, and M.A. Zagorskid. 2013. "Record-Setting Algal Bloom in Lake Erie Caused by Agricultural and Meteorological Trends Consistent with Expected Future Condition." Proceedings of the National Academy of Sciences. 110:6448-6452.

Nearing, M., F. Pruski, and M. O'Neill. 2004."Expected Climate Change Impacts on Soil Erosion Rates:A Review." *Journal of Soil and Water Conservation*. 59(1): 43-50.

Nowak, P., S. Bowen, and P.E. Cabot.2006."Disproportionality as a Framework for Linking Social and Biophysical Systems." *Sociology of Natural Resources* 19(2):153-173.

O'Neill, M., M. Nearing, R. Vining, J. Southworth, and R. Pfeifer. 2005. "Climate Change Impacts on Soil Erosion in Midwest United States with Changes in Crop Management." Catena (61): 165–184.

Ribaudo, M., J. Savage, and M. Aillery. 2014. An Economic Assessment of Policy Options to Reduce Agricultural Pollutants in the Chesapeake Bay. USDA, Economic Research Service, ERR-166. Available online: http://www.ers.usda.gov/publications/err-economic-research-report/err166.aspx

Reimer, A. P., D. K. Weinkauf, and L. S. Prokopy. 2012. "The Influence of Perceptions of Practice Characteristics: An Examination of Agricultural Best Management Practice Adoption in Two Indiana Watersheds." *Journal of Rural Studies* 28(1):118-128.

Scavia, D., J.D. Allan, K.K. Arend, S. Bartell, D. Beletsky, N.S. Bosch, S. B. Brandt, R.D. Briland, I. Daloğlu, I. J. V. DePinto, D. M. Dolan, M. A. Evans, T. M. Farmer, D. Goto, H. Han, T. O. Höök, R. Knight, S. A. Ludsin, D. Mason, A.M. Michalak, R.P. Richards, J.J. Roberts, D.K. Rucinski, E. Rutherford, D.J. Schwab, T.M. Sesterhenn, H. Zhang, and Y. Zhou. 2014. "Assessing and Addressing the Re-eutrophication of Lake Erie; Central Basin Hypoxia," *Journal of Great Lakes Research* 40:226-246.

Shortle, J., M. Ribaudo, R. Horan, and D. Blandford. 2012. "Reforming Agricultural Nonpoint Pollution Policy in an Increasingly Budget-Constrained Environment," *Environmental Science and Technology* 46(3):1316-1325.

Singer, J.W., and S.M. Nusser. 2007. "Are Cover Crops Being Used in the U.S. Corn Belt," *Journal of Soil and Water* Conservation 62(5):353-58.

Soil and Water Conservation Society (SWCS). 2003.Conservation Implications of Climate Change: Soil Erosion and Runoff from Cropland.http://www.swcs.org/documents/filelibrary/ advocacy_publications_before_2005/Climate_changefinal_112904154622.pdf

Tyner, W. 2015."Data Needs and Empirical Difficulties for Economic Analysis."Presented at Economics of Soil Health, Washington, D.C. Available online: http://www.farmfoundation.org/webcontent/Economics-of-Soil-Health-1904.aspx

U.S. Climate Change Science Program (USCCSP). 2008. "The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States. A Report by the U.S. CCSP and the Subcommittee on Global Change Research." Contributors: P. Backlund, A. Janetos, D. Schimel, J. Hatfield, and others. U.S. Dept. of Agriculture.

U.S. Department of Agriculture, Farm Service Agency (USDA-FSA). 2013. "Conservation Reserve Program Sign-Up 45 Environmental Benefits Index (EBI)."

U.S. Department of Agriculture, National Agricultural Statistics Service (USDA-NASS). 2012. "Census of Agriculture, 2012." Available online: http://www.agcensus.usda.gov/Publications/2012/

U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS). 2014. "Soil Health Literature Summary—Effects of Conservation Practices on Soil Properties on Areas of Cropland data product." Available online: http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/ mgnt/?cid=stelprdb1257753

Wade, T. and R. Claassen. 2015. "Modeling No-Tillage Adoption by Corn and Soybean Producers: Insights into Sustained Adoption." Presented at the 2015 AAEA & WAEA Joint Annual Meeting, San Francisco, CA.

Wade, T., R. Claassen, and S. Wallander. 2015. "Conservation-Practice Adoption Rates Vary Widely by Crop and Region." USDA-Economic Research Service. Available online: http://www.ers.usda.gov/publications/err-economic-research-report/err147/report-summary.aspx

Walthall, C.L., J. Hatfield, P. Backlund, L. Lengnick, E. Marshall, M. Walsh, S. Adkins, M. Aillery, E.A. Ainsworth, C. Ammann, C.J. Anderson, I. Bartomeus, L.H. Baumgard, F. Booker, B. Bradley, D.M. Blumenthal, J. Bunce, K. Burkey, S.M. Dabney, J.A. Delgado, J. Dukes, A. Funk, K. Garrett, M. Glenn, D.A. Grantz, D. Goodrich, S. Hu, R.C. Izaurralde, R.A.C. Jones, S-H. Kim, A.D.B. Leaky, K. Lewers, T.L. Mader, A. McClung, J. Morgan, D.J. Muth, M. Nearing, D.M. Oosterhuis, D. Ort, C. Parmesan, W.T. Pettigrew, W. Polley, R. Rader, C. Rice, M. Rivington, E. Rosskopf, W.A. Salas, L.E. Sollenberger, R. Srygley, C. Stöckle, E.S. Takle, D. Timlin, J.W. White, R. Winfree, L. Wright-Morton, and L.H. Ziska. 2012. "Climate Change and Agriculture in the United States: Effects and Adaptation." USDA Technical Bulletin 1935. Washington, D.C.

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Enhancing Water Productivity in Irrigated Agriculture in the Face of Water Scarcity

Susanne M. Scheierling and David O. Treguer

JEL Classifications: Q15, Q25, D24
Keywords: Irrigated Agriculture, Multi-factor Approaches, Water Productivity, Water Scarcity, Single-factor Productivity

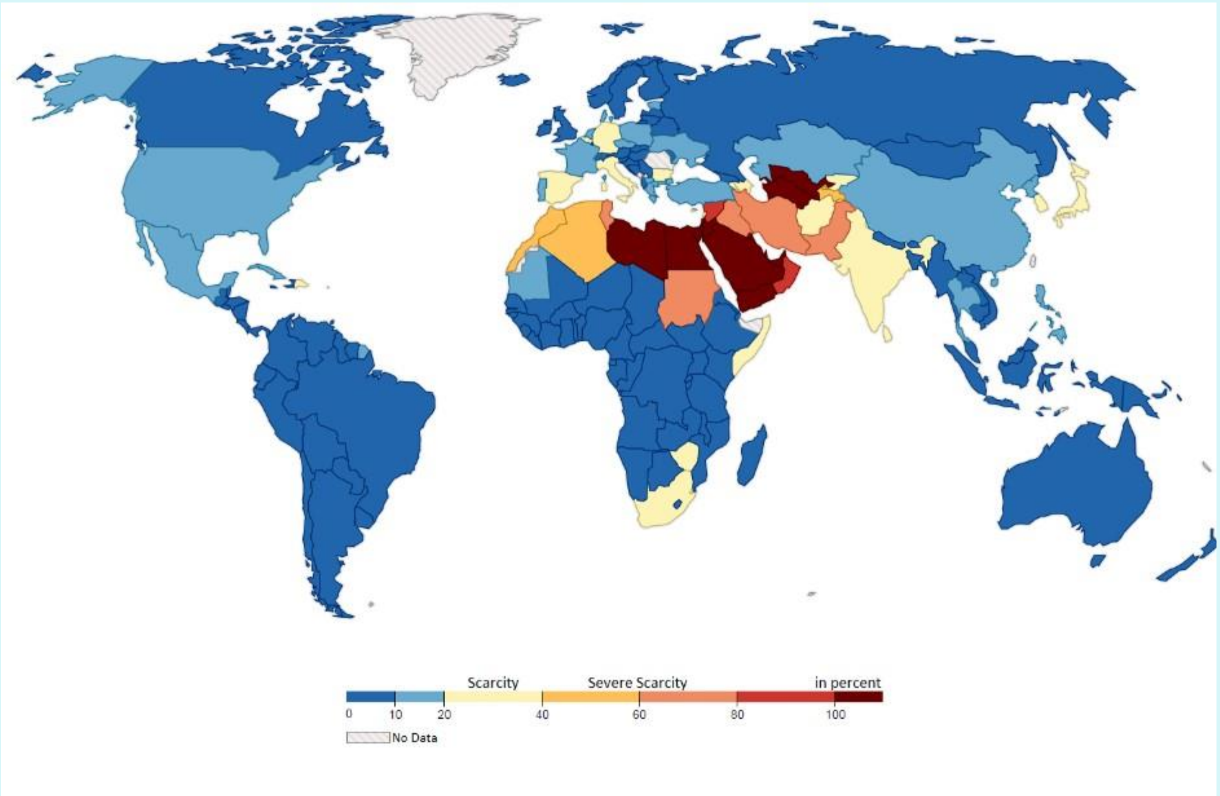
With growing water scarcity in many parts of the world and projections that indicate the need to increase agricultural production and, concurrently, agricultural water use, it is increasingly advocated to focus efforts on enhancing water productivity in irrigated agriculture. Given the large quantities of water involved, and the widely-held perception that water use in agriculture is relatively inefficient, even small improvements in agricultural water productivity are believed to have large implications for local and global water budgets. Many international organizations concerned with water management are promoting increase in agricultural water productivity as an important policy goal, and significant public and private investments are being made with this in mind (FAO, 2012; World Bank, 2013; WWAP, 2016). However, most reports and public communications on agricultural water productivity are quite vague. If a definition of the term is given or implied, it is usually along the lines of "more crop-per-drop"—emphasizing water quantity as if it were the only input that mattered—and approaches for enhancing water productivity or efficiency are seldom discussed systematically. The topic is complex due to a number of challenges.

Linking Irrigated Agriculture and Water Scarcity

A first challenge relates to defining water scarcity and showing water used in irrigated agriculture as a contributing factor. This is made difficult by the particular supply and demand characteristics of water, including its mobility, its fluctuating and unpredictable supplies over time and space, and its varying quality. The interdependency among its users is also pervasive. In irrigated agriculture, for example, it is not unusual to find that 50% or more of the water withdrawals from a watercourse are returned, in the form of surface runoff or subsurface drainage, to the hydrologic system (Young, 2005). Only the remainder is "consumed", or lost to the atmosphere, through evaporation from plant and soil surfaces and through transpiration by the plants.

A range of definitions of water scarcity have been proposed and various indicators applied (UNEP, 2012). A widely used indicator is based on a comparison between total water withdrawals and total renewable water resources at the national level. A country is considered to experience "scarcity" if total water withdrawals are between 20% and 40% of total renewable water resources, and "severe scarcity" if this value exceeds 40%. Figure 1 displays this indicator based on the latest available data from the Food and Agriculture Organization (FAO, 2016a). Countries in the Middle East and North Africa (MENA) are all shown to experience severe water scarcity. In other parts of the world, including most countries in South Asia and Central Asia, water is also considered to be scarce or severely scarce. Some countries' water withdrawals are even higher than their total renewable water resources. Saudi Arabia is the most extreme case, withdrawing almost ten times the amount of renewable resources available, and thus relying mostly on non-renewable groundwater.

Figure 1: **Total Water Withdrawals as Percent of Total Renewable Water Resources, 2013 or Latest Year Available**

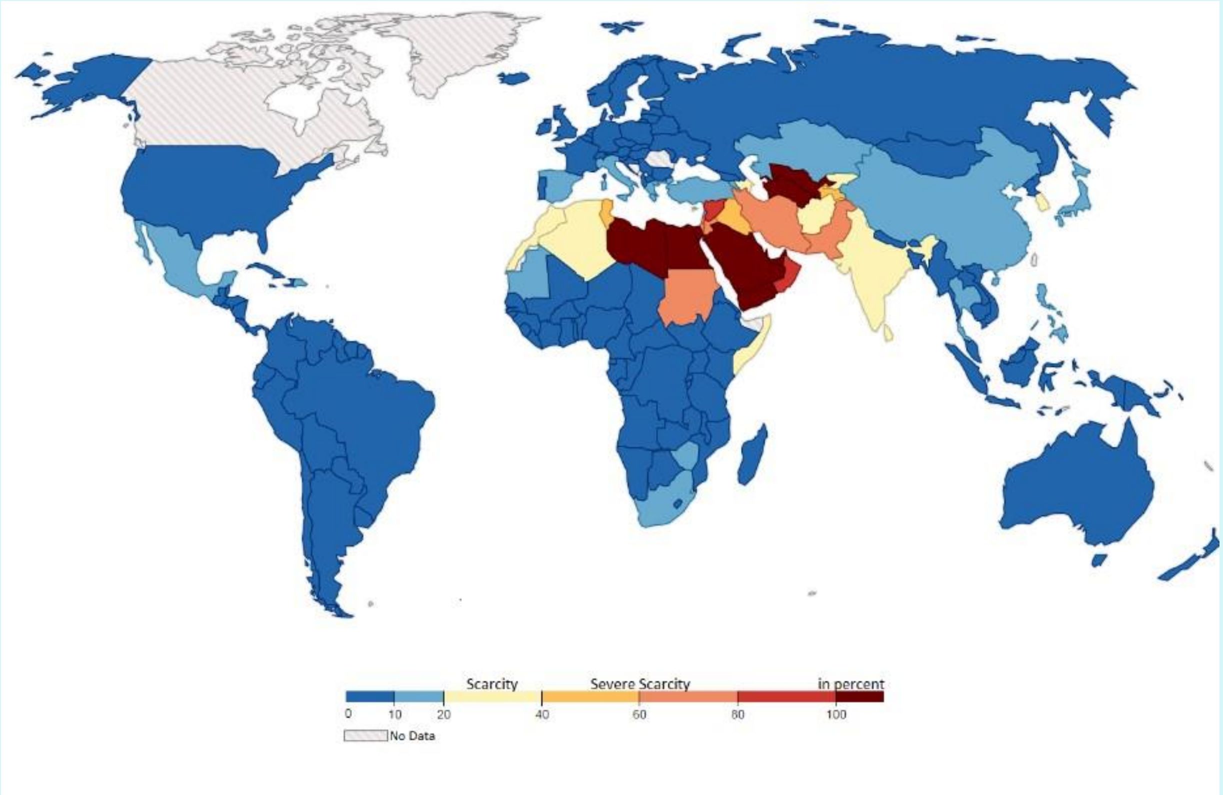


Source: Authors' calculations based on FAO, 2016a.
Notes: Total water withdrawals refer to the annual quantities of water withdrawn for agricultural, industrial and municipal purposes. Total renewable water resources include internal and external water resources (i.e. the annual flow of rivers and recharge of aquifers plus inflows from upstream countries).

In order to illustrate the link between water scarcity and irrigated agriculture, we modify the indicator and, instead of total water withdrawals, include only agricultural water withdrawals in comparison with total renewable water resources. Figure 2 shows the data for the modified indicator. The astonishing result is that the classification of countries with "scarcity" and "severe scarcity" is almost the same as in Figure 1 even though only agricultural withdrawals are considered. This shows the central role of irrigated agriculture in such assessments of water scarcity. In Saudi Arabia, water withdrawn for irrigated agriculture alone is more than eight times the amount of total renewable water resources; in Libya it is about 5 times, in Yemen 1.5 times, and in Egypt slightly more than the amount of total renewable water resources.

Some caveats apply to both indicators. On the one hand, they may underestimate water scarcity. Since they refer to the national level and apply annual water data, they do not indicate water scarcity situations that may occur at the regional or local levels—especially in large countries, such as China—or during the year. They also do not consider water quality issues, or water requirements for the environment. On the other hand, they may overestimate water scarcity since withdrawals include the reuse of return flows that in some instances, especially in the case of irrigated agriculture, can be substantial—such as in Egypt's Nile delta.

Figure 2: **Agricultural Water Withdrawals as Percent of Total Renewable Water Resources, 2013 or Latest Year Available**



Source: Authors' calculations based on FAO, 2016a.
Notes: Agricultural water withdrawals refer to the annual quantities of water withdrawn for irrigation, livestock and aquaculture purposes.

The available data do not allow for an analysis of how changes in agricultural withdrawals have affected water scarcity over time. However, a look at historical data on area equipped for irrigation can provide some insights (FAO, 2016b). Globally, the area equipped for irrigation increased from 164 to 324 million hectares (ha) over the past 50 years. The largest percentage increase occurred in Saudi Arabia (from 0.3 to 1.6 million ha), followed by Libya (from 0.1 to 0.5 million ha) and Yemen (from 0.2 to 0.7 million ha), and these three countries are now experiencing some of the most severe water scarcity. Large increases, in both percentage and absolute terms, also occurred in China (from 45 to 68 million ha) and especially India (from 26 to 67 million ha), a country that is now considered as water scarce.

Agricultural water withdrawals will continue to be a major factor in shaping the water situation worldwide, not least given the expected need for an increase in irrigated area due to continued population growth, rising meat and dairy consumption, and expanding biofuel use (Alexandratos and Bruinsma, 2012). Projections on the likely changes in irrigated area vary, and become more uncertain when the impacts of climate change are taken into account (Elliott et al., 2014). The latter projections suggest that by the end of this century renewable water resources may allow a net increase in irrigated agriculture in some regions—such as in the northern United States, eastern United States and parts of

South America and South East Asia—while in other areas the previous expansion would need to be reversed—with a move to rain-fed management in some irrigated regions—such as the western United States, China, MENA, Central Asia, and South Asia.

Defining and Estimating Water Productivity and Efficiency in Irrigated Agriculture

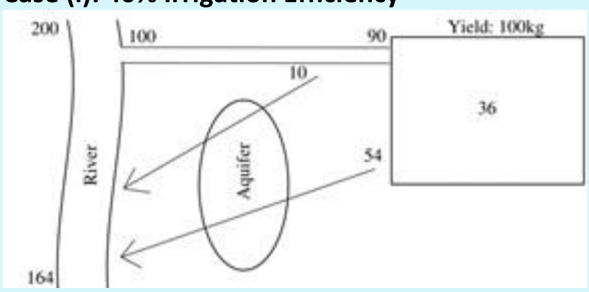
A second challenge relates to the terms agricultural water productivity and efficiency. The various disciplines involved tend to define and estimate the terms in different ways, and to focus on different measures of water. In civil engineering, for example, conveyance efficiency—the ratio of water received at the farm gate relative to the water withdrawn from a water source—is an important term. In irrigation engineering, irrigation efficiency—the ratio of water consumed relative to the water applied on the farm or field—is a classical concept (Jensen, 2007). Agronomists often use the term water use efficiency, and apply different definitions, such as the ratio of yield relative to water consumed (Hsiao et al., 2007). Much of the irrigation literature over the past two decades has addressed water productivity enhancements with crop-per-drop ratios, and strongly influenced the public discussion on agricultural water productivity along these lines (Giordano et al., 2016). The nominator of such ratios can be in physical terms (e.g. kilograms of crop yield) or in so-called “economic” terms (usually yield multiplied by price), and the denominator is expressed in one of the water measures (water withdrawn, applied, or consumed).

Aside from the formulation, the assumption that an increase in such a ratio (for example, as a result of a switch in irrigation technology) would indicate a desirable change, can be problematic. This is illustrated in Figure 3.

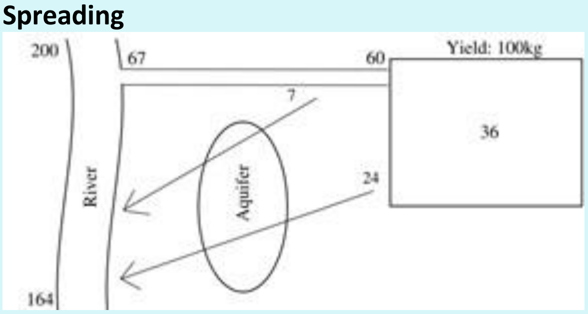
Consider an irrigated area that is initially assumed to produce 100 kg of a particular crop. Water is withdrawn from a river and delivered to the area in a canal with a conveyance efficiency of 90%. Seepage from the canal and water not consumed by the crop are assumed to return via a shallow aquifer to the river. In case (i), with an irrigation efficiency of 40%, withdrawal from the river amounts to 100 m^3, water applied is 90 m^3, and consumption 36 m^3. The crop-per-drop ratio (in kilograms per cubic meter) in terms of water withdrawn is then 1.0, in terms of water applied 1.1, and in terms of water consumed 2.8. In case (ii), after the farmer moves to a more capital-intensive irrigation technology (for example, from a gravity system to sprinklers) with an irrigation efficiency of 60%,

Figure 3: **Effects of Changes in Irrigation Efficiency**

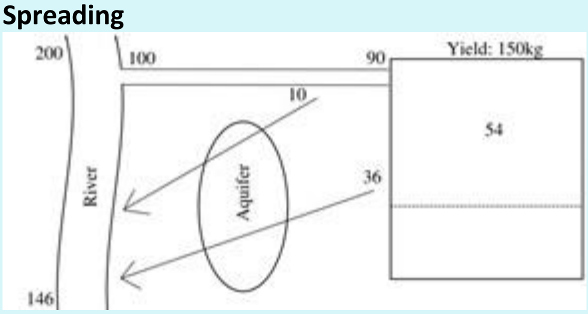
Case (i): 40% Irrigation Efficiency



Case (ii): 60% Irrigation Efficiency, No Water Spreading



Case (iii): 60% Irrigation Efficiency, Water Spreading



Source: Scheierling et al. 2014.

water application can be reduced from 90 m^3 to 60 m^3, and withdrawals from 100 m^3 to 67 m^3. The respective crop-per-drop ratios increase significantly, to 1.5 and 1.8. Yet because consumption and yield does not change, the crop-per-drop ratio in terms of water consumed stays the same at 2.8, as would the river flow downstream of the irrigated area. In case (iii) the farmer, after switching to a higher irrigation efficiency, continues to withdraw the original amount of water and spreads it over an expanded area. Production would increase to 150 kg, and water consumption to 54 m^3. The crop-per-drop ratios for all water measures would stay the same as in case (ii), yet the river flow downstream is reduced from 164 m^3 to 146 m^3. These cases show that the crop-per-drop ratios are influenced by the underlying water measure, and an intervention, such as the introduction of a new irrigation technology, may increase some ratios but not others. A change in a particular ratio may be the result of different causes, and an unchanged ratio may mask significant changes in the underlying water measure as well as in the resulting water availability for downstream uses and/or environmental requirements. These shortfalls of crop-per-drop ratios tend to be neglected in the public discussion.

In economics, including the field of agricultural production economics, productivity and efficiency aspects are defined and analyzed differently than in the irrigation literature. The productivity of a firm is defined as the ratio of its output to its input, and the efficiency is a comparison between observed and either maximum values of output given inputs, or minimum levels of inputs given output (Fried et al., 2007). A recent survey of the agricultural productivity and efficiency literature that explicitly includes water aspects in productivity and efficiency measurements showed that—while the irrigation literature mostly uses single-factor productivity measures, such as the crop-per-drop ratios—agricultural production economics relies on multi-factor approaches such as total factor productivity (TFP) indices and frontier studies (Scheierling and Treguer, 2016).

Studies based on TFP indices are mostly carried out at the national level. They compare a single output or an aggregate output index to an aggregate input index, with different ways of aggregation leading to different TFP indices. When trying to incorporate water as a separate input, studies applying TFP indices tend to face data problems. Approaches to at least partially account for water aspects include the approximation of irrigation water through the area of land irrigated, and the price or opportunity cost of water through irrigation water fees. For example, in a study of TFP in the global agricultural economy based on FAO data, Fuglie (2010) divides cropland into rainfed cropland and area equipped for irrigation, and includes irrigation fees in the cost share of agricultural land. A limitation of such studies is that they do not provide much insight into the effect of irrigation water on agricultural productivity patterns, or on water scarcity.

Frontier studies, on the other hand, tend to be carried out at the farm level. They measure efficiency relative to a reference "best practice" or efficient frontier, constructed from observed inputs and their output realization. Various statistical techniques are used to calculate the level of inefficiency as the distance to the frontier. Technical efficiency is then an index that ranges between 0% and 100% , and can be interpreted as a proxy measure for managerial effort. It can be studied with an output-orientation (focusing on the ratio of the observed and the maximum levels of output that can be produced with a given level of input and technology) or an input-orientation (focusing on the ratio of the minimum feasible and observed quantity of inputs needed to produce a given level of output and technology). A recent survey of frontier studies incorporating water aspects showed that the majority analyze technical efficiency with an output-oriented approach (Bravo-Ureta et al., 2016). Only a few studies estimate input-oriented technical efficiency, and also analyze the technical efficiency specifically for the input water (focusing on the ratio of the minimum feasible and observed quantity of water applied, given the level of technology and the observed levels of output and all other inputs). Findings for the water-specific technical efficiency suggest that, even without changes in technology, large gains in technical efficiency may be achieved from efforts to improve farmers' managerial ability related to irrigation water, and water applications could be significantly reduced without affecting yields. However, water quality or return flow issues are not taken into account in these studies.

Clarifying Objectives

A third challenge is that the objective(s) underlying efforts to enhance agricultural water productivity and efficiency are often not clearly spelled out. In much of the irrigation literature, the maximization of agricultural water productivity (usually measured as a crop per drop ratio) seems implicitly assumed to be the overarching objective, and calls are made for efforts to "close the gap" of farmers or whole regions that are below levels achieved elsewhere. In an early critique, Barker et al. (2003) pointed out that while a higher water productivity—in terms of crop per drop—tends to be viewed as inherently better than a lower one, this may not be the case from the perspective of the farmer or the economy as a whole; this is because enhancements in water productivity may require more labor and other inputs, and therefore might not be cost-effective.

It can be argued that at least three objectives may be pursued with enhancements in agricultural water productivity. The two key objectives are increasing agricultural production, in some cases linked with an attempt to not worsen water scarcity; and conserving agricultural water in response to pressures for reallocating water to other uses (including environmental requirements) or for coping with water scarcity (Scheierling et al., 2014). A third objective that may be linked to the other two objectives is increasing, or at least maintaining, agricultural net revenues.

In the agricultural production economics literature, all three objectives have, to some extent, been reflected. The studies based on TFP indices have focused on increasing agricultural production. Frontier studies have mostly been output-oriented, and thus also more interested in how agricultural production could be raised. A few input-oriented studies use the notion of water-specific technical efficiency to investigate potential water conservation. However, due to their focus on the farm level, they take a perspective that in many cases may be too narrow for deriving broader implications for improving irrigation water management to cope with water scarcity. This is because they seem to only consider water applied, and implicitly assume that any reduction in this measure would constitute water saving. However, this may not be the case in areas where return flows are an important water source for downstream users. Furthermore, given the current institutional arrangements in many locations, farmers may have little incentive to release this water for other uses. This aspect has so far not received much attention, even in studies aimed at conserving water.

Among the frontier studies with estimates of water-specific technical efficiency, a few also evaluate the potential cost savings from adjusting the volume of irrigation water to a technically efficient level while holding all other inputs at observed levels. This is a way to provide some insight into the third objective of increasing agricultural net revenues. A caveat in this case is that the related improvements in managerial efforts may be associated with costs that are not considered in the estimation.

Assessing the Choice of Policy Interventions

Finally, a fourth challenge concerns choosing suitable policy interventions for enhancing agricultural water productivity and efficiency. The understanding of these terms and the related estimation methods often determine the recommendations. In the past, definitions from civil and irrigation engineering have dominated the irrigation literature and the public discussion—as well as the applied interventions, with a focus on investments for improved infrastructure and irrigation technologies. The implicit assumption has been that these investments would contribute to both increased agricultural production and water conservation—at least in terms of water applied. Furthermore, in both developed and developing countries such investments are often subsidized so that they also contribute to the third objective, increasing agricultural net revenues.

The estimation methods also influence the policy recommendations (Scheierling et al., 2014). On the one hand, studies in the irrigation literature that estimate crop per drop ratios for particular crops in terms of yield to water consumed—often employing agro-hydrological models in combination with remote sensing—tend to recommend better soil, water, and crop management to increase the ratios. Frontier studies, on the other hand, tend to emphasize the large potential of moving farms towards the production frontier by improving farmers' managerial skills, and recommend training programs on the use of irrigation technologies and the management of irrigation water.

It seems that more attention should be given to the underlying objectives of efforts to enhance agricultural water productivity. In many parts of the world, especially in the semi-arid and arid regions where water scarcity is already severe and the exploitation of nonrenewable groundwater at unsustainable levels, the conservation of agricultural water is likely to become a main objective. This will require to keep in mind the particular context in which the interventions are to take place. An important aspect is whether return flows matter for downstream uses. Broadly speaking, if they do not matter—due to a lack of downstream uses, or highly saline aquifers that prevent reuse—and water application amounts are fixed, interventions may focus on optimizing the share of applied water for crops' transpiration needs. The adoption of more capital intensive irrigation technologies and strengthened farmers' management skills would move production closer to the so-called frontier. If institutional arrangements permit, the "saved" water could then be transferred to other uses. However, if return flows do matter (that is, if conveyance and on-farm "losses" can be reused, as in Figure 3) and especially if environmental flows and/or water rights of downstream users depend on them—as is the case in some western states of the United States—then interventions may need to focus on reducing water consumed. Only this reduction could be considered "saved" water that is available for reallocation without affecting downstream uses. Suitable interventions would either decrease evaporation (for example, by applying mulching techniques or conservation tillage) or transpiration (for example, by switching to varieties with shorter growing season length). Subsidies for more capital-intensive irrigation technologies in such a context often would not reduce water consumption and may even increase it, especially if water spreading occurs (Scheierling et al., 2006). Also an increase in volumetric charges for irrigation water may not make much additional water available but significantly affect agricultural net revenues. Since it is usually the amount of water applied—and not consumed—that is charged, farmers have an incentive to make adjustments for reducing the former and keeping the latter as much as possible at the same level (for example, with better irrigation scheduling). Substantial amounts of additional water can then only be made available by changes to low consumptive use crops or to non-irrigated agriculture (Scheierling et al., 2004).

Going Forward

In many regions with growing water scarcity and unsustainable water use, coupled with the influence of climate change, it may be not be possible that water application amounts in agriculture can remain fixed, as assumed above. In such cases, the institutional arrangements governing water reallocations will become a central feature of water policy, and reform efforts need to focus on limiting the negative impacts on agricultural production and farmers as well as on downstream users, including the environment.

There seems to be scope for advancing economic assessments of agricultural water productivity, including all sources of productivity, and providing insights on how water could be used more efficiently and productively in different contexts and with different objectives. This may involve learning from and possibly harmonizing approaches used within economics and other concerned disciplines. Deductive methods—such as hydroeconomic models—that are not much discussed in the agricultural productivity and efficiency literature but constitute an important part in the agricultural and irrigation water economics literature, could also be more specifically applied to assess agricultural water productivity in a multi-input multi-output framework. These methods have the additional advantage that they can be applied from field or farm to basin and national levels, and consider the potential interlinkages among water users with the incorporation of the different water measures. In order to facilitate this progress, more efforts will have to be made to improve the availability of data on irrigation water use.

For More Information

Alexandratos, N., and J. Bruinsma. 2012. *World Agriculture towards 2030/2050*. The 2012 Revision, ESA Working Paper No. 12-03, Rome: Food and Agriculture Organization of the United Nations.

Barker, R., D. Dawe, and A. Inocencio. 2003. “Economics of water productivity in managing water for agriculture.” In *Water Productivity in Agriculture: Limits and Opportunities for Improvement*, eds. J.W. Kijne, R. Barker, and D. Molden, 19-36. Wallingford, UK: CAB International.

Bravo-Ureta, B.E., R. Jara-Rojas, M.A. Lachaud, V.H. Moreira, S.M. Scheierling, and D.O. Treguer. 2016. *Agricultural Productivity and Water: Evidence from the Frontier.* Policy Research Working Paper, World Bank, Washington, D.C. Forthcoming.

Coelli, T.J., D.S.P. Rao, C.J. O’Donnell and G.E. Battese. 2005. *An Introduction to Efficiency and Productivity Analysis.* 2nd ed. Springer, New York, USA.

Elliott, J., D. Deryng, C. Mueller, K. Frieler, M. Konzmann, D. Gerten, M. Glotter, M. Floerke, Y. Wada, N. Best, S. Eisner, B.M. Fekete, C. Folberth, I. Foster, S.N. Gosling, I. Haddeland, N. Khabarov, F. Ludwig, Y. Masaki, S. Olin, C. Rosenzweig, A. Ruane, Y. Satoh, E. Schmid, T. Stacke, Q. Tang, and D. Wisser. 2014. “Constraints and Potentials of Future Irrigation Water Availability on Agricultural Production under Climate Change.” *Proceedings of the National Academy of Sciences (PNAS)* 111(9), 3239-44.

Food and Agriculture Organization of the United Nations (FAO). 2012. *Coping with Water Scarcity: An Action Framework for Agriculture and Food Security.* Water Reports 38, Rome: FAO.

Food and Agriculture Organization of the United Nations (FAO). 2016a. *AQUASTAT Main Database*. Available online: http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en

Food and Agriculture Organization of the United Nations (FAO). 2016b. *FAOStat*. Available online: http://faostat3.fao.org/home/E

Fried, H.O., C.A. Knox Lovell, and S.S. Schmidt. 2007. “Efficiency and Productivity.” In *The Measurement of Productive Efficiency and Productivity*, eds. H.O. Fried, C.A. Knox Lovell and S.S. Schmidt, 1-106. New York, NY: Oxford University Press.

Fuglie, K.O. 2010. “Total Factor Productivity in the Global Agricultural Economy: Evidence from FAO Data.” In *The Shifting Patterns of Agricultural Production and Productivity Worldwide,* eds. J.M. Alston, B.A. Babcock, and P.G. Pardey, 63-95. Ames, Iowa: The Midwest Agribusiness Trade Research and Information Center.

Giordano, M.A., H. Turral, S.M. Scheierling, D.O. Treguer, and P.G. McCornick. 2016. *Beyond 'More Crop per Drop': Evolving Thinking on Agricultural Water Productivity*. International Water Management Institute (IWMI) Research Report, Colombo, Sri Lanka. Forthcoming.

Hsiao, T.C., P. Steduto, and E. Fereres. 2007. "A Systematic and Quantitative Approach to Improve Water Use Efficiency in Agriculture." *Irrigation Science* 25 (3): 209-231.

Jensen, M.E. 2007. "Beyond Irrigation Efficiency." *Irrigation Science* 25 (3): 233-245.

Scheierling, S.M., R. Young, and G.E. Cardon. 2004. "Determining the Price Responsiveness of Demands for Irrigation Water Deliveries vs. Consumptive Use." *Journal of Agricultural and Resource Economics* 29(2): 328-345.

Scheierling, S.M., R.A. Young, and G.E. Cardon. 2006. "Public Subsidies for Water-conserving Irrigation Technologies: Hydrologic, Agronomic and Economic Assessments." *Water Resources Research* 42, W03428.

Scheierling, S.M., D.O. Treguer, J.F. Booker, and E. Decker. 2014. *How to Assess Agricultural Water Productivity? Looking for Water in the Agricultural Productivity and Efficiency Literature*. Policy Research Working Paper 6982, World Bank, Washington, D.C.

Scheierling, S.M., and D.O. Treguer. 2016. "Water Productivity in Agriculture: Looking for Water in the Agricultural Productivity and Efficiency Literature." *Water Economics and Policy* 2(3). DOI: 10.1142/S2382624X16500077.

United Nations Educational, Scientific, and Cultural Organization (UNESCO). 2009. *Water in a Changing World: The United Nations World Water Development Report 3*. Paris: UNESCO Publishing, and London: Earthscan.

United Nations Environment Programme (UNEP). 2012. *Measuring Water Use in a Green Economy.* A Report of the Working Group on Water Efficiency to the International Resource Panel. Nairobi, Kenya.

World Bank. 2013. *Agriculture Action Plan 2013-2015. Implementing Agriculture for Development*. Washington, D.C.: World Bank.

United Nations World Water Assessment Programme (WWAP). 2016. *The United NationsWorld Water Development Report 2016: Water and Jobs.* Paris, UNESCO.

Young, R.A. 2005. *Determining the Economic Value of Water: Concepts and Methods*. Washington, D.C.: Resources for the Future.

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Role of Institutions, Infrastructures, and Technologies in Meeting Global Agricultural Water Challenge

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With the declining share of water for agriculture and increasing demand for food and other farm products, many countries are facing a major challenge both in sustaining farm productivity in irrigated areas and in expanding irrigation into rain-fed regions. This challenge has far reaching local and global implications in terms of food security and livelihood, agricultural trade, and agro-based economic activities. This is especially true given persistent water use inefficiency within agriculture and binding physical limits for supply augmentation with a national boundary.

How to tackle the water challenge of agriculture? An invariable answer is the management of water demand within agriculture. While the answer is logical, it gives only the direction but not the complete pathway for the final solution. As such, the answer pegs additional but complex questions. Can the options for implementing water demand management be practical equally across water sources, crops, and socio-economic contexts? Are these options operationally independent? If not, what kinds of linkages and synergies do exist among them? More fundamentally, can the options be effective in achieving their individual and collective goals within a structural and functional vacuum? What roles do institutions, infrastructures, and technologies—both within and beyond agricultural sector—play in filling such a vacuum?

Use Inefficiency, Amid Scarcity

The water challenge of agriculture is characterized by two apparently distinct narratives. The first one captures the macro symptoms of an increasing water scarcity and their next level effects on sectoral water share and on productivity and livelihoods. Binding hydrological limits and political pressures of non-farm sectors magnify these effects. But, the second narrative captures the persisting use inefficiency and low productivity of water and the resultant magnitude of resource and economic loss within and beyond agriculture. Factors like aquifer depletion, pollution, and salinity add additional complications.

These narratives, though distinct, are neither competitive nor mutually exclusive. When taken together, they actually capture not only the crux of the water problem but also the clue to its answer. From an analytical perspective, the first has a focus more on the micro effects of macro and supply side aspects. The second has a focus more on the macro effects of micro and demand side aspects. From a policy perspective, the first underlines large scale investment and infrastructure as well as national and sectoral level institutional reforms. The second emphasizes local and field level aspects like agronomic and farm practices, technologies, and institutions and infrastructures. While their relative focus and priority differ, the narratives negate neither the diagnosis nor the prescription of each other.

Macro policy options are certainly important. But, the justification and pressures for undertaking them have to come from below, particularly from agriculture itself, having the dominant water share. Considering the inefficient water use in agriculture, the sector cannot generate the kind of pressure needed to prompt macro policy reforms. The inefficient water use in agriculture is actually concealing a hidden water potential—with its corresponding dormant output potential—of vast magnitude. If these water and output potentials can be realized through some dramatic rise in use efficiency and productivity, agriculture can certainly enhance farm output even while releasing huge amounts of water for other sectors.

Clearly, a water-wise efficient and productive agriculture can both generate tremendous pressures for performance in other sectors and also provide powerful justification for more infrastructural investments and institutional initiatives at the national level. The central role of improvements in water use efficiency at the local level as a main means for addressing water problems both at the sectoral and national levels is rather unmistakable. So also is the strategic role of water demand management in agriculture.

Options for Water Demand Management

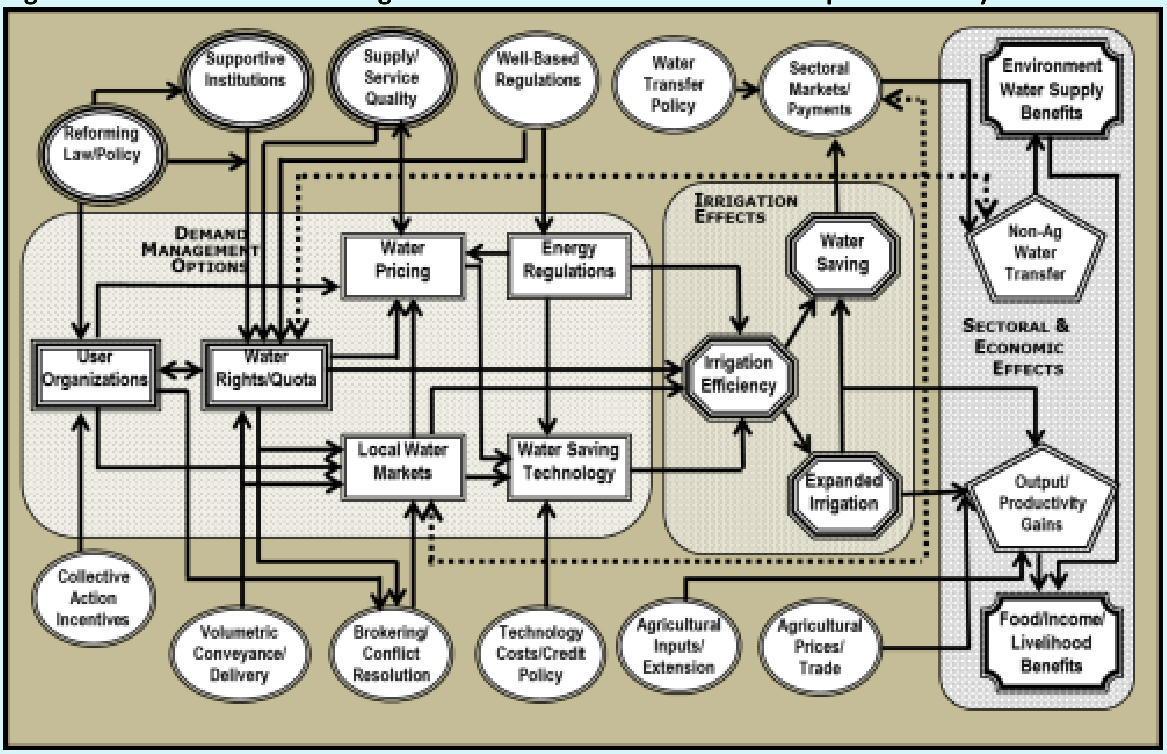
Water demand management is implemented through six main options: water pricing, water markets, water rights, energy regulations, water saving crop and irrigation technologies, and user organizations. The key features of these options include:

- Some are context-specific whereas others are applicable in more generic context. For instance, water pricing is applicable essentially in canal regions, whereas the option of energy regulations and water saving technologies are largely relevant for groundwater regions. But, the remaining two options are context independent.
- Impacts of options such as water saving technologies, water rights, and energy regulations are more direct and immediate whereas the same for others are only indirect and gradual.
- Against their true potential, their actual efficiency effects, as observed in many countries, are too meager and too thinly spread to have any major impact on aggregate water demand. The reasons for this are their limited area coverage and operational effectiveness, which are themselves an outcome of the lack of coherent strategy.
- Options also differ considerably in terms of their immediate adoptability and political economy acceptability. On this count, the option of water rights is the most difficult one in countries that do not have them at present. Although user organizations and water saving technologies are politically easier to implement, they do require active government policies and favorable agronomic conditions.
- Despite their differences and limitations, the options have fundamental operational linkages among them. An understanding of these linkages and their impact pathways is critical for designing a coherent and effective demand management strategy.

The Analytics of Water Demand Management

Figure 1 depicts the analytics of water demand management in agriculture along with its sectoral and economy-wide ramifications. It unbundles the impact pathways and linkages among institutions, infrastructures, technologies, and the general economic and policy environment. The impact pathways trace the effects of agricultural water use to sectoral and economy-wide goals. Figure 1 is able to place water demand management both in the strategic context of water and agricultural institutions as well as in the larger context of sectoral and economic goals. Figure 1 has five analytically distinct but operationally linked segments. The first segment shows the sequential linkages among demand management options. The next segment captures the joint effects of these options on the irrigation sector, where the water savings from efficiency improvement lead to either an expanded irrigation or an increased water savings within existing supply. The third segment captures the sectoral and economy-

Figure 1: Water Demand Management: Functional Structure and Impact Pathways



Source: Adapted from Saleth and Amarasinghe, 2010

wide consequences of the effects from irrigation sector. The remaining two segments cover, respectively, the immediate institutional structure and the fundamental institutional environment. Several points deserve attention.

Since the institutions and their linkages, taken together, form the institutional context of demand management, Figure 1 does capture the institutional structure. But, the institutional environment of demand management, as defined by the interactive roles of hydrological, demographic, cultural, social, economic, and political factors, actually operates beneath the entire system. In addition, given the sequential linkages among them, some options are obviously more important than others. This is either due to them being the necessary conditions for others—for example, user and community organizations—or due to the extent of their linkages with others—for example, water rights and quota system. Thus, the ability of an option to influence water use depends not just on how efficiently it is designed and implemented but also on how well is its aligned with other related options and how effective are the supportive institutional and technical conditions.

Since institutions are defined jointly by legal, policy, and organizational aspects (Saleth and Dinar, 2004), all options—except water saving technology—can be viewed as institutions in themselves. As such, the linkages among these options form part of the institutional setting of water demand management. The institutional structure for demand management covers not only the institutions that are directly related to individual options but also those related to water delivery-related infrastructures, farm input and extension systems, agricultural markets, and price and investment policies. Since these sectoral and macro-economic policies affect the returns to farm level water saving initiatives, they determine the levels of economic incentives and technical scope for the adoption and extension of the options.

Finally, from an impact perspective, the overall performance of a demand management strategy depends on the way it is designed and implemented. The strategy has to be designed in a way to exploit the functional and structural linkages among the options and also benefit from the synergies of the sectoral and macro-economic policies. For instance, the efficiency and equity benefits of water markets can be increased manifold when such markets operate within a volumetric water rights system and are also supported well by user-based management and enforcement mechanisms. Likewise, water pricing policy can be more effective both in cost recovery and in water allocation, if it is combined with volumetric delivery and user based allocation system structures.

Table 1: Functional Linkages and Impact Pathways: International Examples and Evidences

Linkages/Impact Pathways	Geographical Area	Examples/Evidences
Legal and policy reforms-User organization-Water rights-Local water markets-Irrigation efficiency-Output/productivity gains	Asia; Africa; Latin America; Multi-country	Rosegrant and Binswanger (1994); Easter and Quang (2014)
User organization-Volumetric delivery-Water rights-Water pricing-Irrigation efficiency-Productivity gains	North Gujarat, Western India	Kumar (2000 and 2005)
Water rights-Local water markets-Irrigation efficiency-Water saving	Multi-country, South-West Asia, Australia	Easter and Quang (2014); Ahmad (2000); NWC (2010)
Water rights-Local water markets-Irrigation efficiency-Environment flow benefits	Gujarat, Western India	Kay, et al. (1997); Kemper (2007)
Water rights-Water markets-Water saving technology-Irrigation efficiency-Water saving-Urban water transfer	South America	Perry (1999)
Water rights-Local water markets-Water pricing-Irrigation efficiency-Food, income, and livelihood Gains	Victoria, Australia	Bjornlund and McKay (1999)
Supportive institutions-Water rights-User organisation-Water markets-Irrigation efficiency- Food, income, and livelihood benefits	South Asia; Spain; California; Chile	Easter, et al., (1999)
Brokering-Local water markets-Irrigation efficiency-Water saving/ Expanded irrigation/ Output/productivity gains- Food, income, and livelihoods benefits	Multi-country India	Easter and Quang (2014); Saleth (2012);
Water saving technology-Irrigation efficiency-Water saving-Environment flow benefits	Arid and semi-arid areas of China	Deng, et al. (2006)
Technology cost/credit policy-Water saving technology-Irrigation efficiency-Expanded irrigation- Food, income, and livelihoods benefits	Kansas High Plains, US	Peterson and Ding (2005)
Well-based regulations-energy regulation-water pricing	Lower Jordan River Basin	Venot and Molle (2008)
Energy regulation-irrigation efficiency-Output/productivity gains-Food, income, and livelihoods benefits	Batinah Coast, Oman; Bihar, Gujarat, and Uttar Pradesh, India	Zekri (2008) Kumar, et al. (2011)
Water pricing-Water saving technology-irrigation efficiency-Water saving-Productivity gains	India	Dhawan (2002)

International Examples and Anecdotal Evidences

There are many international examples and anecdotal evidences for the functional linkages and impact pathways depicted in Figure 1. Table 1 provides a sample of these.

Many countries have, in fact, exploited the strategic role of these institutional and impact linkages not only in the particular context of water demand management but also in the more general context of water sector institutional reforms (Saleth and Dinar, 2005 and 2006).

Towards a Viable Strategy for Demand Management

In countries already having mature water institutions and superior infrastructural and technological conditions, as in the United States and Australia, the demand management strategy has a fairly straight path. But, in the case of many agrarian countries, the strategy will have a major challenge in view of the prevailing institutional vacuum, infrastructural and technological bottlenecks, and, above all, political apathy. In both cases, however, what is being observed is a casual and *ad hoc* constellation of several uncoordinated demand management efforts that are focused more on goals such as cost recovery, energy saving, and user participation than on efficiency and productivity. It is possible to identify several key design and implementation aspects that are needed for a coherent and viable demand management strategy regardless of the context.

The demand management strategy needs to treat the options as an interrelated configuration that is functioning within an institutional structure capturing the overall legal, policy, and organizational factors and an institutional environment capturing the general economic, infrastructural, technological, and resource conditions. Such an approach will help in exploiting the synergies from institutional linkages and positive feedbacks from the general economic and infrastructural conditions.

The strategic and institutional logic for crafting the demand managed strategy as part of a larger program of water sectors reforms is clear. But, the task is not easy due to the heavy economic and political costs involved in transacting such a change. Fortunately, there are well-tested reform design and implementation principles that can overcome the financial and political constraints to negotiate the reform process. The design principles relate to the prioritization, sequencing, and packaging of institutional components based on impact, costs, and feasibility and the implementation principles cover strategic aspects like timing, coverage, and scale.

The delineation of an appropriate time frame is critical. Within that time frame, options yielding quicker benefits in the short-run—for example, water saving technologies; energy regulations; water pricing—should receive priority while gradually creating conditions for long-term options. For example, user associations are long-term options that can facilitate the emergence of downstream institutions. Options like water rights should be planned after infrastructure development to facilitate volumetric delivery. Besides sequential prioritizing, programs can also be packaged—for example, system modernization with management transfer and improved service quality with higher water rates.

The overall aim is to put in place a critical set of institutions during the time frame, facilitating the natural process of institutional evolution. When a critical mass of institutions is in place, inherent institutional features such as scale economies in reforms will facilitate the emergence of complementary institutions over time.

Finally, it is very important to seize the opportunities provided by both internally caused factors such as a water crisis, financial bankruptcy, and aged water infrastructure as well as factors outside the system, such as a macro-economic crisis, an energy shortage, droughts and floods, and political change. This is because these are the times that the political opposition for change is likely to be low.

For More Information

Ahmad, M. 2000. "Water Pricing and Markets in the Near East: Policy Issues and Options." Water Policy, 2(3), 229-242.

Bjornlund, H., and J. McKay. 2000. "Do Water Markets Promote Socially Equitable Reallocation of Water? A Case Study of a Rural Water Market in Victoria, Australia." Rivers, 7(2), 141-154.

Deng, X.P., L. Shan, H. Zhang, and N.C. Turner. 2006. "Improving Agricultural Water Use Efficiency in Arid and Semi-arid Areas of China." Agricultural Water Management, 80(1), 23-40.

Dhawan, B.D. 2002. "Technological Change in Indian Irrigated Agriculture: A Study of Water Saving Methods." Commonwealth Publishers, New Delhi, India.

Easter, K.W., and Q. Huang (eds). 2014. "Water Markets for the 21st Century: What We have Learned?" Springer, New York, U.S.

Easter, K.W., M.W. Rosegrant, and A. Dinar. 1999. "Formal and Informal Markets for Water: Institutions, Performance, and Constraints." The World Bank Research Observer, 14(1), 99-116.

Kay, M., T. Franks, and L. Smith. 1997. "Water: Economics, Management and Demand." E & FN Spon, London, UK.

Kemper, K. E. 2007. "Instruments and Institutions for Groundwater Management." M. Giordano and K. Villholth. Eds. The Agricultural Groundwater Revolution: Opportunities and Threats to Development. CABI Publishing, Oxfordshire, UK, pp. 153-172.

Kumar, M.D. 2000. "Institutions for Efficient and Equitable Use of Groundwater: Irrigation Management Institutions and Water Markets in Gujarat, Western India". Asia-Pacific Journal of Rural Development, 10(1).

Kumar, M.D. 2005. "Impact of Electricity Prices and Volumetric Water Allocation on Energy and Groundwater Demand Management: Analysis from Western India". Energy Policy, 33(1), 39–51.

Kumar, M.D., A.S. Scott, and O.P. Singh. 2011. "Inducing the Shift from Flat-Rate or Free Agricultural Power to Metered Supply: Implications for Groundwater Depletion and Power Sector Viability in India". Journal of Hydrology 409(1–2), 382–394.

National Water Commission. 2010. "The Impacts of Water Trading in the Southern Murray–Darling Basin: An Economic, Social, and Environmental Assessment." Canberra, Australia.

Perry, C.J. 1999. "The IWMI Water Resources Paradigm: Definitions and Implications". Agricultural Water Management, 40(1), 45-50.

Peterson, J.M. and Ding, Y. 2005. "Economic Adjustments to Groundwater Depletion in the High Plains: Do Water-saving Irrigation Systems Save Water?" *American Journal of Agricultural Economics*, 87(1), 147-159.

Rosegrant, M.W. and H.P. Binswanger. 1994. “Markets in Tradable Water Rights: Potential for Efficiency Gains in Developing Country Water Resource Allocation.” World Development, 22(11), 1613-1625.

Saleth, R.M. 2007. “Water Rights and Entitlements.” In John Briscoe and R. P. S., Malik, eds. Handbook of Water Resources in India. World Bank and Oxford University Press, New Delhi, pp: 282-305.

Saleth, R.M. 2012. “Water Marketing in Agriculture.” *Indian Journal of Agricultural Marketing*, 25(3), 18-40.

Saleth, R.M., and U. Amarasinghe. 2010. “Promoting Irrigation Demand Management in India: Options, Linkages, and Strategy.” Water Policy, 12(6), 832–850.

Saleth, R.M., and A. Dinar. 2004. “The Institutional Economics of Water: A Cross Country Analysis of Institutions and Performance.” Edward, Elgar, Cheltenham, UK.

Saleth, R.M., and A. Dinar. 2005. “Water Institutional Reforms: Theory and Practice”. Water Policy, 7(1), 1-19.

Saleth, R.M. and A. Dinar. 2006. “Water Institutional Reforms in Developing Countries: Insights, Evidences, and Case Studies.” Ramon Lopez and Michael Toman, eds. Economic Development and Environmental Sustainability: New Policy Options. Oxford University Press, New York.

Saleth, R.M., and A. Dinar. 2008. “Linkages within Institutional Structure: An Empirical Analysis of Water Institutions”. Journal of Institutional Economics, 4(3), 375-401.

Venot, J. P., and F. Molle. 2008. “Groundwater Depletion in the Jordan Highlands: Can Pricing Policies Regulate Irrigation Water Use?” Water Resources Management, 22(12), 1925–1941.

Zekri, S. 2008. “Using Economic Incentives and Regulations to Reduce Seawater Intrusion in the Batinah Coastal Area of Oman.” Agricultural Water Management, 95(3), 243–252.

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