

Water Linkages Beyond the Farm Gate: Implications for Agriculture¹

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Abstract

Changes in water demand in other large water using sectors can affect agricultural water access and water costs. The relative importance of other large water using sectors varies by region but includes municipal, energy and industrial uses. Sectors which use energy intensively particularly need careful consideration, due to the water consumption embedded in energy use. In considering competition for water and potential effects on agriculture, it is useful to distinguish water withdrawals from water consumption.

Analyses of competition for agricultural water need to consider not only physical availability and use patterns, but also water costs to users in the form of price paid per unit (if any), pumping, conveyance and treatment costs and other charges related to water use. Climate change alters both water demand and supply through changes in precipitation, timing and quantity of runoff and temperature effects. Examination of past use patterns and availability is instructive, but not predictive of future patterns.

Changes in water costs can have a significant impact on regional water use patterns. Responsiveness to changes in costs varies across regions and use sectors. Water prices and other costs paid by water users often are not under the direct control of policymakers, and can be politically difficult to alter. However, well-functioning water markets send a signal of water's value to water users, a signal that assists in voluntary trading to assist regional economies in adapting to scarcity.

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Incentive-based agreements to trade water, money and exposure to shortage risk play a crucial role in regional adaptation to drought and climate change. Such agreements mitigate high costs, conflict and uncertainty over scarce water. The agricultural sector, as the largest water consuming sector in most regions of the world, can play a leadership role in regional adaptation to scarcity. A proactive stance will not only make the agricultural sector more resilient, but also can help buffer regional economies from disruptions linked to water scarcity.

Introduction

This paper provides an overview of water scarcity challenges in economic sectors beyond the farm gate that may affect agricultural water access and costs. The paper was commissioned to provide a non-technical introduction to inform conference dialogue related to water and agriculture. Given the highly complex set of topics embedded in the themes of this overview paper, readers may wish to refer to references provided for in-depth treatment. The paper is organized into the following sections: water use, scarcity and competition for water; adaptation mechanisms to water scarcity, potential effects on farm sector and conclusions.

Water Use and Water Scarcity

Climate change is altering water demand and supply through numerous mechanisms and with differing effects in different regions (IPCC 2014; Dettinger, Udall, and Georgakakos 2015). Future demand and supply patterns cannot reliably be projected based on past data. Nevertheless, examining data on water use trends provides a starting point for considering adaptation to an uncertain future.

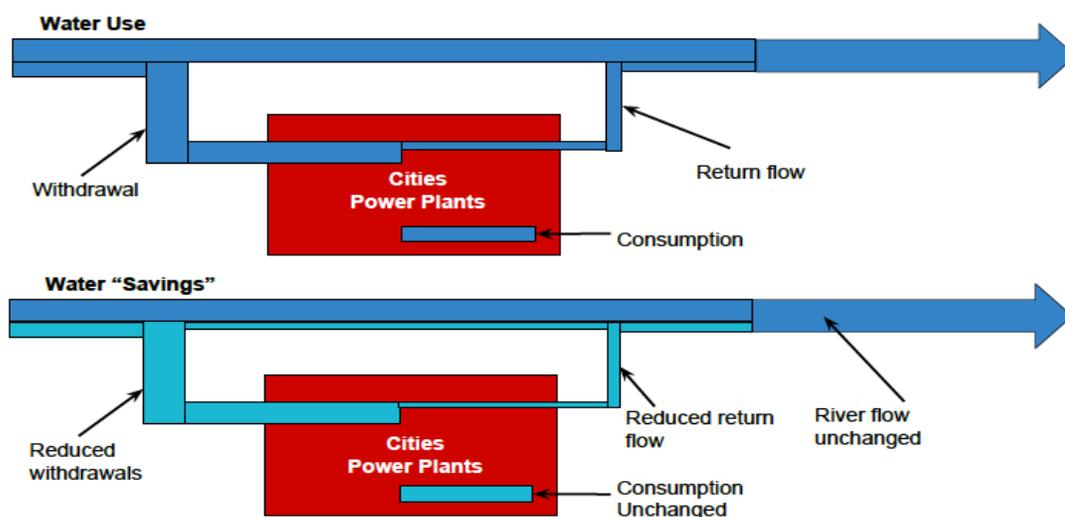
Water Use Data – Withdrawals Versus Consumptive Use

In examining water use among sectors and considering competition for water, it is important to distinguish between water withdrawn for a particular use and water consumptively used. Water consumptively used is no longer available in the watershed in which the use is occurring because it has been evapo-transpired or otherwise made unavailable for reuse.

The figures in this paper refer to withdrawals because that is the only data available over a series of years at global and national scales.³ Water withdrawals data is useful to an extent, but does not provide a clear picture of the impacts of water use by one sector on other sectors. Much of the water withdrawn for household use and for some industrial uses (like power plant cooling) returns to streams and aquifers and is used again multiple times. When farmers irrigate crops, a portion of the water removed from rivers and aquifers is “consumptively used” (evaporated or taken up by plants) and no longer available for other nearby uses. The portion of irrigation water that is not consumptively used (called return flows) seeps back into surface and groundwater at varying rates and becomes available for reuse (Brauman 2016).

Figures on consumptive use would be more useful than data on withdrawals for an accurate picture of “water use” by sector, particularly to assess effects of water conservation efforts. “Conservation” by cities, farms and industry does not necessarily reduce consumptive use and produce “saved water” available for other uses. The effect of various water conservation practices on consumptive use needs to be evaluated on a case-by-case basis. Figure 1 illustrates this principle. Water-saving devices and practices can reduce the amount of water withdrawn, but the amount consumed and downstream flow levels may remain unchanged (Brauman 2016).

Figure 1. Water-Saving devices and Practices



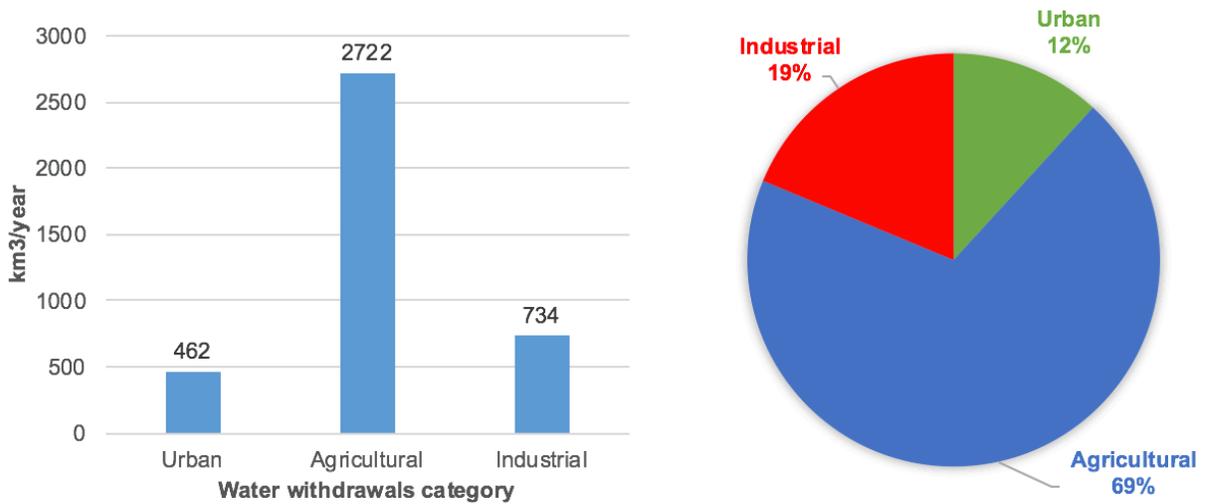
Graphic adapted from: (Brauman 2016)

³ It is possible to calculate consumptive use by sector for specific regions using detailed region-specific data and models, but this is not within the scope of this overview paper.

Water Withdrawals By Sector

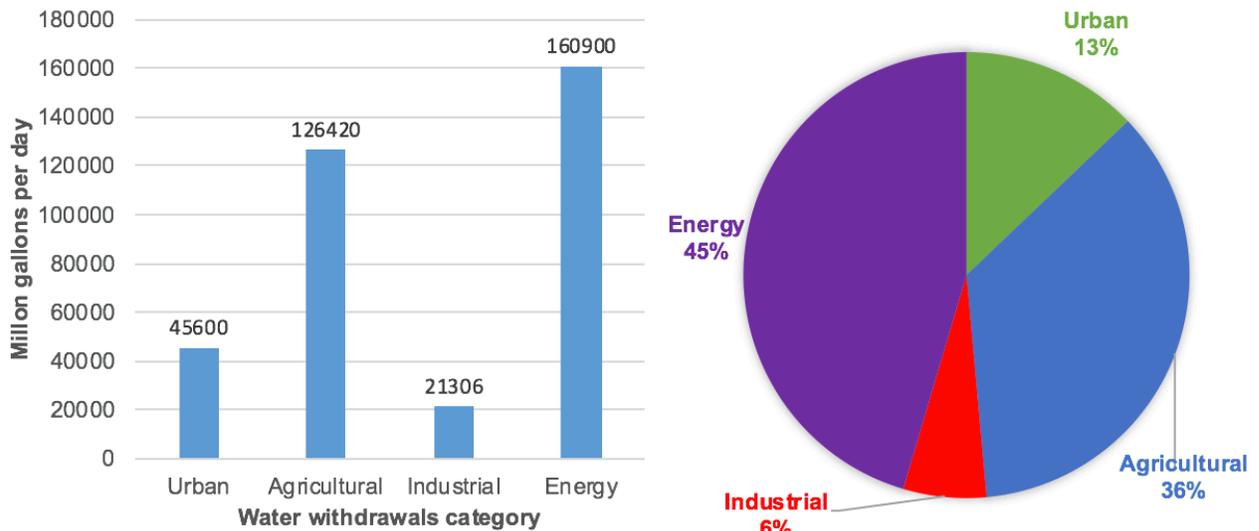
Globally and within the U.S., water withdrawals for crop irrigation far exceed water withdrawals for industrial and municipal purposes. This is the case for every continent except Europe, where water withdrawals for industry exceed those for agriculture (Maupin et al., 2010; “Water Withdrawal by Sector” 1-2). Figures 2 and 3 show water withdrawals by category at different spatial scales from global to U.S.

Figure 2. Withdrawals By Category In The World (2007)



Data from: "Water Withdrawal by Sector" 2014

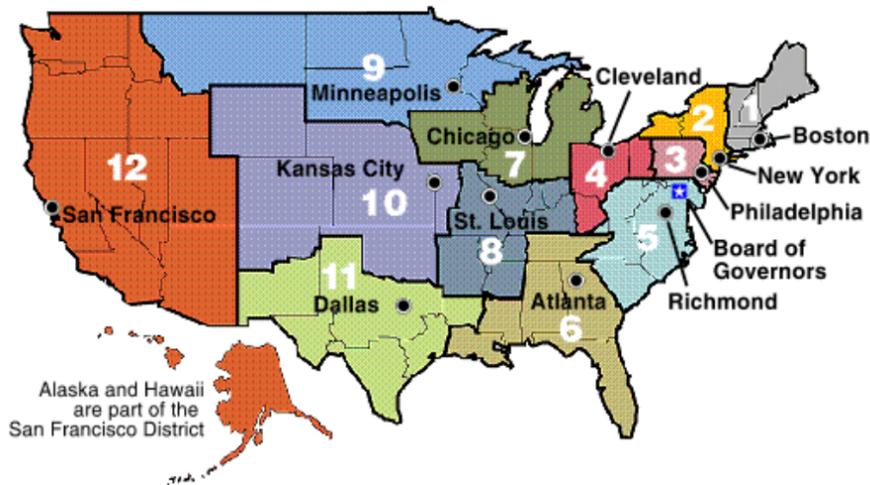
Figure 3: Withdrawals By Category In The US (2010)



Data from: Maupin et al., 2010

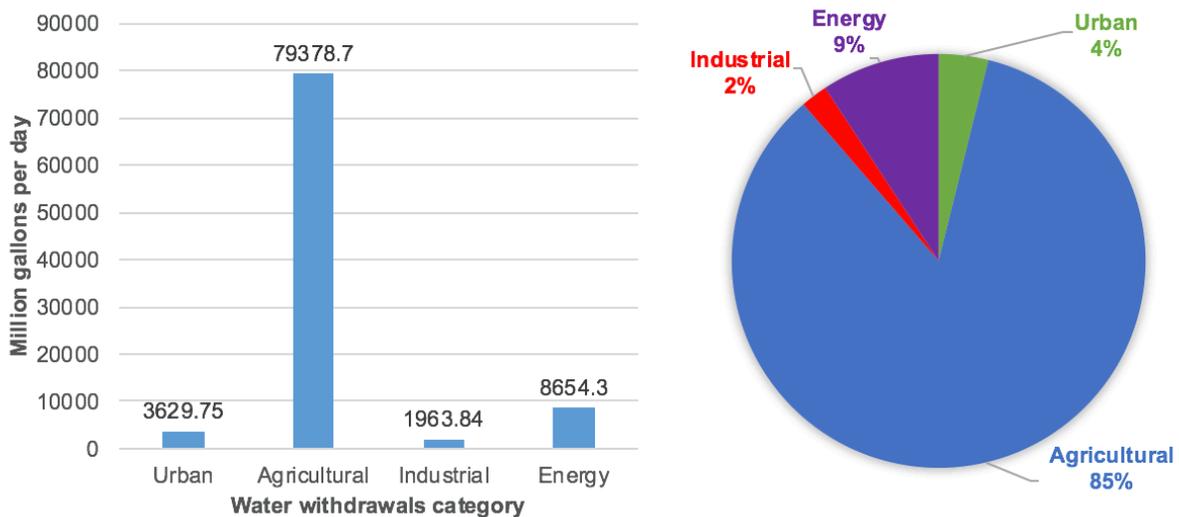
Figure 4 shows a map of U.S. Federal Reserve Bank (FRB) Districts, which include multiple states. Figures 5 and 6 show water withdrawals by category in two contrasting western U.S FRB Districts. The proportion of urban water withdrawals is much higher in the westernmost FRB District 12, which includes highly urbanized states such as California and Arizona. Agricultural withdrawals comprise the vast majority of water withdrawals in Arizona and California, even though 90% of the population lives in urban areas and most of the state’s economic activity occurs outside of the ag sector.

Figure 4: Federal Reserve District Map



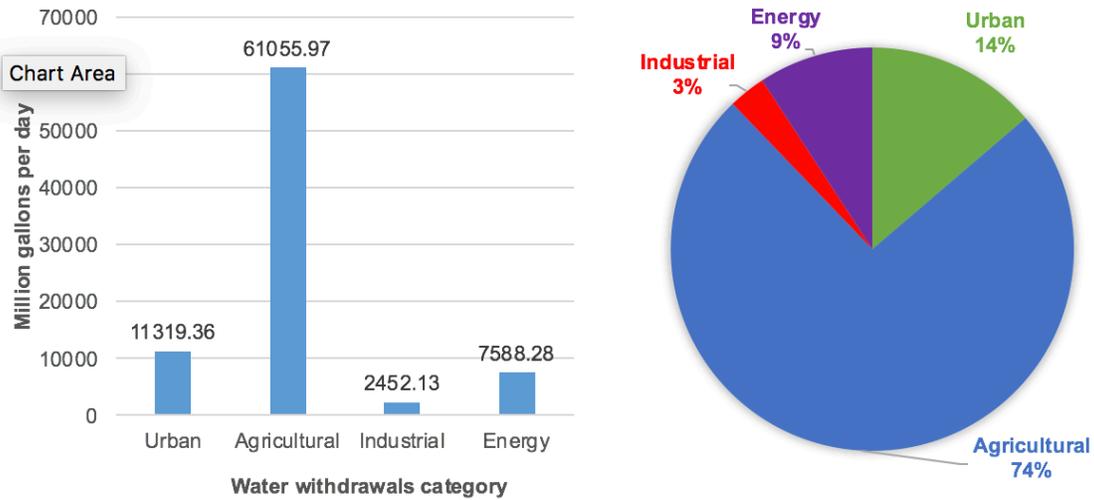
Source of graphic: FRB, 2005

Figure 5: Withdrawals By Category In FRB District 10 (2010)



Data from: Maupin et al., 2010

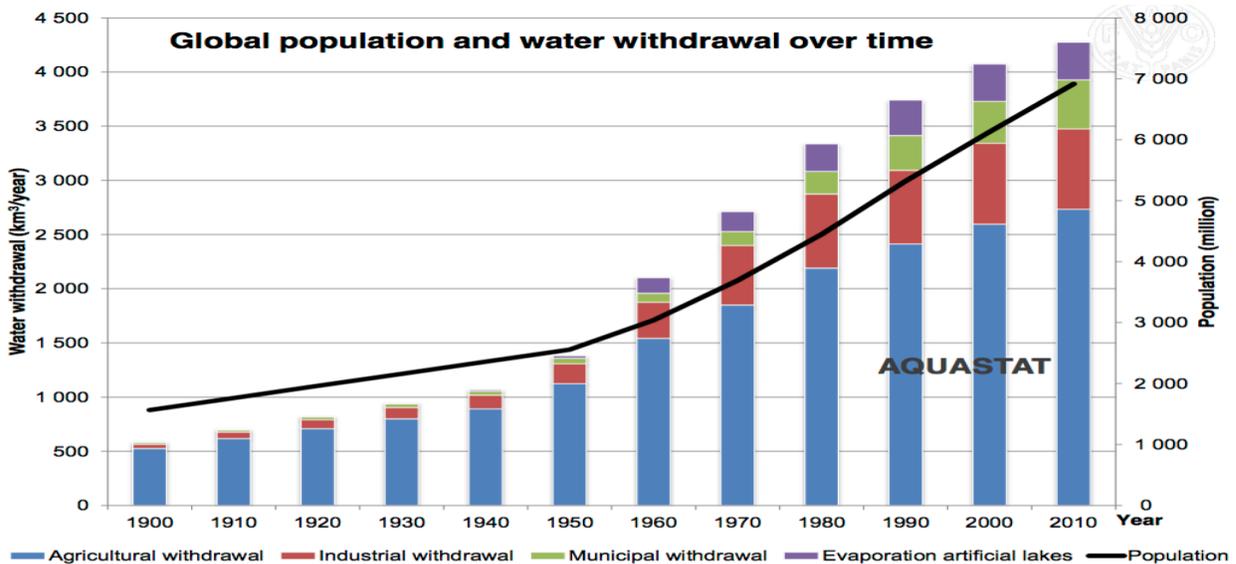
Figure 6: Withdrawals By Category In FRB District 12 (2010)



Data sourced from: Maupin et al., 2010

Figure 7 shows global water withdrawal data by category over the period 1900 – 2010, with world population also indicated. The thermoelectric sector is shown as a significant source of water withdrawals. However, a high proportion of this sector’s withdrawals are for power plant cooling water. Most of this water is returned to the hydrological system, with only a small portion being consumptively used. Consequently, the thermoelectric sector has a lower impact on water availability for other uses than suggested by Figure 7.

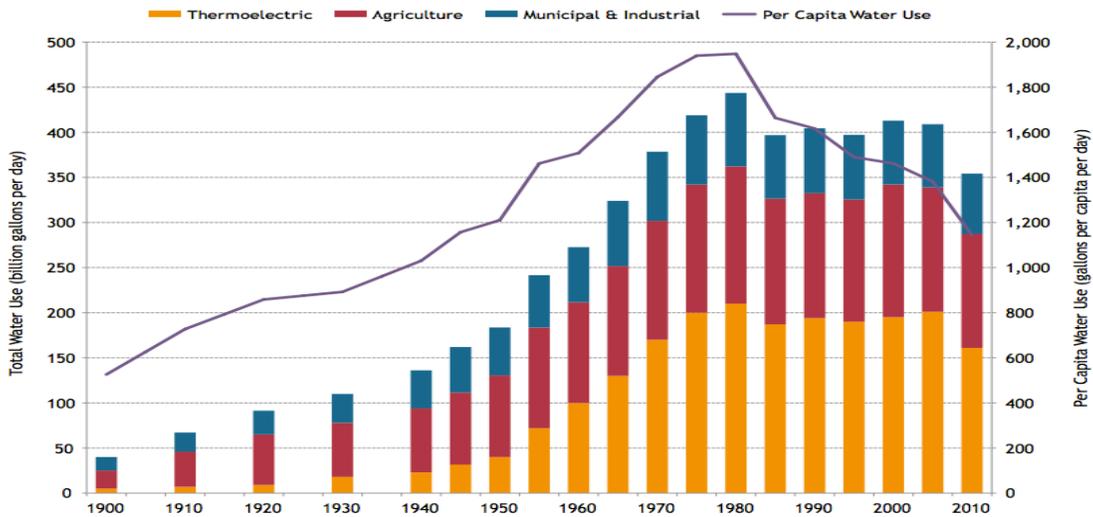
Figure 7: Global Population And Withdrawals By Category (1900-2010)



Source of graphic: FAO, 2010

Figure 8 shows total water withdrawals within the U.S. over the period 1900 – 2010, with per capita use included for reference. The decline in U.S. water use per capita, indicated in Figure 8, is driven by many factors, including the changes in per capita municipal and industrial use (shown in Figure 9). Declining per capita use in cities is a result of many interactive factors, discussed below under urban adaptation mechanisms.

Figure 8: Total Water Use (Freshwater and Saline Water) By Sector (1900-2010)

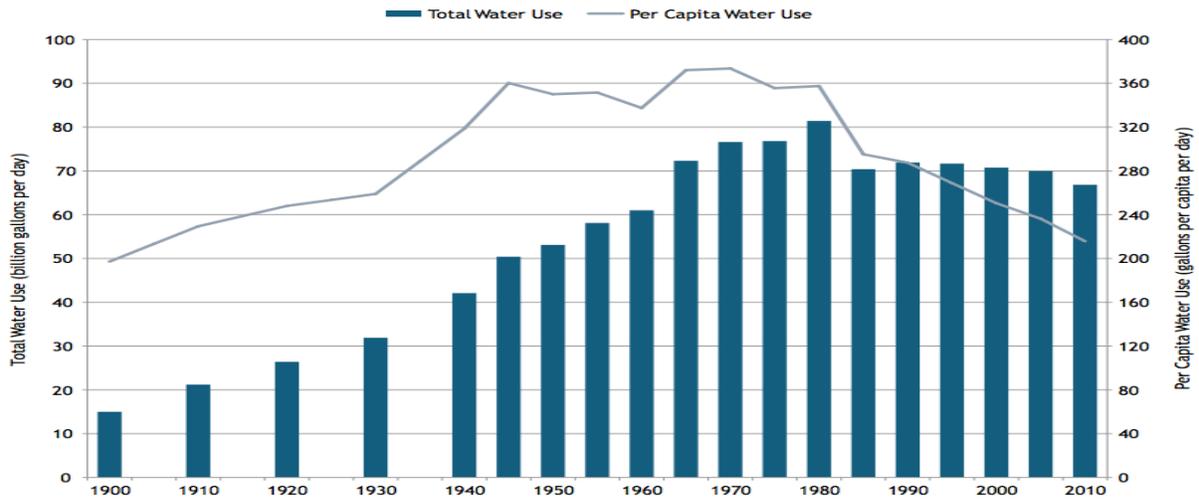


Notes: Municipal and industrial (M&I) includes public supply, self-supplied residential, self-supplied industrial, mining, and self-supplied commercial (self-supplied commercial was not calculated in 2000-2010). Agriculture includes aquaculture (1985-2010 only), livestock, and irrigation. Between 1900 and 1945, the M&I category includes water for livestock and dairy. [Sources: Data for 1900-1945 from Council on Environmental Quality (1991). Data for 1950 from USGS (2014a). Population data from Williamson (2015).] Source of graphic: Donnelly and Cooley, 2015

By some measures, the US has experienced significant increases in economic productivity per unit of water withdrawn over time, shown in Figure 10. The source report for Figure 10 defines economic productivity of water as “dollars of Gross Domestic Product (GDP) generated per unit of water withdrawn”, measured on an annual basis. This measure has increased steadily and significantly, indicating that the U.S. is producing more GDP per unit of water withdrawn.⁴

⁴ GDP has been criticized as a measure of economic productivity for neglecting to include changes over time in natural capital, such as water and air quality and habitat. This indicator of economic productivity of water could usefully be refined (with considerable work) to reflect a broader spectrum of economic considerations, and to reflect consumptive use by sector rather than water withdrawals. Nevertheless, this indicator shows significant change over time in patterns related to U.S. economic production and water use.

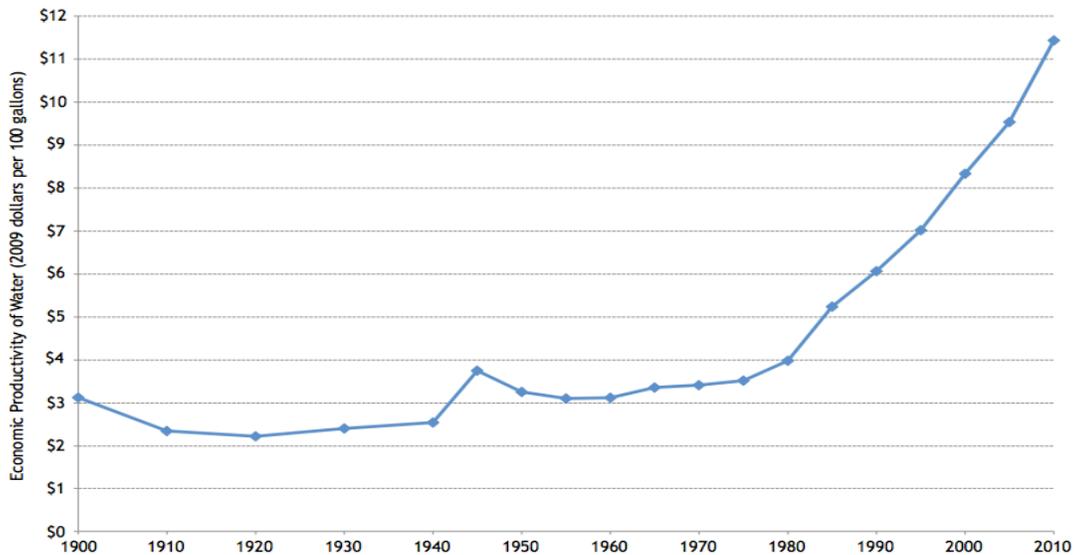
Figure 9: Total And Per Capita Water Use For M&I Sector (1900-2010)



Notes: Self-supplied commercial was not calculated in 2000, 2005, or 2010, which would account for some of the reduction in use that occurred during that period. In addition, USGS documentation notes that water-use estimates for self-supplied industrial use were more realistic in 1985 than in 1980 and would account for some of the reduction between these years (Solley et al. 1988). M&I water use from 1900-1945 also includes water for livestock and dairies. Some years include public supply deliveries to thermoelectric; although it was not possible to exclude these deliveries for all years, the years for which data are available suggest that this use was relatively very small. D.C. was excluded from the analysis due to lack of data. [Sources: Data for 1900-1945 from Council on Environmental Quality (1991). Data for 1950 from USGS (2014a). Population data from Williamson (2015).]

Source of graphic: Donnelly and Cooley, 2015

Figure 10: Economic Productivity of Water (1900-2010)



Notes: [Sources: Data for 1900-1945 from Council on Environmental Quality (1991). Data for 1950 from USGS (2014a). Population data from Williamson (2015).]

Source of graphic: Donnelly and Cooley, 2015

Competition for Water Across Sectors

There are multiple pathways by which changes in non-farm sectors can affect the amount of water available for agriculture, the conditions of its availability and its cost. This paper considers the urban sector, the energy sector and other large industrial sectors. These sectors account for the largest water withdrawals globally and in the U.S., after crop irrigation. Changes in water demand or water supply for any of these large water use sectors have the potential to affect agriculture, through increased regional competition for water.

Another pathway linking water-using sectors involves forward and backward economic linkages, through provision of inputs to agriculture and processing of agricultural outputs⁵. Forward and backward-linked sectors affect agricultural demand for water through their effects on agricultural profitability (for example: cost of fuel, prices paid by processors to farmers)⁶. Forward and backward-linked sectors consume water and so compete directly with farms for water. These linked sectors are more active water consumers in the same time periods when ag water demand is high, so can exacerbate regional competition over limited water.

When agricultural production is more profitable, other factors remaining equal, the value of water in agriculture rises and overall agricultural water demand in a region increases. Depending on the water allocation mechanisms operating in a region, higher agricultural demand may cause water prices to rise and/or conflict over water to escalate. The existence of a regional market in which water can be leased and purchased serves as a “pressure relief valve,” providing an alternative to political and legal wrangling over access to water.

Economic Perspectives on Water Scarcity, Demand and Supply

From an economic perspective, scarcity arises when water is not available to satisfy

⁵ Backward-linked sectors provide inputs to agriculture, such as fertilizer, seed, farm equipment, fuel and water. Forward-linked sectors purchase crops and livestock and add value to farm outputs through processing and distribution. Examples include cotton gins, feedlots, textile mills and grain processing facilities.

⁶ Due to the brief and non-technical nature of these papers, the focus here is on competition over water rather than on specific forward and backward linkages.

demand at current costs paid by water users. In common usage, the term water “demand” often is used to refer simply to patterns of water use and the term “supply” is often used to refer simply to physical availability of water. However, in considering competition for water across sectors it is important to adopt an economic perspective on demand and supply.

Regional water demand functions are temporally and spatially specific, varying across seasons, years and locations. A demand function indicates how quantity used varies with costs paid by users. The responsiveness of quantity used to cost (price is a component of cost) is measured by “price elasticity of demand”. In regions facing reduced supply due to drought, if water costs paid by users do not rise to bring supply and demand back into equilibrium then excess demand will occur at prevailing prices. Other (non-price) allocation mechanisms will be invoked to determine how much water various groups can use. Examples of non-price mechanisms include mandatory curtailment by an administrative agency and legal battles over water access.

Water supply functions capture the relationship between the price providers of water receive per unit they supply and the amount they will provide (price elasticity of supply)⁷. The supply function thus conveys changes in the cost per unit of water to those seeking additional water. In regions where growing cities and water-strapped industries look to the agricultural sector to acquire additional water, the net returns per unit of water consumed in growing crops influence the costs that other sectors will have to pay to lease and purchase ag water (Schuster and Colby 2011). For example, when hay prices are higher prices paid to lease water from farmers are higher (Pullen and Colby 2008). Agricultural profitability per unit of water consumed shapes the water supply function for other sectors seeking water from agriculture.

When considering a region’s water supply, renewability is a factor. In some locations, precipitation regularly replenishes groundwater. In other regions, like central Arizona, groundwater reserves were formed eons ago and are not recharged by precipitation in meaningful amounts. Recent findings indicate that groundwater provides a significant

⁷ Many water providers cannot provide additional amounts when users’ willingness to pay per unit provided increases, due to long term contracts (as with Bureau of Reclamation water projects) and other restrictions. Consequently, a regional water supply function may appear as a series of upward rising steps with each step representing a quantity of water provided by a specific provider at a specific price to users.

portion of surface flows, estimated at over 50 percent in the Colorado River Basin (Miller et al., 2016). Analyses of water scarcity need to consider use of renewable versus non-renewable water supplies.

Adaptation Mechanisms To Water Scarcity

Regional adaptations to water scarcity take many forms, including altering water rates, facilitating water trading, restricting outdoor water use in cities, mandating conservation practices and curtailing customary agricultural and industrial use levels.

The Key Role of Incentives

While water prices likely are the first type of incentive that comes to mind, economic incentives occur in numerous forms. Some incentives are direct and can be used as policy instruments to influence water use, such as water rates charged to customers of an urban water provider. Other incentives are directly linked to the cost per unit of water used but are not easily altered by policy makers, such as the cost a farmer pays to pump groundwater from a private well.

Other incentives operate less directly and are influential but uncertain, such as a potential fine for an irrigation district exceeding its water allotment or a looming court ruling that may impose penalties for failing to provide water for endangered fish. An even more amorphous yet still influential, set of incentives relates to public values for water to provide recreation opportunities and habitat protection. These values are partially expressed through support for public agency restoration of rivers and wetlands, and through successful NGO fundraising for a multitude of programs that acquire water for environmental needs through leases and purchases and through litigation and lobbying (Water Funder Initiative 2016; EPA 2015).

To the dismay of economists, water prices charged to urban, agricultural and industrial water users are not yet widely used as a mechanism to reflect changes in water scarcity. For urban water customers, even when water rates are under the control of municipal

policymakers, there is a political reluctance to raise water prices⁸. For agricultural and industrial water users, the costs per unit of water used can be difficult to alter as a policy instrument. Water costs paid by farms or industrial users may be based on groundwater pumping and thus are primarily determined by prevailing energy costs. Surface water costs paid by farmers in many areas of the western U.S. are set under long term contracts with the Bureau of Reclamation.

In regions where water costs paid by various sectors do not vary to reflect changes in demand and supply, signals generated by active water trading can be an important incentive mechanism in areas where active trading occurs. The signal of value transmitted by well-functioning water markets gives incentives for water users of all types to consider whether they could reduce their own consumption and earn more by making water available for lease or purchase. Other types of direct incentive signals include rebate programs and cost-sharing to water-efficient practices and technologies. In the absence of voluntary reallocation pathways, such as rebates and water trading, pressure builds for water-short parties to pursue water access through the courts and administrative processes.

Adaptation Mechanisms for Urban Water Use

As Figure 9 above indicates, U.S. water use per capita has been dropping since the 1980s, in part due to a shift from water-intensive manufacturing to a services sector economy and in part due to advances like more water efficient appliances and changes in plumbing codes (Pottinger 2015). However, there is still much room for improvement in outdoor water use, indoor efficiency, water recycling and storm water capture and use. Urban water use per capita is significantly higher in older neighborhoods, due to housing with old water-wasting fixtures. Outdoor landscape patterns are changing, with programs that give incentives for homes and businesses to replace lawns with low water use landscape. In addition, improved measurement and monitoring down to the household use level (smart meters) is growing, though not yet widespread. Smart meters give households real time information to adjust their water use in response to incentives.

⁸ However, many U.S. cities recently have had to significantly increase water charges to ensure revenue sufficiency in the face of declining use (Walton 2015).

Although municipal officials are reluctant to raise water rates, many U.S. cities have adopted higher rates and new types of rate structures in order to generate sufficient revenues to cover their costs in the face of declining per capita use. A recent analysis in California indicates that water providers which levy drought surcharges are in generally in better financial condition than water agencies that charge flat rates per unit used. The energy sector in California has separated the costs of energy delivery from the service of providing their commodity, and some leaders in the urban water sector are considering how to do this too (Pottinger 2016).

Recycling urban wastewater and capture and reuse of storm water can stretch existing urban supplies. However, capital costs are significant and loan programs assist in furthering this approach. For example, the California State Water Board is facilitating loans for recycled water programs to move the state toward its policy goal to be recycling 1 million acre-feet annually by 2020. (Pottinger 2015) Streamlining the permitting process for recycled and storm water projects is another helpful urban adaptation mechanism (PPIC 2015). Referring back to Figure 1, it is important to note that not all urban conservation efforts reduce the consumptive use of water in the urban sector and create a net water savings available for other uses. One clear strategy for reducing urban consumptive use is to reduce outdoor landscape consumption, a strategy pursued by a growing number of cities which pay households and businesses to remove lawns (Pottinger 2015).

Urban adaptation in the future may include innovative wastewater treatment technologies that generate energy from captured methane to power the water reclamation process as a net zero-energy wastewater treatment system (Pottinger 2016). A zero-energy approach reduces the significant amount of water consumed in energy production and use (more on this below).

Smart water-trading platforms are not currently widespread in the U.S. but can facilitate investment and innovation in water efficiency improvements. For instance, a “smart market” would allow a large industrial user which invests in water recycling (and thus requires less of the high-quality water in their area) to readily lease or sell their “saved water” to other users in the system.

Adaptation Mechanisms for Industrial and Energy Sector Water Use

A large portion of energy used worldwide is consumed in capturing, treating, and conveying water to customers and in the course of water use by farms, businesses and households (Liu et al., 2012). In California, for electricity specifically, the water sector accounts for nearly 20 percent of the state's electricity demand (CEC 2006; CPUC 2010a & b). Moreover, large amounts of water are consumed in generation of energy through electric power plants, petroleum refining, etc. The complex set of feedbacks between water and energy is sometimes referred to as the water-energy nexus (Fisher and Ackerman 2011). For the purposes of this overview paper, it is sufficient to emphasize that many programs which reduce energy use also reduce water consumption, with specific water savings varying by location and energy conservation practice.

Thermoelectric power plants, the largest withdrawers of water in the U.S., use both freshwater and saline water and vary tremendously in water intensity. An average a plant in Arizona uses 0.4 gallons per kilowatt per hour (kWh) while a plant in Rhode Island uses 75 gallons per kWh, with differences determined by the type of cooling system employed (Donnelly and Cooley, 2016). Overall, water-use intensity of thermoelectric power production has fallen by over 40% in the past three decades. Further improvements can decrease even further the water withdrawals required by thermoelectric plants, but (harkening back to Figure 1) their consumptive use of water will not decrease accordingly and may even increase as a higher proportions of power plant withdrawals are used up in the plant cooling process.

Replacing use of conventional energy sources with renewable energy (wind and solar) as the potential to reduce energy-related water consumption, but this determination needs to be made on a technology and location-specific basis. Moreover, comparisons of water consumption across energy sources need to consider the whole life cycle including construction of facilities and manufacture of equipment, household and business use, and end-of-cycle disposal (Christian-Smith and Wisland, 2015).

Regional Water Banks, Temporary and Intermittent Water Trading

Water banks help ease the impacts of water shortages in many areas around the world, including the western U.S. Thoughtfully designed water banks provide a way for water

users to adapt quickly and cost effectively to changing water supply and economic conditions. Water banks are generally formed through dialogue among stakeholders and water agencies to address specific problems within a well-defined geographic area. Consequently, they typically do not confront the same degree of legal and political obstacles that occur with proposed changes in national or state laws regarding water transfers.

A water bank is a legally authorized entity that facilitates transfers of water on a temporary and/or intermittent basis through voluntary transactions. Water banks in the U.S. have been established to: a) allow water users to acquire a more reliable water supply during dry years through voluntary trading; b) provide water users a means to acquire water when their customary access is curtailed due to regulatory restrictions; and c) ease the regional economic burden of complying with legal requirements, such as interstate compacts or mandatory instream flows for fish and wildlife (Colby 2015). Water banks range in geographic scale from neighboring water users to broad regions that cross state lines. (The Arizona Water Bank, for instance, also serves parts of Nevada and California). Water banks in the U.S. are operated by a wide range of organizations, including local, state and federal government agencies, by NGOs and by for-profit businesses.

The seasonal and temporary water trading facilitated by a water bank can significantly reduce economic losses due to supply curtailment, mitigating the impacts of water shortages on regional economies. A water bank reduces economic losses that occur when junior rights are curtailed in order to protect senior entitlements, by giving curtailed water users a cost-effective and convenient way to lease water from seniors willing to accept a payment in return for forgoing their water use. Parties enter into water bank transactions voluntarily after weighing the pros and cons. A well-designed water bank makes these arrangements timely and cost effective. Water banks help preserve local water user control and provide choices when external forces, such as drought or litigation, bring about curtailment of junior entitlements (Colby 2015).

Water banks can administer various kinds of specialized trading arrangements including contingent contracts. Contingent contracts (also called option contracts or dry-year reliability contracts) improve supply reliability for the party paying (the option holder)

farmers to fallow cropland under pre-specified shortage conditions. When the contract is triggered, the option holder pays enrolled farmers to temporarily fallow land (or to suspend irrigation on land already planted). Some programs provide a payment to the irrigation district which supplies water to farmers, in order to cover district-level costs of accommodating a fallowing program, the magnitude of payments, timing of payments and split of payments between irrigation districts and their member farmers are all determined by negotiations⁹. Contingent contracts are useful to improve supply reliability for junior water users, while maintaining a typical agricultural base in average and above average water supply years. Intermittency of irrigation reductions reduces third-party economic impacts, as compared to permanent purchase and retirement of irrigated lands.

Water banks operate in many western U.S states and take different forms, varying with the regional problems they were created to address. In California, water agencies have actively stored groundwater for local water users for decades to enhance supplies provided by surface water. Water banking there now also involves storing water underground for more distant parties. Some southern California water banks built up reserves of several million acre-feet, and the large quantities of water they supplied during the drought of the late 2000s dwarfed quantities provided to ameliorate drought impacts through other voluntary trading mechanism (Hanak and Stryjewski , 2012).

In most U.S. water banks, water is provided through reductions in agricultural consumptive use. Farmers and agricultural districts are key participants in designing and implementing water banks. Native American governments hold quantified senior water rights in many parts of the western U.S., and participate in water leasing and banking (Colby et al, 2005, Thorson et al, 2006).

Potential Effects of Competition for Water On Agricultural Water Access and Cost

To recap, competition for water can affect farm water availability and costs. This occurs through multiple pathways, including voluntary trading (with market price signaling changes in water's value) and through forced changes in farm water costs and access as a result of administrative and legal processes.

⁹ For examples of these types of arrangements, see O'Donnell and Colby, 2009, Colby, 2015).

In the U.S., legal and political considerations limit the circumstances under which farmers can be required to relinquish water entitlements in order to make water available for other users. However, court rulings and administrative proceedings sometimes do reduce the amount of water available for on-farm use (McClintock 2010; Zaffos 2015). The pressure for involuntary reallocation intensifies during periods of extended drought and during conflicts over water for endangered species, water quality protection and reliable urban supplies.

Regional water trading systems provide an important “pressure relief” mechanism to reduce reliance on litigation and strategies to reduce water available for farming. Support for policies that provide mechanisms for water to be purchased or leased from farms and irrigation districts and transferred to urban and environmental needs provides an alternative to high-cost and high court battles over water. There are regions in which extended litigation and administrative proceedings over water allocation still occur alongside water market transactions. However, well designed water trading mechanisms provide flexible, transparent and cost effective ways to move water in response to drought, changing economic circumstances and special needs.

Regional water trading provides opportunities for farmers and agricultural districts to benefit directly from rising water values through leasing and selling their water entitlements. They also are exposed to higher costs if they need to enter the market to lease or purchase water. Given that agricultural interests hold large senior entitlements in many areas of the western U.S., agricultural entitlement holders will more commonly participate in trading as potential sellers/lessors of a valuable asset, rather than as buyers/lessees. The record of water transactions in the western U.S. demonstrates that agricultural sellers and lessors typically command a price that far exceeds the net returns to on-farm water use (Wichelns 2010; Colby 2015).

Hydraulic fracturing (fracking) to extract oil generates massive demand for water and has become an influential factor in water demand in the regions where it is occurring. Each oil well requires 3 to 5 million gallons of water, and most of this fracking water cannot be reused due to its high salt content. The entrance of this large new water demand has caused water trading prices to increase significantly in some regions (Freyman 2014).

Changes in Water Transaction Prices in Regions with Active Markets

Examining past patterns of change in water values provides indicators of how agriculture can be affected by competition for water across sectors. Statistical analyses of water transaction patterns indicate the potential for agriculture to be affected in several different ways by water demand in other sectors. First, farmers and agricultural districts seeking to lease or purchase water face water market prices influenced by other sectors. Second, the opportunity cost of water used in agriculture is tied to the prices at which water is traded in regional markets. As market prices signal a higher value per unit of water, farmers with tradable entitlements weigh the returns they can earn from leasing or selling water against the returns they expect to earn growing crops.

Loomis et al. (2003) examine water market transactions specifically for environmental purposes in the western United States over the period 1995–99. They find that lease values were similar to values estimated for instream flows using non-market valuation techniques and that environmental values exceed agricultural values for water in specific locations. Brookshire et al. (2004) analyze statistical patterns in water trading in sub-regions of Arizona, New Mexico, and Colorado. Their econometric analyses find that population change, per capita income, and drought indices have a statistically significant effect on the price at which water is traded with trading prices higher in drier years.

Bjornlund and Rossini (2005) examine price and quantity of water allocations traded in parts of Victoria, Australia. Results indicate that the most important determinants of water price and volume were seasonal allocation levels, rain, and evaporation. The authors find that irrigators make good use of water markets to manage their variable water supply.

Brown's (2006) econometric model of western U.S. water transactions examines water sales and leases, and includes transactions for municipal, urban, or environmental purposes in 14 western U.S. states. Findings suggest higher lease prices occur in drier time periods, larger county populations, and for municipal and environmental uses. For water sales, findings suggest that higher sales prices are related to smaller county populations, municipal use, surface water, and smaller volumes of water traded.

Pullen and Colby's (2008) statistical models identify water right seniority and factors influencing agricultural profitability (such as hay prices) as key influences on transaction prices. Jones and Colby (2010) analyze hundreds of water leases across four western states (Arizona, California, New Mexico, and Utah) over a 29 year period. Statistically significant variables influencing lease price include per capita income, drier weather and population growth.

Basta and Colby's 2011 econometric models of hundreds of western US water transactions over the years 1987 - 2010 include urban housing price indices, urban area population and drought indices. Although each regional model is unique, for all models, urban housing price index is positive and statistically significant, and volume of water involved in a transaction and urban population change are significant. While the influence of drought on transaction price varies across areas, drought in the area of water supply origin for a city is a more consistent influence on transaction price than drought in the urban area itself. Hansen, Howitt, and Williams (2014) develop econometric models encompassing thousands of western U.S. water sales and leases and find that agricultural production levels and land values are influences on market activity, as well as measures of drought and water supply variability.

Although water trading in the western U.S. is limited in geographic scope, analysis of areas with several decades of active transactions provide evidence of potential effects on agriculture of increased competition for water. Drought, changes in urban economic activity, population changes and changes in farm production and profitability all influence water transaction prices and thus the water value signals transmitted to farmers.

Conclusions

This overview paper introduces themes raised in the complex interrelationships between agriculture and other water using sectors and between climate change, the energy-water nexus, water scarcity and competition and adaptation mechanisms.

The agricultural sector has a unique opportunity to play leading role in shaping adaptation to water scarcity. Taking a position that the best defense is a proactive offense, agricultural

organizations and water districts are developing collaborative partnerships and risk sharing arrangements with other large water users. Farmers and agricultural organizations fruitfully propose and support state and federal policy reforms that establish water banks and other innovative forms of water trading which address agriculture and other sectors' water needs and provide for equitable consideration of third party impacts (Family Farm Alliance, 2010, Colby, 2015). Agricultural districts are key players in water banks and other innovative mechanisms to adapt to water scarcity (Marshall et al., 2015, Colby, 2015). These efforts further water trading as a regional pressure relief valve and reduce impetus for legal and political maneuvering attempts to curtail agricultural water access.

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