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Adaptation, Climate Change, Agriculture, and Water

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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 In Africa, the fraction of water withdrawn for agriculture is 83% and in Asia, it is 80%.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

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