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The multiple personalities of water conservation

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Abstract

"Water conservation" means different things to different people and the principles of depletion and diversion are often confounded and misconstrued, particularly when the different perceptions of the value of water and units of analysis are involved. Many public policies and public and private investments have been implemented in the name of conserving water, particularly in irrigated agriculture. Unfortunately, many of these policies and investments cannot make additional water available to new users owing to the nature of closed basin hydrology. The assumption that farmers are low-efficiency irrigators is used to justify transfer of income and wealth to agricultural water users and others through direct investments and cost sharing programs. Instead, these programs serve to sustain and increase consumptive use of water in agriculture and disrupt the existing hydrologic balance. In arid climates, where deficit irrigation is practiced, conventional water conservation measures such as drip irrigation often result in increased depletion at the individual farm level and less water available for other users.

This paper discusses water conservation misconceptions, particularly those related to irrigated agriculture in the arid southwestern United States. Deficit irrigation is a common practice throughout the southwest, the region is experiencing rapid population growth and naturally limited water supplies have been exacerbated by current drought conditions. In this paper, the water conservation impacts of drip irrigation, irrigation scheduling and canal lining are discussed in the context of the hydrological assumptions that are used to promote these technologies. The potential of drip irrigation, irrigation scheduling and canal lining to sustain and increase crop evapotranspiration in deficit irrigation environments is illustrated.

Given hydrologic conditions, the authors conclude that accurate basin-wide accounting of water use, including equitable distribution based on existing legal entitlements would significantly contribute to water conservation efforts.

Keywords: Agriculture water conservation; Consumptive use; Deficit irrigation; Efficiency; Evapotranspiration; Hydrology; The multiple personalities of water conservation

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Introduction

The phrase "water conservation" means different things to different people, but it generally implies an act or policy that will result in additional water for other uses. However, misconceptions and misinterpretation of the term "water conservation" have created a serious disconnection between the physical reality of the hydrologic system on the ground and public perception of water issues. The public has often been incorrectly convinced that certain activities (such as increasing agricultural irrigation efficiency) will actually free up additional fresh water. According to Allen *et al*. (1997: p 73): "These incorrect views are so pervasive and strongly held that billions of dollars have been proposed for investments to correct for low irrigation efficiencies with the general public actually believing that their water problems will be solved".

Overall, water conservation is a cultural and political icon that is considered by many to be beyond reproach. In today's highly charged water resource debates, skepticism about water conservation proposals is tantamount to an assault on religious sanctities. Unfortunately, water conservation *intentions* carry more weight than water conservation *evidence* in policy debates, funding opportunities and newspaper headlines. Furthermore, confusion about what is the correct unit of analysis for predicting or assessing water conservation outcomes has led to policies and investments in technologies that can result in less water for other users in a basin. The objective of this paper is to address "water conservation" misconceptions, particularly related to irrigated agriculture in the arid southwestern United States, a region experiencing rapid population growth, where naturally low water supplies are exacerbated by current drought conditions. Generally, there are three perspectives on water conservation. The first is the depletion principle, which holds that a true water loss is the amount of water which is lost to the atmosphere through evapotranspiration (ET) or direct evaporation from wet surfaces. The second perspective is diversion, which identifies water loss as the portion of water diverted from the main supply source. The third perspective uses the change in value of a unit of water as a means of evaluating desirable water use.

The depletion principle

The depletion principle holds that evapotranspiration (ET) from the watershed's surface is the true depletion or loss of water from a hydrological basin. The principle is based on the theory of the conservation of mass, where water diverted and applied in irrigation in excess of ET is not necessarily lost because much of it flows back into the basin from which it was withdrawn. This water eventually becomes available to other users at other times in other locations. This implies a multiplier effect for water diversion, with one user's water "inefficiency" serving as the source of another user's water supply. However, a fraction of diverted water in a basin may be unavailable for other users because of evaporation from open water surfaces and moist soil, contamination, because the water returns to the basin too late or too far away to be of practical use, or because the water flows into an irretrievable sink (such as the ocean) or an area beyond reach (such as another country). The depletion principle can be misconstrued by assuming that reducing depletion through increased application efficiency will always result in "extra" water.

The diversion principle

The competing view of "water loss" holds that the portion of the water which is diverted from a basin (i.e. removed from its natural course or physical location through a canal, pipe or other conduit) is lost to the basin's natural water system. This principle is the foundation of water allocation and water rights throughout much of the world. Using this principle, water is unavailable to new or would-be users (including the environment) as a result of the actions of other users (usually those holding higher priority water rights). In this conceptual framework, perceived water losses are often based on the importance and benefit the observer attaches to any particular use of diverted water (e.g. agriculture versus in-stream flows). For example, farmers often consider water diverted for environmental protection a waste of resources, whereas environmentalists hold an opposing view of waste. The diversion principle considers hydrologic systems to be zero-sum entities, where one user's diversion is always another user's loss. The diversion and the depletion principles clash dramatically when hydrology, politics and special interests collide. The depletion principle is hydrologically correct but goes against conventional wisdom based on the diversion principle. The depletion principle encompasses temporal and spatial elements and jars popular notions of what constitutes "efficient" water use. The diversion principle is the focus of numerous public policies as well as public and private investments designed to conserve water, based on the belief that water scarcity can be solved through increased efficiency and reallocation of water from one user to another.

The value principle

The value principle arises from the belief that the optimal approach to water conservation is to increase the return per unit of water consumed or diverted. Unfortunately, the value of water is highly subjective and dependent on an individual's perspective and objectives, as well as on the accounting stance or unit of analysis chosen. Value can be defined in social, economic, environmental, or political terms and also from global, societal, community, or individual perspectives. Application of the value principle is accurately captured by the well known saying that "water flows uphill toward money", especially when the uphill flow is toward golf courses and other similar uses.

Irrigated agriculture and water conservation

Almost 70% of the world's freshwater resources are devoted to agriculture – primarily for irrigation. In many developing countries, agriculture uses 85–95% of available water. Increased demand for water across the globe by industry, households and for environmental purposes continues to drive efforts to reduce water used in irrigated crop production. Technicians and scientists around the world tirelessly seek and apply new technologies and management practices in an effort to increase on-farm irrigation and delivery efficiencies, where on-farm irrigation efficiency is usually defined as the portion of water applied to a crop that is actually consumed by the plants. Delivery efficiency is percentage of diverted water actually delivered to farm fields. The conventional approach is that "water conservation" and "high irrigation efficiency" are good, while low irrigation efficiency results in wasted water. The assumption is that if irrigation efficiency can be increased, water will be available for reallocation to other users, including the environment. In-stream flows will be enhanced, riparian habitats will be supported, endangered species will thrive and overall environmental quality will be improved if on-farm irrigation efficiency increases.

However, the magic bullet of increased irrigation efficiency is currently under reconsideration by many irrigation professionals. The integrated nature of most basin-wide water resource systems has led to a discrediting of the quick technological fix for water conservation long promised by increased irrigation efficiency. Keller *et al.* (1996) propose the concepts of integrated water resource systems (IWS) and effective efficiency as alternatives to traditional conservation and efficiency metrics. Effective efficiency accounts for the fractions of freshwater effectively consumed by evapotranspiration, which flow to a sink, or which are significantly degraded in quality. The IWS approach explicitly recognizes the water conservation tradeoffs that exist within an interdependent water resource system. Using effective efficiency concepts, a water resource system where on-farm irrigation (or micro-level) is only 50% efficient can be almost 100% efficient at the macro (or basin) level depending on the amount of water reuse within the watershed. Use of a unit of analysis other than a basin (such as an individual farm or an irrigation district) can lead to exact opposite conclusions about the potential for water savings from increased irrigation efficiency.

Irrigated agriculture is the primary user of freshwater supplies throughout the western United States. Over-appropriation of surface and ground water supplies is the standard condition in many of the region's irrigated areas. Water rights litigation and adjudications are underway in many areas, where both irrigated agriculture and non-native riparian vegetation are typically viewed as sources from which conserved water can be directed to other uses. Much of the western United State's water resource systems are currently facing the tight (or tightening) water supplies, increasing population, economic activity and competition for water supplies typical of closed basins (Seckler, 1996).

Water conservation is a perennial hot issue in the west and southwest USA and irrigated agriculture is under pressure to change. Unfortunately, many of the traditional policy prescriptions and technologies that have been and currently are being promoted throughout the region could result in *less* water for new users and *increase* water consumption. Examples of "negative water conservation", the complexity of water conservation issues in closed basins and the impact of different units of analysis with respect to water conservation are used below to illustrate this situation.

Drip irrigation versus water conservation

For several years, western US farmers have faced a steady barrage of recommendations to use sophisticated irrigation technology and thus increase on-farm irrigation efficiency. Drip irrigation technology is commonly recommended as a means to do this. Drip irrigation allows for precise application of water into the plants' root zones, with very little deep percolation loss.

There is generally a linear relationship between ET and yield over a wide range of crops and water applications. Consequently, irrigation technologies that provide for application of water to the plant at optimal times and locations in the root zone will increase crop consumptive use of water even as irrigation efficiency increases[1]. For example, the yield-ET relationship for alfalfa in the desert southwest

[1] Because sub-surface drip irrigation of alfalfa does not have to be suspended during harvest, the consumptive use of drip irrigated alfalfa is also higher than surface irrigated alfalfa, where the crop usually experiences significant water stress when harvesting machinery is in the fields.

USA is as follows (Sammis, 1981):

$$Y = 0.14 + 0.12 \times ET$$

where Y = yield in metric ton ha^{-1} and ET = seasonal evapotranspiration in cm.

Alfalfa is grown throughout the western United States. A typical evapotranspiration (ET) requirement of alfalfa is approximately 1.2 ha-m/ha. This level of consumptive use in the desert southwest is an example of deficit irrigation, where a crop is irrigated with less water than would allow the crop to reach its potential yield. Assuming an on-farm irrigation efficiency of 75%, the farmer would need to apply ~1.6 ha-m/ha of irrigation water[2]. Thus, 1.2 ha-m/ha are consumed by the plant and 0.4 ha-m/ha return to ground water through deep percolation. This level of ET will result in approximately 15 ton ha^{-1} of alfalfa. If the farmer decides to implement drip irrigation, consumptive use can easily increase to 1.8 ha-m/ha, with a potential yield of 22 ton ha^{-1}.

Water "waste", either through deep percolation or runoff will be reduced through drip technology, but more water will be used consumptively. The individual farmer who adopts the technology will have increased gross product and gross income per unit of land. This scenario of increased on-farm efficiency is an example of negative water conservation, because of the increased consumptive use of previously "wasted" water, even though it may be a financially sound decision for individual farmers.

Farmers in regions that rely exclusively on groundwater for crop production have also been urged to adopt drip irrigation technology. A farmer who pumps water to surface irrigate sandy soils could potentially lose half of his applied water back to groundwater (i.e. 50% irrigation efficiency). From this farmer's point of view, half the water is lost and is probably not recoverable in the same cropping season. Future re-pumping of the water in a subsequent growing season will incur additional energy costs. However, from a hydrologic perspective, the portion of the water which is returned to groundwater, assuming no quality degradation, is not lost and is still in the groundwater reserve.

Thus, if the groundwater-pumping, sandy-soil farmer converts to drip irrigation technology and achieves 90% irrigation efficiency, he will have eliminated 40% of his annual water "loss". But, less water is now available in the basin in the future for the new drip irrigation farmer and for other users as well. Furthermore, the quality of water remaining in the underground aquifer may also be diminished. From the drip irrigator's private perspective, the new technology has led to water conservation. The drip irrigation has resulted in more yield and probably more net economic return, but from the hydrologic point of view there is now less groundwater available (and possibly lower quality water) for the individual in the future as well as for the basin's pool of users. The drip system may result in net energy conservation by avoiding a double lift of the same groundwater; however, depending on lift, the additional energy demands of the drip system will partially offset the savings in pumping costs. In conclusion, drip irrigation results in positive water conservation at the farm level, but not necessarily at the basin level.

The tendency of farmers to either intensify (e.g. increase yields) or extensify (increase irrigated area) as a result of improved application efficiencies has led state-level water authorities to redefine water rights in terms of consumptive use or depletion, so as to protect downstream users. The investment and

[2] An on-farm irrigation efficiency of 75% is actually low by the standards of commercial farms in southern New Mexico, where these efficiencies have been found to be as high as 93.2% (pecans), 93% (alfalfa) and 95% (cotton) as a result of deficit irrigation practices (Samani & Al-Katheeri, 2001; Samani *et al.*, 2005).

management intensity necessary for technologies such as drip irrigation as well as the yield benefits could be expected to result in both intensification and extensification of production. This outcome has been repeated throughout the history of agricultural technology adoption, across a wide variety of technologies and will continue as long as water use decisions are made in the context of private profit-seeking behavior.

Deficit irrigation is a common practice among arid region farmers who are faced with a limited water supply. The practice results in lower yield per unit of land but higher returns per unit of water (Hargreaves & Samani, 1984; Perry, 1999; Samani *et al*., 2005). In a deficit irrigation environment, there is a large unmet demand for water in crop production. Increased on-farm irrigation efficiency through modern technology helps to reduce individual farmers' ET deficits. In a water deficit irrigation environment, any new water saved as a result of technology or policies is likely to be readily consumed by the system until the threshold is reached where existing demands are satisfied.

Irrigation scheduling versus water conservation

Irrigation scheduling involves applying water to growing plants in accordance with their consumptive use needs. With scheduling, frequency and duration of irrigations are based on environmental conditions, plant growth stage and predicted ET. Successful irrigation scheduling requires knowledge of plant water needs and an irrigation system that is flexible enough to respond to changing needs throughout the growing season.

Proper irrigation scheduling can significantly increase yields and crop quality. For example, during the nut filling period (late August to early September) in southern New Mexico pecan production, a two day delay in irrigation can result in large yield reductions. Irrigation water applied to pecans and many other crops does not have the same yield and quality impacts throughout the growing season. With correct irrigation scheduling, total yield and yield per unit of ET can both increase. Correct irrigation scheduling can increase the net return from water used by an individual farmer. If a farmer's goal is to produce a higher level of economic return from a unit of consumptive use, then optimally scheduling irrigations to match crop ET can be considered a very desirable practice for an individual water user, but may result in negative water conservation for the basin by increasing total ET.

There are approximately 11,000 hectares of pecans in southern New Mexico. A recent study of irrigation practices on 340 pecan farms in the region showed that farmers (over a wide range of orchard sizes) were over-applying water during periods of low consumptive demand and under-applying during the critical period of high consumptive demand (Figure 1)[3] (Skaggs & Samani, 2005). This mis-timing of water applications results in significant yield reductions and low water use efficiency (i.e. yield return per unit of water consumptively used). Figure 1 indicates that the average application of water is fairly consistent with average crop water needs over the entire growing season, with over-application balanced by under-application. However, irrigation is a means to an end and pecan yields are compromised by the irrigation patterns shown.

[3] The irrigation district data used to create Figure 1 are reported in acres for land area and acre-feet for water applied. US customary units are used in Figure 1 to be consistent with the structure of the data received from the irrigation district.

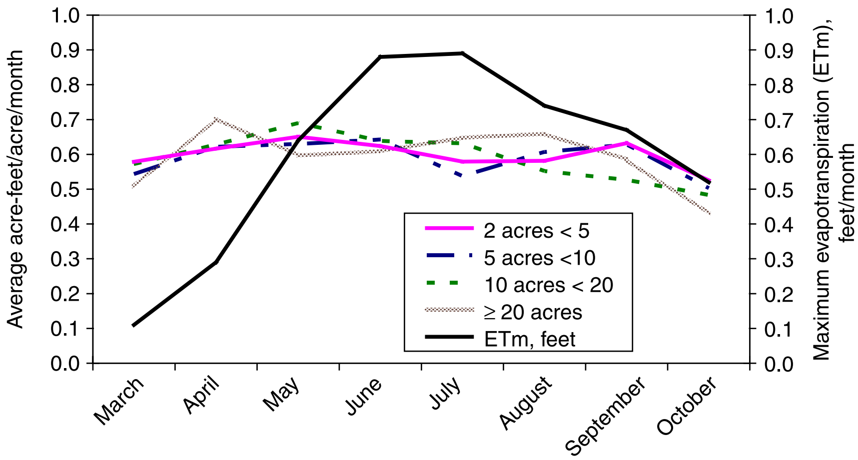

Fig. 1. Under and over-application of irrigation water to pecans in southern New Mexico (Skaggs & Samani, 2005).

Like efficiency enhancing drip irrigation technology, optimal irrigation scheduling can also result in increased consumptive use and subsequent reductions in water available to downstream and future users. The surface water shown as over-applied in the spring months in Figure 1 returns to the hydrologic system and is no longer available to the trees to which it was applied. The water eventually re-enters the aquifer or the river and contributes to surface water supplies later in the growing season, miles (and possibly a state or nation away) from where it was originally applied. It is likely to be degraded in quality as a result of salt leaching and contributes to groundwater recharge in the region. Widespread adoption of accurate irrigation scheduling could significantly increase on-farm water use efficiency, yields and pecan growers' incomes; however, it would also reduce the basin's downstream flows (whatever quality they might be), have a negative impact on groundwater recharge and contribute to salt accumulation. Again, there is little congruence between the water conservation objectives of an individual farmer and other water users in the basin. Proper irrigation scheduling can help increase the value or return per unit of water consumed by the crop. This is consistent with the "crop per drop" concept which emphasizes increased yield per unit of water consumed – an application of the value principle from a farmer's point of view.

Canal lining versus water conservation

Canal lining is often considered to be a "magic bullet" for reducing water "losses". However, canal lining can result in negative water conservation and is unlikely to produce more water for new users. A good example is provided by the acequias of northern New Mexico which are adjacent to the Rio Grande and its tributaries. Acequias are very old (ancient in some cases) and unregulated irrigation canals which are essentially man-made Rio Grande tributaries, as they contribute to return flows in the main river channel. In such cases, lining a canal will simply make farm diversion more efficient and result in extra depletion by farmers as they transform the diverted water into higher on-farm crop yields. The consequence of this will be reduced in-stream flow, lower water quality and reduced return flows for downstream water users – and overall increased net depletion in the upper reaches of the river basin. Likewise, any other increase in delivery efficiency will have the same impact. The exception would be in a lower reach of a river basin, where there are no downstream users and where freshwater flows enter into an irretrievable sink (e.g. an ocean).

The belief that canal lining will conserve water is international in scope. Millions of dollars are spent annually in the United States and other countries to line canals for the purpose of increasing water supplies for urban, industrial and agricultural users (Perry, 1999). Canal lining projects are likely to increase gross economic returns for existing farmers or the irrigation district in the affected area. Thus, canal lining may be valuable as a means of increasing farm household and district revenues, but it may have no capacity to increase water available for other users. Yet, canal lining remains politically popular worldwide as a water conservation tool even though groundwater recharge, stream discharge dampening and wetlands may experience a negative impact.

What is true water conservation?

Given the discussion above, it might seem that positive water conservation in agriculture simply is not possible. The three examples present situations where the conventional wisdom is incomplete and where the three technologies illustrate the "ET sustainment" described by Allen *et al*. (1997: p 72). Applying the words of those authors to the examples given above, water conservation initiatives incorporating drip irrigation, irrigation scheduling and canal lining "sustain the water supply for one project at the potential expense of downstream projects, cities and perhaps the environment".

However, for many water conservation advocates, the notion that drip irrigation may actually result in greater consumptive use of scarce water resources is completely heretical. Yet, this "conservation" outcome happens. Accurate irrigation scheduling may also increase consumptive use, depending on existing water application practices and efficiencies, soil characteristics, the nature of return flows and other factors. Canal lining may make delivery more efficient, but at the cost of depleting water from the basin-wide hydrologic system. So, what changes in technology or management practices *can* result in positive water conservation?

Water conservation is basically sound or appropriate water management, which depends primarily on individuals' objectives, although the hydrologic and socio-economic environment in which the management is being implemented cannot be ignored. For a commercial farmer, achieving higher yields through efficient water application is sound water management. For a downstream farmer, water flowing through a drain system as a result of an upstream farmer's over-application is the result of sound water management because it created *their* water supply. For an advocate of the environment, greater in-stream flows are sound water management, even though those in-stream flows may be the result of very "sloppy" upstream water management. For a growing community with ever greater demands for recreational opportunities, using water to create high quality golf course experiences is sound water management. Dozens more location, time and objective-specific examples of sound water management could be given here. However, regardless of the number of examples, they all imply that there is and will be little widespread agreement about what water conservation objectives should be and what metrics should be used to measure conservation.

As discussed above, technological magic bullets often proposed for agricultural water conservation purposes may actually increase total basin-level depletions. This fact is rarely advertised by technology vendors, or those who advocate the use of public funds to support these technology investments (either directly or through cost sharing programs). It seems that the more expensive the technology, the more likely it is to compromise basin-wide water conservation objectives (e.g. drip irrigation, canal lining).

If regions are to get serious about agricultural water conservation in the future, then one of the first steps that should be made is accurate accounting of basin-wide water use, which would lead to more equitable distribution of the water resource based on existing legal entitlements. If comprehensively implemented, accurate accounting would be likely to release water for new users. At the current time, accounting for water use throughout much of the western United States is inadequate or non-existent, owing to institutional and legal structures and clear incentives not to measure water. To put it bluntly, water deliveries to individual farms are often not measured and many water users are getting more than they are legally entitled to receive. Lack of large-scale accounting may be cheap for water managers, but it contributes to an informal water resource management structure which relies on ignorance and inadequately defined property rights for its perpetuation. Throughout much of the western United States, more data, information, knowledge and understanding of the water resource are not considered to be good things by many members of the interested water resource community. Ignorance resulting from the lack of rigorous water measurement and accounting preserves and protects the status quo, as well as providing incentives for opportunistic scofflaw behavior by many water users.

Drip irrigation and irrigation scheduling are always promoted as sure-fire ways to achieve positive water conservation. However, in areas where deficit irrigation is a common practice, high on-farm irrigation efficiencies can be obtained with surface irrigation and without rigorous irrigation scheduling, although the result is lower than potential yields. Under deficit irrigation, farmers spread water over larger acreages to achieve balance between numerous objectives which include, but are not limited to, crop yields[4]. Drip irrigation and irrigation scheduling adopted under deficit irrigation conditions are likely to increase the consumptive use of water resources and crop yields. Widespread adoption of either technology would be likely to lead to increased depletions and *less* water for other users in a basin.

Well-meaning environmental groups often assume that farmers are low efficiency irrigators, who only need more information, more tools and financial support in order to reduce the amount of water they apply to their crops (Romo, 2005). However, any tools designed to improve the efficiency of on-farm irrigation and help profit-oriented farmers more accurately time and perform irrigations and deliver water to their fields are likely to increase basin-wide consumptive use. Unfortunately, the trade-offs between the objectives of individual farm irrigators and the condition of the entire basin in which they operate seem to be lost on many well-intentioned people who are concerned about water conservation. There seems to be an automatic assumption on the part of many conservation advocates that the interests of individual farm irrigators are aligned with basin-wide interests. Nothing could be further from reality, given the relationship between crop consumptive use and yields.

Public investments have been used very successfully to sustain and increase on-farm ET in the United States. The result has been a reallocation of income and wealth through government programs such as the USDA's Environmental Quality Incentives Program (EQIP). EQIP provides federally funded cost sharing (up to 75%) for on-farm investments in "water conserving" technologies. Other federal programs provide assistance to irrigation districts to improve delivery infrastructure (e.g. the Bureau of Reclamation's Water 2025 program).

[4] These objectives involve whole farm risk management through crop rotations and spatial distribution of crops.

Generally, the idealistic approach to sound water management seeks to reduce consumptive use of water and increase in-stream flows. However, in the face of increased population and constantly growing demands on the water resources from a variety of users, this approach is unrealistic and highly unlikely. Water management is dependent on both individual and basin-wide concerns, priorities and values. The steps which are most likely to result in "new" water are also the most politically unpopular because they involve increased accountability on the part of individual users, irrigation districts and state authorities. Increasing water resource accountability would be a dramatic change in the status quo and would require and result in exponential increases in data and information about water use. Increased accountability would be a major culture change and quite different from the popular technological band aid approach (e.g. drip irrigation, irrigation scheduling and canal lining) to water problems.

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