Impact of Agricultural Water Conservation on Water Availability

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Abstract

Agricultural water diversions in the U.S. in 2000 were roughly 189 million MegaLiters (153 million acre-feet) per year (Hutson et al. 2004), representing 65% of the freshwater diversions (excluding thermoelectric power). The market value of crops sold from irrigated agriculture in the U.S. exceeds $38 billion/year, representing 40% of the market value of all harvested crops on only 9% of the crop land (NASS 2002). Thus while agriculture is an attractive target for obtaining water for other segments of the economy and environment, large shifts in water away from irrigated agriculture may eventually have a negative impact on the economy. Agricultural water conservation is touted as a good method for reducing water diversion while minimizing the impact on production. However, very few studies have documented the actual amount of water saved from agricultural water conservation efforts. In some hydrologic settings, reducing water diversions to agriculture does not automatically save water, since the extra water not consumed may be used downstream. Further, there is evidence that water conservation programs that target improved application efficiency can actually increase water consumption as the result of improvement in irrigation uniformity. There are situations under which improvements in the irrigation systems will reduce the amount of water that is irrecoverably lost or will result in less water quality degradation. In arid environments, water is required for leaching salts brought in with the irrigation water. More water is needed for leaching as the salinity of the water increases. Thus reducing the water salinity can result in less irrigation water demand, potentially making more water available for other uses. In the paper, we provide a framework for examining the impact of water conservation practices and programs on water availability and present examples where water conservation efforts have been successful.

Context of Irrigated Agriculture

The 2002 Census of Agriculture (NASS 2002) shows total harvested crop land in the United States at 123 million ha (303 million ac). Irrigated land during 2002 was 22 million ha (55 million ac), with roughly half of that as harvested crop land (11 million ha or 27 million ac). Thus in 2002, irrigated land represented 9% of the harvested crop land. The market value of crops sold from harvested crop land was $95 billion in 2002. The market value of crops from irrigated crop land was $38 billion. This does not include other production on irrigated land (total $55 billion), e.g. pasture. Thus irrigated agriculture produced roughly 40% of the market value on 9% of the harvested crop land. This increased value is both the result of improved crop quality and the tendency to use irrigation on higher value crops.

According to the USGS (Hutson et al. 2004), roughly 189 million MegaLiters (153 million ac ft) of freshwater were withdrawn for irrigation during 2000. This represents 40% of all freshwater withdrawals, or 65% excluding withdrawals for thermoelectric power. Surface water and groundwater represented 58 and 42%, respectively, of the total irrigation withdrawals.

The market value of products resulting from irrigation withdrawals is on average $290 per MegaLiter ($55 billion divided by 189 million), or $360 per ac-ft. (Individual values can be an order of magnitude higher or lower). By comparison, water prices for agriculture range from less than $5 to more than $100 per MegaLiter. The cost of new water sources for some western cites are approaching $200 per Megaliter, but are typically still less than the average market value of agricultural output resulting from the water.

USGS estimates that roughly 25 million ha (62 million ac) were irrigated during 2000. They also estimate that during 2000 the irrigated areas were 12 million (48%), 11 million (46%) and 1.7 million (7%) ha, for surface, sprinkler and micro-irrigation, respectively. These years do not match up with the Census of Agriculture and the land areas do not match because they reflect different estimation methods.

The 2002 Census of Agriculture reports the following for irrigated crops in million ha: Hay and pasture 12.9, Grains 8.9, Cotton/sugar-beet/tobacco 4.3, Oilseeds (including soybeans) 2.5, Orchards 1.8, Vegetables 1.0, Potatoes 0.4, and other 0.3. The total cropped area is more than the total irrigated land area because of double cropping (i.e., 32 versus 22 million ha). The land area of a crop is almost inversely related to the market value per acre. Unfortunately, the census is not broken down so that this could be readily determined, but generally one expects hay and grains to be on the low end of market value per land area and vegetables at the high end, with cotton and orchards in the middle. This also relates to the type of irrigation system utilized. Farmers growing low market value crops generally can not afford high cost irrigation systems. Thus a large amount of the low-value crops are grown with surface irrigation, since it is less capital intensive, while higher value crops can afford the cost (and benefit from the quality improvement) of pressurized irrigation systems, particularly perennial crops like orchards. There are exceptions, for example lettuce is extensively grown under surface irrigation, while in many locations pastures are irrigated with sprinklers. However, unless the mix of crops substantially changes, land areas under microirrigation are not likely to make sudden large increases. Growth will be steady as crop mixes shift toward higher valued crops, dictated by water cost and other pressures. However, one would not expect huge changes, for example, in hay and pasture acreages since these also support livestock and dairy production. Thus we cannot expect huge changes in water made available for other uses by large-scale changes in the type of irrigation technology.

Water Balance

For any type of water conservation program, it is important to understand what happens to the applied irrigation water, i.e., where does all the water ultimately go? It is not sufficient to improve the "apparent" application efficiency (measured by a variety of indicators) because of the influence of hydrology and geology within a river basin on recycling and reentry of diverted water into some part of the surface water system. There is no single efficiency term that is useful in all contexts and for all purposes. If one understands what happens to all components of the diverted water, then one can assess what benefits result from water conservation.

A good example from the urban sector is low-flush toilets. While they are beneficial for reducing costs for water treatment and for metering scarce water during droughts, in humid environments far from the ocean, low-flush toilets may be of little benefit to the total fresh water resource. Take for example a city on the shore of the upper Mississippi River. Water is withdrawn from the river, treated for municipal use, and distributed to users. Following each toilet flush, the waste water enters sewers and goes to a wastewater treatment plant, where it is treated and discharged back to the river. A low-flush toilet reduces the amount of water diverted from the river, and may reduce the cost of water and wastewater treatment, but nearly all of the diverted water returns to the river to rejoin the water not diverted, and although perhaps degraded in quality, is generally reusable downstream. There is very little if any water conservation benefit to the river.

In contrast, many ocean cities discharge their wastewater into the ocean. Here, essentially all diverted water is consumed and consequently a low-flush toilet will reduce the amount of fresh water discharged to the ocean – a real water conservation benefit. This illustrates the importance of following the water as it is manipulated by man and within the greater hydrologic system.

The same situations occur in irrigated agriculture. Efficiencies are often defined to determine the required size of a water supply and irrigation system. They do not necessarily infer an unintended loss of useable water to the fresh water system. In high-mountain meadows, nearly all unused irrigation water is returned to the hydrologic system and ends up as stream flow. Here improving field efficiency has little to do with reducing basin water losses, but has more to do with improving production and reducing costs and, in some cases, may improve the timing of stream discharge for the area and may keep more water in a stream during summer. In reality only the consumed water is lost (due to phase change) when high in a basin. Whether conserved water remains in the stream depends on water rights, where in many situations, "senior" water rights holders may legally elect to lay claim to all streamflow. In arid areas, particularly those near the ocean or a saline sink, unused irrigation water is often not recovered and is lost for future use due to its entry into the saline system. Here, improvements in irrigation efficiency have a direct benefit if near a saline system. Unfortunately, it is not always so black and white. Some unused water is relatively easily recoverable, some unused water is degraded in quality but still usable, some unused water recharges groundwater, but may not be reusable for years while in transit or storage underground.

Burt et al. (1997) suggested a systematic way to examine the water that is diverted for irrigation. In evaluating the performance of irrigation systems, one has to be careful to establish appropriate physical boundaries and time frames, since water is often in transit or in temporary storage. One can only evaluate the performance of an irrigated area by examining the irrigation water when it leaves the defined boundaries of interest. The applied irrigation water can be placed into several categories:

1. Water consumed by the crop within the area for beneficial purposes.
2. Water consumed within the area under consideration but not beneficially.
3. Water that leaves the boundaries of the area under consideration but is recovered and reused.
4. Water that leaves the boundaries of the area under consideration but is either not recoverable or not reusable.
5. Water that is in storage within the boundaries.

This categorization can help to identify improvements that would result in true water conservation. The following five points expand on and explain the five categories above:

1. Here, the water is used to produce a crop and is consumed by transpiration from stomates of leaves or from soil beneath or between plants. Reducing this water consumption generally reduces yields or marketable products. Evaporation from soil averages from 10 to 20% of total consumption (ET). Buried drip irrigation claims a benefit here, since the soil surface is sometimes not wetted and thus the evaporation component can be reduced with only slight increase in transpiration. However, claims of large savings in water consumption are physically unreasonable, since buried drip systems can generally only reduce evaporation by about one-half and consequently can create savings of only 5 to 10% of total consumptions and likely only 2 to 5% of total water diverted.
   One option is to fallow land or take it out of production. This results in real water conservation, particularly in arid environments, since ET is substantially reduced. However, fallowing land can have negative environmental consequences if not done properly (soil salinization, wind erosion, etc.).
   Genetic improvements to produce more crop with less water are possible in

some cases, but usually it's more crop with the same water (or the same yield on less acreage and thus less water). This limitation occurs because crop biomass accumulation is through photosynthesis where carbon dioxide enters the plant through the same stomates as water vapor exits. Therefore, the ratio of yield to transpiration in a specific climate is limited by the physiology of the crop variety.

2. This includes water that is lost through 1) evaporation from soil away from crops and open water surfaces and 2) evapotranspiration from weeds, trees, phreatophytes, etc.. Many of these losses are difficult or costly to avoid, but there are opportunities in some cases. Some of the lost water may have environmental benefits by supporting trees, windbreaks, incidental wetlands etc. that are attractive to wildlife.
3. Water that is recovered and reused is not a target for water conservation. The water is already being reused, so reducing this from entering the irrigation system often has no real benefit. There are exceptions, for example where it reduces cost or improves the quality of this water, or where leaving the water in a reach of a stream has an environmental benefit. In some cases, the delay in unconsumed irrigation water returning to the stream has an environmental benefit by buffering streamflow during droughts or winter periods.
4. This water is the primary concern for water conservation efforts. Here water is unrecoverable because of large depths to groundwater or is not reuseable because of salinization or entry into a saline body. A reduction in water applied for irrigation means that it can be used for other purposes. It is truly water saved. However, there are cases where this water provides environmental benefits, such as mitigation of salt water intrusion underground, even though it has no human use.
5. Irrigation water that is in storage within the area of consideration is not considered as used. Its ultimate fate is yet to be determined. The delay caused by storage may have positive or negative economic and hydrologic impacts.

Application Efficiency and Irrigation Uniformity

All irrigation systems have some nonuniformity. This nonuniformity influences yields and irrigation efficiency. Figure 1 shows a typical distribution of infiltrated water resulting from irrigation, where infiltrated water depths are sorted in increasing order. If the net amount of water applied during an irrigation (amount applied less runoff) is the same as that required (e.g., to fill the soil water deficit), then because the distribution of water is never perfect, half of the field will receive too much water while the other half not enough.

The normal response of a farmer to this distribution of water is to apply more so that a larger fraction of the field has an adequate amount. In Figure 1, with a coefficient of variation (*CV*) for depth of infiltrated water within a field of 0.2 (20%), we would have to add 134% of the required amount to provide an average in the lowest quarter of points that is equal to the required amount (100 in these graphs). The coefficient of variation is the standard deviation divided by the mean. We would have to add roughly 170% of the required amount to provide 98% of the field with adequate water for full ET. Because of the tradeoff in extra water versus the amount in deficit, as well as other practical considerations, satisfying the average of the low quarter of the field has been a practical guideline in the U.S. for half a century. An alternative to adding extra water is to improve the uniformity of water application. By reducing the coefficient of variation from 0.2 to 0.1, less water has to be applied to satisfy the low-quarter criteria, where only 15% extra water would be needed, as opposed to 34%, as shown in Figure 2 to meet the average of the low quarter criterion. An added benefit when the uniformity is improved is that the amount of deficit in the area under irrigated is less and the potential for water logging and salinization is reduced.

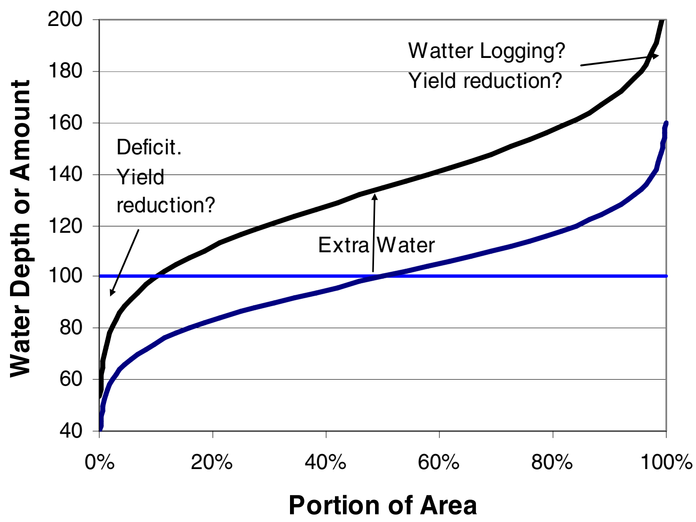

Figure 1. Adding extra water results in less of the field receiving too little water. CV = 20%.

Most water conservation programs geared toward improving irrigation efficiency have resulted in irrigation systems that provide better distribution uniformity. This translates to less deep percolation and less of the crop under deficit. Both of these are considered to be positive benefits by farmers and provide motivation to undertake conservation programs (in addition to any cost sharing on irrigation systems). The reduced deep percolation is generally the motivation for the conservation sponsor. The general results of such improvements are more yield and more water consumption, both resulting from the improvement in uniformity. In areas where excess infiltration results in water logging, improving uniformity

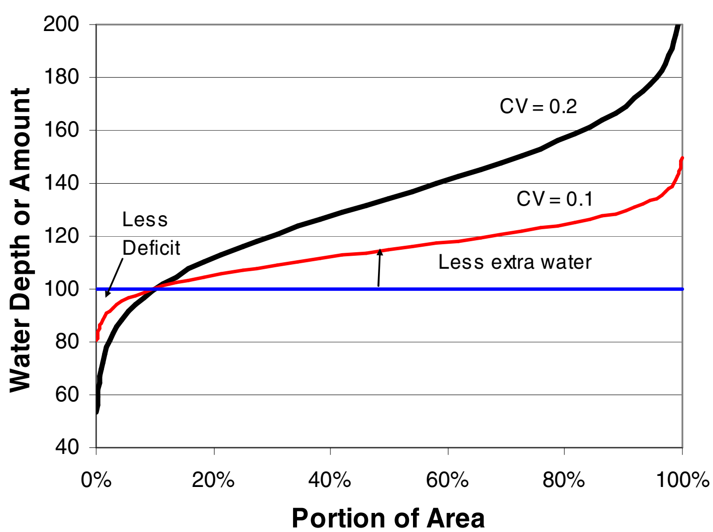

Figure 2. Improving the uniformity results in less extra water required and less deficit in the area receiving an inadequate supply.

should improve yields, but may not increase water consumption since water logged areas may consume more water, due to capillary flow to the soil surface, than a cropped area. If deep percolation and runoff waters are captured and reused downstream, then improvements in field irrigation efficiency may result in no net gain in water available on a watershed basis, and may actually reduce water available downstream, depending on the lag time of return flows. Where groundwater is pumped from an unconfined system, conservation efforts seldom provide new water.

Water conservation efforts in irrigated agriculture are usually focused on:

- Improving the infrastructure of the irrigation system so that water can be controlled more easily.
- Improving the management of the irrigation system so that the right amount of water is applied at the right time.

Water conservation programs that improve the irrigation infrastructure are the most straightforward to implement. It is relatively easy to document improvements in the application efficiency of irrigation events, although this may not translate well to seasonal efficiency and generally does not translate to river basin efficiency. The application efficiency is typically defined as the amount of water added to soil water storage (with perhaps some qualifiers about this storage being useful to the crop) divided by the amount of water applied. Generally there are two areas where application efficiency can be improved: 1) reducing the amount of water that runs off the field and 2) reducing the amount of water the percolates through the soil and is not stored, often called deep percolation. The first is relatively easy to observe, measure, and improve. This water can also be collected and reused. The deep percolation water is difficult to observe or measure. It typically results from a nonuniform distribution of infiltrated water or intentional leaching of salts.

Water conservation efforts that focus on water management are geared toward determining when to irrigate and how much water to add. Timing of irrigation is generally geared toward avoiding plant stress. However, there is often significant variability in soil properties such that even with uniform irrigation, plant stress shows up in some areas of the field before others. Thus again, there may be a balancing of allowing some areas to show stress before irrigating, to reduce numbers of irrigations and total amount of water applied. Irrigating frequently can result in excess evaporation from wetted soil. All of this is complicated by nonuniform and unknown rainfall contributions, unknown and variable soil water storage capacity, unknown and variable rooting depths, and unknown and variable evaptranspiration demands. Documenting the improvements resulting from improved water management alone can be difficult, unless there has been gross over- or underirrigation.

The physical irrigation system may place lower limits on how much water can be efficiently applied. Efficient irrigation scheduling and metering of water to the soil may suggest irrigating when the soil water deficit is, say, 30 mm when the irrigation system, because of its type or design, is only capable of applying a minimum 60 mm, with reasonable efficiency. Thus the physical and management improvements need to go hand-in-hand.

Salinity Issues

The above discussions about categories of water destination and what constitutes conserved water is clouded by water quality issues. The situation is not as black and white as portrayed. Natural waters pick up salt from soils and rocks. When water is used by plants, the salts are left behind in the soil. If salts are allowed to build up in soil, crop growth will be impaired. Additional water is needed to leach these salts from the soil to maintain a healthy soil environment for plant growth. In humid regions, there is sufficient rainfall to leach salts. In arid areas, leaching typically must come from additional irrigation water – part of the deep percolation water. The amount of water needed and beneficially used for maintaining a salt balance is somewhat controversial. However, as the water salinity increases, the amount of water required for leaching goes up. Thus for a given crop, as the water salinity increases, more water needs to be infiltrated into the soil. In this regard, reducing water salinity in effect conserves water.

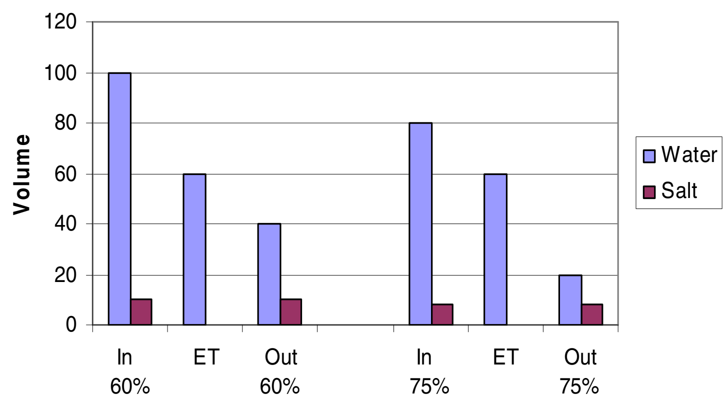

Figure 3. Water and salt budgets for irrigation systems having a conservative slat balance, for consumed fractions of 60% and 75%

As water is used for irrigation within an arid river basin, the amount of salt in the remaining water is progressively greater as one moves downstream. An example of this is the Colorado River system. The consumption of irrigation water results in an increase in river-water salinity caused simply by concentration effects. Such concentration effects are not influenced by irrigation efficiencies, unless, as in some geologic environments, the deep percolation water that passes through the root zone removes salts from underlying soil and rock. An example of this is the Mancos shale formations of western Colorado and eastern Utah. Here, the more water that passes through the soil and rock, the more salt that is added to the river system. In such settings, water conservation efforts aimed at reducing deep percolation will result in less salinity added to the river, which in effect saves water.

For visual simplicity, Willardson et al., (1994, 1998) and Allen et al, (1996, 1997, 2003) encouraged the use of fractions over efficiencies to describe the breakdown of components of water disposition. Figure 3 shows the effects of changing the consumed fraction of diverted water from 60% to 75% when the salt is in balance (i.e., salt entering project with irrigation water equals salt leaving project with drainage water). For simplicity in this example, there is one unit of salt per 10 units of water. Note that the consumed water (ET) carries no salt so that the incoming salt is concentrated in less outflowing water (In this case, 2.5 times more concentrated). By improving the efficiency, less water and salt come in, the consumption is the same, less salt also flows out, but the exiting water is still much more concentrated (4.0 times more concentrated). Here, the increase in consumed fraction (e.g., due to efficiency improvement) results in slightly less salt in the returning water, but only because less salt was diverted. Depending on other factors, the improvement in efficiency may or may not make more water available on a watershed basis.

When the excess water leaches salt from soil and rock, the situation changes drastically. The more water that passes through the system, the more salt that is mined and returned to the river. As shown in Figure 4, increasing the consumed fraction reduces the amount of salt returning, but the concentration of salt in the water is slightly higher. Here, improving efficiency has a huge impact since it changes the mass of salt added to the downstream water supply.

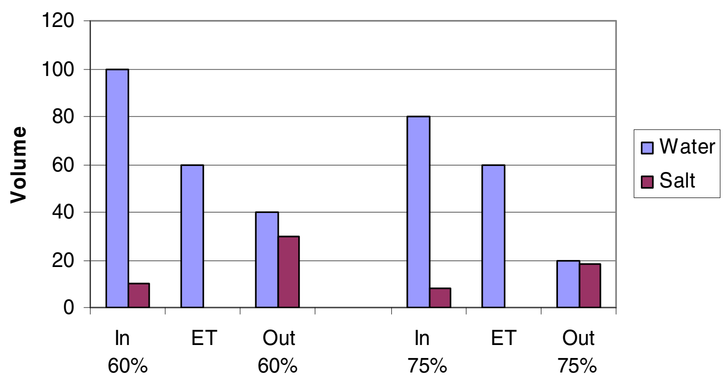

Figure 4. Water and salt budgets for irrigation systems that are mining salts via deep percolation through saline geologic formations, for consumed fractions of 60% and 75%.

Case Studies

Efficiencies. Rice et al. (2001) demonstrated some of the complexities of evaluating field irrigation systems and the implications for water conservation. In this study, a sloping furrow irrigated cotton field was monitored for four seasons. Irrigation inflow, runoff, and advance were measured each irrigation. Soil water was measured through the entire season to determine additions to soil water from irrigation and water consumption. The application efficiency was determined for each event and the irrigation efficiency was determined as a cumulative effect over time. Application efficiency (AE) was determined as the volume of soil water deficit at the time of irrigation divided by the volume applied (assuming 100% fulfillment of soil water deficit). Irrigation efficiency (IE) was calculated as the beneficial use (consumption by the crop) divided by the volume applied, accumulated from the start of the irrigation season, as described by Burt et al (1997).

Figure 5 shows the results from 1994. The actual seasonal irrigation efficiency was roughly 60%. Clearly, evaluation of this field based on measurement of application efficiency for one irrigation event might give misleading results. Low application efficiencies during the second irrigation when the crop roots were not very deep is common since the short root zone is dry and the irrigation systems cannot apply light amounts of water. Low application efficiencies late in the season are caused by not adjusting the application depth for the soil water deficit, or irrigating too frequently. For this field, runoff was not recovered, so the easiest method to improve irrigation efficiency for the field was to recover and reuse the runoff. Attempts to reduce runoff, i.e. through irrigation of every other furrow, for this field resulted in more deep percolation and no real improvement in IE. Unrecovered runoff for this field resulted in soil evaporation and phreatophyte ET from borrow ditches. Thus it constitutes a loss to the river basin. Deep percolation may eventually reach deep groundwater, but some may be lost from vadose-zone evaporation. Here improvements in irrigation efficiency may likely represent true water savings, depending on the ultimate fate of unevaporated surface runoff and deep percolation.

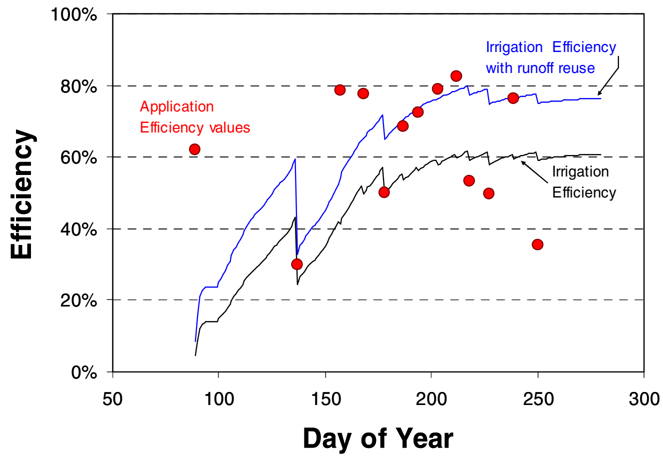

Figure 5. Application and irrigation efficiencies for sloping furrow cotton field, 1994.

Table 1. Average water use before and after Wellton-Mohawk On-farm Irrigation Improvement Program (Bathurst 1988) on 19,278 ha.

Crop	Water Use		Basal ET[*]	Basal ET/Water use	
	(mm)		(mm)	(Ratio)	
	Before	After		Before	After
Alfalfa	3,124	2,362	1,880	0.60	0.80
Cotton	1,676	1,346	1,047	0.62	0.78
Wheat	1,194	813	660	0.55	0.81

[*]From Erie et al. (1982)

Efficiency Improvement. From 1975 to 1986, the Soil Conservation Service (SCS, now Natural Resources Conservation Service or NRCS) implemented an improvement program in the Wellton-Mohawk Valley (Bathurst 1988). Improvements in irrigation systems were made on 19,278 ha out of the roughly 24,000 ha irrigated. Prior to the project, land was graded with conventional equipment and most surface irrigated fields had some slope. After the project, nearly all the land was converted to level basins with laser-controlled equipment. Table 1 gives the water use on three of the major crops before and after the project. Also shown is the basal ET for these crops, taken from Erie et al. (1982). Rainfall in the area is negligible (roughly 75-100 mm/yr) and is typically much less than soil evaporation, which is often considered beneficial due to cooling effects and reduction in transpiration demand (Clemmens and Hunsaker 1999). Thus the ratio of basal ET to water use (applied) gives a rough indication of irrigation efficiency. On average, efficiencies increased from about 60% to 80%. Drainage flows from the district changed from over 250,000 Megaliters/yr to less than 125,000 Megaliters/yr from the early 1970s to the late 1980s, reflecting real changes in on-farm performance.

Changes in crop yield have been a controversial aspect of documenting improvements in irrigation performance. In general, increased irrigation uniformity increases crop yield by reducing areas of both over and under application. However, genetic and cultural advances in crop production also tend to increase yield over time. Table 2 shows the changes in crop yield in the Wellton-Mohawk valley from the on-farm improvement program. Some of this yield increase is likely the result of better water management (e.g. irrigation scheduling) and may not be entirely due to the conversion to laser-graded level basins. The higher yields likely translated into <u>higher</u> transpiration and thus <u>higher</u> water consumption.

Table 2. Average crop yields before and after Wellton-Mohawk On-farm Irrigation Improvement Program (Bathurst 1988) on 19,278 ha.

Crop	Units	Before	After	Difference	% Difference
Alfalfa	metric tons/ha	3.1	3.5	0.4	12%
Cotton - lint	Kg/ha	212	238	26	12%
Wheat	metric tons/ha	6.1	7.4	1.2	20%

Drainage water from this project is pumped from the aquifer, because the groundwater under this section of the Gila River is blocked from flowing downriver by a large underground rock outcropping. The drainage water is pumped into a canal that caries the drainage water to the Sea of Cortez. The salinity of the drainage water is roughly 3700 ppm, so is unusable for irrigation of most crops. These water conservation improvements have reduced water diverted from the river, and since none of this drainage water returns to the river for downstream use, all this water is considered conserved. However, the saline drainage water is currently is the only Colorado River water entering the Sea of Cortez. Even with the high salinity, it is still relatively fresh compared to sea water and is considered an environmental benefit.

Water capture and reuse. In more humid regions, rainfall provides most of the crop water requirements. The last decades have seen significant expansion in irrigation in the humid south because of the benefits of a few irrigations during a growing season, even when annual rainfall far exceeds crop water needs. The Grand-Prairie Irrigation Project in eastern Arkansas provides a good case study for examining water conservation issues in humid areas. It consists of 246,000 cropped acres. Rice started being grown there in 1904. Groundwater withdrawals from confined aquifers exceeded recharge as early as 1910 and groundwater levels have continued to decline since. In the late 1980's, the Grand Prairie irrigation district was formed in order to develop an irrigation diversion from the White River. A significant on-farm component was added to the project, including storage reservoirs and tailwater pits to capture both irrigation tailwater and rainfall runoff.. It was generally believed that low irrigation efficiencies in the area contributed to the groundwater decline and would over tap the White River.

A study was conducted by the NRCS to evaluate the effectiveness of the proposed on-farm improvements to capture rainfall and to improve irrigation efficiencies on these systems (Robinson et al. 2003). This study evaluated water use on a small watershed consisting of several farms, for which on-farm improvements had already been planned as part of the project. On-farm reservoirs and sumps are used to capture irrigation tailwater and rainfall runoff. The initial study modeled the hydrology of the area with the SPAW model (Saxton 2002). Weather data for 1961-1966 were used to examine the impact of improvements. The output from SPAW was analyzed to assess specific impacts of reservoirs and tailwater sumps. Results are shown in Table 3, based on assumed values of field application efficiency. One farm had no sumps or reservoirs, but its runoff was captured by other farms downstream. Because of extremely tight soils, groundwater recharge (even to surface aquifers) was considered to be insignificant.

Table 3. Efficiencies under post-project conditions for 7-farm watershed.

Field Application Efficiency	Average Farm Irrigation Efficiency	Range in Farm Irrigation Efficiencies	Watershed Irrigation Efficiency	Groundwater pumped as a fraction of ET_{iw}	Rainfall runoff captured as a fraction of ET_{iw}
50%	84%	50-91%	87%	0.68	0.47
60%	88%	60-92%	90%	0.51	0.60
70%	90%	70-93%	92%	0.46	0.63
80%	92%	80-94%	94%	0.44	0.62

First, Table 3 shows that the use of tailwater sumps resulted in farm irrigation efficiencies that were much higher than the field application efficiencies. Second, because water running off one farm can be captured downstream, the efficiency from a watershed basis is also higher than the average farm irrigation efficiency. Under the pre-project conditions, essentially 100% of the irrigation requirement was met from groundwater pumping. Under most scenarios, this can be cut in half under post-project conditions. Table 3 also shows that once the field application efficiency reaches roughly 70%, further improvements provide little benefit from a watershed basis. This because the sumps and reservoirs are able to handle the volume of water running off at these efficiencies, but at lower efficiencies there is too much water that cannot be captured (i.e, this break point is a function of the amount of infrastructure).

With the project in place, this example watershed would be expected to meet crop water requirements, on average, with 1/3 coming from effective precipitation, 1/3 from rainfall runoff captured and used for irrigation (during both the growing and non-growing seasons), and 1/3 coming from groundwater or river diversions. The rainfall runoff, if not captured, would simply add to Mississippi River flows that may already be at flood stages (i.e., mostly not recoverable), and would have to be replaced by groundwater overdraft or White River diversions, which are somewhat controversial for environmental reasons. Thus these water conservation efforts are providing a real benefit, but not because of field application efficiencies.

Benefits of Incidental Groundwater Recharge. The Eastern Snake River Plain (ESRP) of Idaho overlays a huge fractured basaltic aquifer that stretches nearly 300 km from near Yellowstone Park in the northeast to the Thousand Springs area in the southwest, which is a major discharge point for the aquifer. The aquifer system is bordered on the southern edge by the Snake River, a large river system supplied primarily by mountain snowmelt and aquifer discharge. There are a total of 850,000 ha (2.1 million acres) of irrigated land overlying the aquifer system, of which 450,000 ha are supplied by diverted river water and 400,000 ha by groundwater pumped directly from the aquifer. Beginning in about 1860, river diversions supplied surface water to farm application systems via canals. Since about 1970, a slight majority (240,000 ha) of surface irrigation systems have converted to more efficient sprinklers. The "incidental" recharge stemming from deep percolation of "excess" irrigation water from farms and seepage from canals has been the primary source of recharge to the ESRP aquifer, far exceeding recharge from water entering the aquifer via side tributaries and from natural precipitation (averaging only 250 mm yr^{-1}) over the plain. An annual recharge to the aquifer is roughly 9.9 million ML (8.0 million Ac-ft/yr), which can be broken down by: incidental recharge of irrigation water (60%), tributary underflow (17%), precipitation (9%), river losses (9%), and other (5%). The influence of this incidental recharge can be seen from stream-flow records, which changed from a near constant 115 m^3/s in the early 1900s to more than 185 m^3/s in the 1960s Figure 6). Following that period, conversion of "inefficient" surface irrigation systems to high efficiency sprinkler systems has reduced incidental recharge to the ESRP aquifer, and, along with direct ground-water pumping for irrigation, has caused aquifer levels and discharges to the river to decline, being roughly 160 m^3/s in the 1990s. Declines in spring flows have impacted a large spring-fed trout aquiculture and "senior" river water diverters (irrigators), with both groups now in litigation.

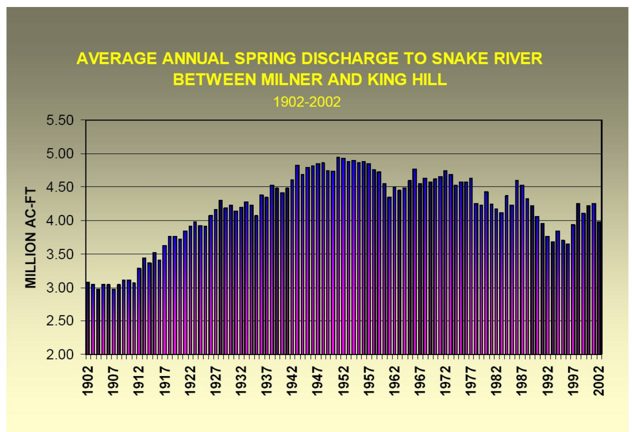

Figure 6. Annual mean aquifer discharge to the Thousand Springs reach of the Snake River from 1902 through 2002, showing the downward trend since 1950 due to direct ground-water pumping and from reduced recharge stemming from conversion to more efficient irrigation systems that use river water and due to direct ground-water pumping (from Brendecke, 2004).

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