# Appendix F10
# Option Characterization –
# Agricultural Water Conservation

# Appendix F10 — Option Characterization – Agricultural Water Conservation

## 1.0 Introduction

Agricultural water conservation has been proposed to reduce the overall water demand in areas currently relying upon water supply from the Colorado River system. Nine options related to agricultural water conservation were submitted for consideration in the Colorado River Basin Water Supply and Demand Study (Study). These options were used to develop agricultural water conservation representative options. The representative options were parsed into 200 kafy "steps" to represent likely project phasing. The submittals are summarized in appendix F2 and the original submittals are available via links from the electronic version of appendix F2 on the compact disc that accompanies this report and the version of appendix F2 on the Study website at http://www.usbr.gov/lc/region/programs/crbstudy.html.

This appendix summarizes the types of options received, categorizes the types of options into the following two categories, explains the methods to characterize the options, and provides the draft characterization results.

- Basin-wide agricultural water conservation
- Basin-wide agricultural water conservation with water transfers

Additional detail related to the options characterization is included in appendix F3. Attachment A of appendix F3 contains more detailed descriptions of the ratings. Attachment B provides the methods used for completing the unit cost calculations. Attachment C presents the detailed characterization information and is available on the compact disc that accompanies this report and on the Study website.

## 2.0 Overall Approach

Nine options were submitted related to agricultural water conservation to reduce the demand in areas receiving Colorado River system water supply. These options ranged in type from specific conservation measures or best management practices (e.g., improved irrigation efficiencies, modernization, conveyance system efficiencies, changes in types of crops under irrigation, etc.) to general implementation approaches that could be used to achieve further water conservation (e.g., water pricing or water transfers).

The concepts received were first organized into six Colorado River Basin (Basin) -wide agricultural water conservation measures reflecting different types of activities that could generate water savings in the agricultural sector. The six agricultural water conservation measures consist of:

- Advanced irrigation scheduling
- Deficit irrigation
- On-farm irrigation system improvements
- Controlled environment agriculture

- Conveyance system efficiency improvements
- Fallowing of irrigated lands

Each conservation measure was first evaluated for potential water savings, and then a potential percentage reduction in irrigation diversions and/or consumptive use was estimated. Projected conserved water yields created by reducing depletions to the Basin were restricted to measures that specifically reduce consumptive use for irrigated areas located within the Basin but considered total reduction in diversions (consumptive and non-consumptive uses) for irrigated lands served outside of the Basin. Each conservation measure was then evaluated in terms of potential adoption rates to estimate the total water yield.

In order to encourage adoption of the targeted water conservation measures, two possible implementation approaches were considered: (1) *Basin-wide agricultural water conservation* through a federal or state incentive-based program to encourage agricultural water use efficiency without specific legal transfer of water or water rights, and (2) *Basin-wide agricultural water conservation with water transfers* between a willing transferor and willing transferee that promotes water conservation and/or short-term or permanent fallowing of irrigated lands to transfer conserved water to the transferee for a similar or different use.

For purposes of this analysis, each of the various conservation measures were examined as a Basin-wide potential, but in reality the measures will have important regional limitations and in some cases may be mutually exclusive. Some of the various measures should not be considered to be additive. Nevertheless, they are broken out in the following sections for the reader to understand the basic assumptions used in the option characterization.

Because levels of current agricultural conservation measures vary throughout the Study Area, different levels of potential savings are possible for a given conservation measure. These savings range from essentially no savings where measures have been fully adopted to significant savings where measures have not been adopted or where adoption rates are relatively low. Disaggregating the savings potential by conservation measure and individual location was beyond the scope of this Study**.** In addition, the conservation measures could produce different amounts of savings depending on the location in the Basin, implementation approach, and combination of measures; therefore, the total quantities are estimated as an aggregate for each implementation approach. Up to 1 million acre-feet per year (mafy) of potential savings by 2060 was considered for both approaches (incentive-based program and water transfers) combined with roughly 500,000 acre-feet per year (afy) potential under each approach category. Note that the categories are considered separately largely because the types of reductions are mutually exclusive (i.e., on-farm reductions produce no savings to a fallowed field.) The representative options reflect additional water conservation above and beyond existing water conservation programs that are already included in the demand scenarios in the Study.

# 3.0 Potential Agricultural Water Conservation Measures

Each of the potential agricultural water conservation measures that were considered in the analysis are generally described below. Additional detail on expected quantity of yield, timing of option availability, and costs are provided in later sections.

## 3.1 Advanced Irrigation Scheduling

This measure involves the application of advanced irrigation scheduling techniques using local climate and soil moisture information to match water deliveries with crop water needs more precisely. In areas of elevated water and/or soil salinity, it also involves the application of soil salinity and crop salt-tolerance monitoring to determine necessary irrigation leaching fractions more precisely. This measure has potential to reduce total water diversions, but is not likely to provide significant reduction in consumptive use.

## 3.2 Deficit Irrigation

Like the advanced irrigation scheduling measure, the deficit irrigation option involves water management techniques that do not rely on any changes in irrigation infrastructure. This measure also requires application of advanced irrigation scheduling practices but takes advanced scheduling one step further to impose water stress on crops during drought-tolerant growth stages, with the goal of maximizing crop water productivity or maximizing farm-gate profitability with marginally reduced crop yield. Deficit irrigation has the potential to reduce both water diversions and consumptive use. In areas in the Upper Basin and adjacent areas that experience significant physical supply shortages, deficit irrigation is not expected to result in reduced basin water consumption or need for Colorado River water because under existing state water laws additional water will be available to reduce shortages to other Basin water users. As described in this appendix, this measure does not include significant under-irrigation to the point of reducing yields by more than 20 percent or substantially reducing farm-gate profitability. Compensated programs for significant deficit irrigation of permanent forage crops such as split season fallowing are addressed separately under the irrigated lands fallowing water conservation measure.

## 3.3 On-farm Irrigation System Improvements

On-farm irrigation system improvements such as conversion from flood to sprinkler and/or drip irrigation methods are included in this measure. Although consumptive use savings are not expected for this conservation method, reductions in total water diversions from reduced tailwater and deep percolation return flows can be expected with appropriate controls on the conservation program implementation approaches.

## 3.4 Conveyance System Efficiency Improvements

Improvements in conveyance system efficiency through delivery canal lining, canal to pipe conversion, improved canal control and/or construction of regulation reservoirs to reduce canal operational spills, and implementation of system-wide drainwater or tailwater recovery systems are included in this option. Although these conservation methods can yield significant reductions in total diversions in many cases, consumptive water use savings are far less and are attributed to evaporation, seepage, drainage, and operational spills to saline sumps, bodies of water, and phreatophyte evapotranspiration loss from irrigation and drainage canals.

## 3.5 Controlled Environment Agriculture

Controlled environment agriculture consists of agricultural production within large-scale greenhouses that optimize crop production and reduce water usage by controlling the environment (temperature, relative humidity, etc.) and continuously recirculating water. The high associated capital and operation and maintenance cost is the primary barrier to implementation of this option.

### 3.6 Irrigated Lands Fallowing

Rotational or permanent fallowing is a common practice that is used to effectively reduce crop consumptive use when water supplies are limited. This practice is commonly applied when economic conditions dictate necessary changes in crop production or for the purposes of: self-regulated water management to fit crop selection and planting areas to within available water supplies, water transfers to reallocate water to other non-agricultural uses, and enrollment of highly erosive or ecologically sensitive cropland in federal programs. Also considered under this option are split season fallowing of permanent forage crops, such as alfalfa. In agricultural areas in the Upper Basin and adjacent areas that experience significant physical supply shortages, irrigated lands fallowing is not expected to result in reduced Basin water consumption or need for Colorado River water because under existing state water laws additional water will be available to reduce shortages to other Basin water users.

### 3.7 Other Considered Options

Some agricultural water conservation options that were submitted for consideration were not considered viable methods for achieving water savings. One example is changing the types of crops that are grown within the Basin. The types of crops that are grown in the Basin depend on a wide array of factors, including local production conditions (climate, soils, water), local and global market conditions (supply, demand, and pricing), existing crop- specific infrastructure (farm harvest equipment and food processing facilities), and the local price of inputs (labor, fuel, water, etc.). Without control of crop selection on all lands within the Basin, payment or incentives to change cropping in one area could shift the production of the replaced high-water-use crop to another location within the Basin, thereby simply shifting the location of water depletion but not reducing the overall Basin water use.

## 4.0 Regional Considerations

The potential agricultural water conservation measures are assumed to apply to the overall Study Area, but significant differences in potential water savings between in-Basin in certain areas and in adjacent irrigated areas due to water budget considerations and downstream uses dependent on return flows. In addition, applied water requirements and evapotranspiration vary across the Basin depending on elevation, climate, soils, irrigation methods, crop types, and other factors. The Study approach considered in-Basin and adjacent area differences as well as broad differences in applied water requirements, but was not planning area- or state-specific in its assessment. The total irrigated areas used in these calculations were 2.1 million acres for in-Basin lands and 2.5 million acres for adjacent lands, as noted in *Technical Report C – Water Demand Assessment*. For some conservation measures and some regions, significant investment has already occurred, and the ability to achieve additional conservation will be limited or more costly. For instance, the 0.45 million acres within the Imperial Irrigation District (IID) are already involved in an aggressive water conservation program and have been removed from the estimates of future agricultural water conservation potential (IID, 2007).

# 5.0 Implementation Approaches

The two primary implementation approaches under consideration for agricultural water conservation are incentive-based programs and water transfers. For either approach, program-controls are necessary to ensure that water conservation investments provide measurable returns in verifiable water savings. Water conservation program controls should address the following issues:

- Conserved water needs to be measurable by a reduction in demand, conservation measures need to be easily observable, and, where costs are not prohibitive, should be verified by volumetric water use measurement.
- Legal mechanisms must be in place to protect conserved water in-stream for intended uses, especially in areas where insufficient stream flow currently limits downstream water users from exercising their full diversion rights.
- Controls may be needed to prevent expansion of effectively irrigated areas associated with water conservation investments.
- Continuing to maintain a healthy agricultural economy and development of associated policy.

A key distinction between incentive-based programs and water transfers as defined here is whether a legal transfer of water or water rights is involved. The incentive-based programs are assumed to be accomplished without legal transfer of water or water rights, whereas the water transfers specifically revolve around legal transfers of water or water rights.

## 5.1 Incentive-based Programs

Incentive-based programs can take different forms depending on the type of water conservation option and the type of collaborator (e.g., water user versus water purveyor). Generally, this option involves providing financial incentives through:

- Grants or low-interest loans to construct infrastructure projects.
- Cost-share payments to offset the costs of irrigation system conversion.
- Incentive payments to growers who adopt water conservation practices and provide documentation of management practices (payments to implement specific observable practices).
- Incentive payments based on a reduction in volume of water diverted or consumptively used (no specific practice is required, but savings must be measured relative to a baseline).
- Water pricing reform.

Several existing federal incentive programs could be applicable under this approach. Potentially applicable programs administered by the U.S. Department of Agriculture (USDA) as of the time of publication of this appendix include the Environmental Quality Incentives Program, Agricultural Water Enhancement Program, Conservation Reserve Program, and Conservation Reserve Enhancement Program. Potentially applicable programs administered by Bureau of Reclamation (Reclamation) include the WaterSMART Grants, Water and Energy Efficiency Grants, and Title XVI Grants.

### 5.2 Water Transfers

Water transfers can represent the legal transfer of water or water rights from one use to another. Within an agricultural water use framework, transfers can be implemented on a temporary basis (one growing season) from year to year or on a permanent basis, essentially through the acquisition of water or a permanent water right. Typically, water transfers are negotiated on a willing-transferor, willing-transferee basis within a state and can be implemented on a direct transferor-transferee arrangement or facilitated through a water bank. Payments can be based on measured volume of reduction in diversion or consumptive use or can be tied to observed practices, such as land fallowing or forbearance of all diversion. Within a state, priority systems for the use of water can affect the ability to implement a water transfer absent the consent of intervening priority users. State water laws generally protect agricultural water transfers and ensures the historical consumptive use is available for the new use.

## 6.0 Quantity of Yield

All of the quantification methods for agricultural water conservation are best described in the context of overall water balance. Agricultural water use may remove all or a portion of the water diverted permanently from the watershed, or it may simply reroute a portion of the water by changing the pathway, timing, and in many cases, the quality of water as it flows through the Basin. The portion of water that is diverted from the streams, used for irrigation, and lost for the purpose of other downstream water uses is called consumptive use. It includes transpiration by crops and other plants, evaporation from water and soil surfaces, and water flows into saline water bodies that cannot be economically recovered. There is another portion of water that is diverted from the streams and used for irrigation, but which returns to the streams either directly through surface runoff or groundwater return flows. These return flows are subject to additional use and appropriation by downstream water users.

Because irrigated lands both inside and outside the Basin are served with Colorado River water, the accounting of water savings must address the differences in depletion to Basin water supply within these two regions. All water exported from the Basin is lost permanently from additional use within the Basin, even though only a portion is consumptively used by crops, and is considered depletion. Within the Basin, only consumptive use is considered depletion. The methods used to quantify potential yield from agricultural conservation all distinguish between conserved water that would have been lost to the Basin versus conserved water that is simply re-routed within the Basin. Generally, any savings in water that would have been exported from the Basin is counted as reduced depletion and therefore potential yield; within the Basin, only reductions in consumptive uses reduce depletion and can thus be counted as potential yield.

Although re-routed water within the Basin may not appear to produce yield from the perspective of the Basin's water balance, it can still have important value for improving the location, timing, and quality of flows. However, in many cases re-routed return flows can adversely affect other uses of the water that relied on the current flow paths and timing. Current water law in Colorado addresses this issue through only allowing an irrigator's historical consumptive use to be transferrable for other uses (Colorado Agricultural Water Alliance, 2008). These effects are captured in the evaluation criteria (legal, water quality, other environmental, and socioeconomic).

Due to the over-allocated and "supply-limited" nature of irrigation water use in the Upper Division States (Colorado, New Mexico, Utah, and Wyoming), and the high degree of sequential reuse of return flows, it is expected that agricultural water conservation savings in these areas will be limited by downstream return flow-dependent uses. For a given funded water conservation project, a portion of the field-scale water savings will likely be demanded by junior downstream users that have historically relied on these return flows. Exceptions to this condition will occur in the most downstream areas of irrigation projects where downstream ability to reuse return flows in other areas is limited. Additionally, there may be distinctions between surface and groundwater return flow impacts, with downstream users being more immediately and directly dependent on surface return flows. The estimated quantities of yield and cost per acre-foot (af) of water conserved are based on field-scale estimates and are not discounted for return flow-dependent uses until the final summary table.

Furthermore, the Colorado River Simulation System (CRSS) model used to evaluate system reliability does not directly represent a significant number of the tributaries in Colorado, Wyoming, Utah, and New Mexico. In Colorado, for example, inflow nodes are only included for the main stem Colorado, Gunnison, Yampa, San Juan, and White rivers. Demands upstream of these inflow nodes are aggregated and represented at those same locations. A significant portion of the aggregated irrigation demands divert from the smaller tributaries and are unable to receive a full water supply during the irrigation season either because of physical flow limitations or the need to bypass water to satisfy downstream senior demands.

Because of CRSS model limitations, supply-limited consumptive use is used to represent irrigation diversion demands in CRSS. Because smaller tributary demands are represented on the main stem of the largest rivers in the Upper Basin, CRSS model may inaccurately show that full-supply demands could be satisfied. This would overstate consumptive uses. It should be clearly noted that the use of supply-limited demands (instead of potential crop demands) understates both demands and associated shortages due to CRSS model limitations. The use of supply-limited demands is consistent with the consumptive uses and losses reported values as well as the 2007 Upper Colorado River Commission depletion schedule estimates.

## 6.1 Estimates by Conservation Measure

The estimated quantities of yield, before discounting for the effect of return flow-dependent use, are discussed in this section for each of the agricultural water conservation measures. Table F10-1 summarizes the percent reduction in consumptive use and percent reduction in total diversions associated with implementing a unit amount of each measure. These estimates are explained in the following sections.

TABLE F10-1
Estimated Potential Water Savings Percentages at the Farm Scale for Each Agricultural Water Conservation Measure

| Water Conservation Measure | Reduction in Consumptive Use (In-Basin) | Reduction in Total Diversion (Outside Basin) |
|---|---|---|
| Advanced Irrigation Scheduling | 0% | 13% |
| Deficit Irrigation | 13% | 20% |
| On-farm Irrigation System Improvements | 0% | 20% |
| Conveyance System Efficiency Improvements | 1% | 20% |
| Controlled Environment Agriculture | 50% | 50% |
| Irrigated Lands Fallowing | 40 to 100% | Up to 100% |

Water savings for reductions in total diversion have not been discounted for effects of return flow-dependent use.

Generally, the estimates of potential water savings from each water conservation measure were made by multiplying the potential percent reduction in consumptive use (in-Basin) and total diversions (outside Basin) by the estimated consumptive use and diversions within each Basin state[1] from the 2060 CRSS simulation results and finally, multiplying by an estimated adoption rate. In estimating adoption rates, it was considered that some fraction of water users are already implementing the conservation measure and some fraction of the remaining water users would not be receptive to the measure. For instance, if 50 percent of irrigators were using flood irrigation and it was estimated that 50 percent of those irrigators would engage in a program to upgrade on-farm irrigation systems to drip or sprinkler, the overall adoption rate would be 25 percent.

## 6.2 Advanced Irrigation Scheduling

Advanced irrigation scheduling focuses on improved water management methods that typically do not require physical changes or improvements to irrigation system equipment. Estimates of the potential reduction in applied water from improved irrigation scheduling and soil salinity management were taken from Eching (2002) as reported in Cooley et al. (2008), who found a 13 percent reduction in applied water and 8 percent increase in yield resulting from the use of advanced irrigation scheduling by 55 growers across California. The *Imperial Irrigation District Efficiency Conservation Definite Plan* (IID, 2007) estimated between 0.2 and 0.38 acre-feet (af) per acre reduction in applied water from different ways of implementing irrigation scheduling. When compared to the average irrigation applied water amount within IID of about 5.1 af per acre (IID, 2007), this represents an applied water savings of 4 to 8 percent. For the purposes of this discussion, the 13 percent water savings estimate is used for reduction in applied water only.

For in-Basin implementation, the consumptive use reduction benefit of this option was assumed to be zero. As reported by Eching (2002), increased yields were also associated with the reductions in applied water through advanced irrigation scheduling. This can

[1] Arizona, California, Colorado, New Mexico, Nevada, Utah, and Wyoming.

occur when water deliveries are more closely matched to periods of crop water demand, thereby reducing water stress and increasing crop yields and crop consumptive use.

For purpose of water savings estimates, 25 percent of all irrigated acres outside the basin were assumed to adopt irrigation scheduling. Based on these assumptions, about 270,000 afy of depletions from the Basin could be reduced.

## 6.3 Deficit Irrigation

Deficit irrigation has been defined in multiple ways (Smith, 2011). However, for purposes of this analysis, the definition presented by Geerts and Raes (2009) has been adopted, where deficit irrigation is "deliberately tolerating drought stress for maximizing the productivity of water". Stated another way, deficit irrigation is minimizing water use while maintaining crop yield or maximizing crop yield per unit of water use.

Deficit irrigation has been demonstrated to reduce water use by about 20 percent and maintain or improve yield and crop quality on almond and pistachio crops in California (Goldhamer et al., 2006). Deficit irrigation of grain crops such as winter wheat has also been shown to maintain or improve overall farm-gate profitability with reduced irrigation and subsequent marginally reduced grain yield (English and Nakamura, 1989). On-farm research in the Columbia River Basin demonstrated that the optimum farm net income occurred with irrigation water use reductions of 20 to 30 percent on winter wheat (English, 1990) and that crop consumptive use was reduced by about 13 percent with a 20 percent reduction in applied water (English and Nakamura, 1989). The most profitable level of stress irrigation will depend on crop prices relative to irrigation costs, and growers are often reluctant to stress irrigate due to the risk of over-stressing and causing too much loss in yield. Nevertheless, these studies indicate a large potential for deficit irrigation while maintaining profitable agriculture.

Deficit irrigation research being conducted by the USDA Agricultural Research Service in Greeley, Colorado has documented water use and crop yield relationships for a number of field crops including corn, wheat, sunflower and dry beans (Trout and Bausch, 2012). This information has been used by the Northern Colorado Water Conservancy District (Altenhofen, 2012) to establish farm gate economics of deficit irrigation for these crops and to establish possible incentive payments to compensate for projected yield losses. For example, deficit irrigated corn with 80 percent of maximum yield at a 50-percent reduction in consumptive use would require an annual incentive payment of about $150 per af with corn at $4 per bushel.

For purposes of estimating potential savings, it was assumed that 50 percent of orchards, vineyards, small grains, corn, and sunflower acreage would adopt deficit irrigation. Without detailed cropping information on all lands irrigated with Colorado River system water, general crop percentages reported within the 2007 agricultural census for the Basin States was utilized (USDA, 2007). The census data indicate that no more than about 1 percent of land irrigated with Colorado River system water is in orchards or vineyards. The census data also indicate that small grains (wheat, barley, oats, rye) accounts for about 6.3 percent and irrigated corn accounts for 3.2 percent of total harvested cropland within the Basin. Using the 2011 crop production summary from the National Agricultural Statistics Service (2011), sunflowers were harvested on about 100,000 acres in Colorado in 2011, which represents about 1.4 percent of the total Basin irrigated acres within the planning area. Based on these land area percentages totaling 11.9

percent, the 50 percent adoption rate assumptions, and the per-acre water savings estimates, the potential water saving from applying deficit irrigation to the selected crops is estimated to total about 130,000 afy.

As noted above, in areas in the Upper Basin and adjacent areas that experience significant physical supply shortages, deficit irrigation is not expected to result in reduced Basin water consumption or need for Colorado River water because under existing state water laws additional water will be available to reduce shortages to other basin water users. Therefore, when this option is included in a portfolio, the portion of the 130,000 af water savings in the Upper Basin will be used directly to reduce other Upper Basin users' shortages, both within the Basin and in adjacent areas.

## 6.4 On-farm Irrigation System Improvements

On-farm irrigation efficiency is typically defined as the water consumed through crop consumptive use divided by the total irrigation water applied. Flood irrigation methods in general tend to operate at lower on-farm irrigation efficiencies than sprinkler or drip irrigation methods because of higher volumes of surface runoff (tailwater), subsurface runoff (tilewater), and deep percolation (groundwater return flow). However, while converting from flood to sprinkler or drip irrigation methods reduces total diversions, it is not likely to reduce consumptive use significantly and could actually increase consumptive use in some instances. This results from increased evaporation with sprinkler methods and increased crop evapotranspiration with improved water distribution uniformity. On the basis of reduced depletions divided by investment costs, the cost of converting from flood to sprinkler or drip within the Basin was considered too high to justify for water supply mitigation due to the marginal to negative consumptive use benefits. However, benefits for out-of-Basin application of on-farm irrigation system improvements could be significant (where return flows can be adequately addressed) and were included in the analysis where reductions in total irrigation diversion could be counted as water savings. It was recognized in this analysis that incentives for converting flood irrigation to sprinklers are already being provided in the Basin for water quality enhancement through the Colorado River Basin Salinity Control Program. However, the basis for funding those projects is not for water supply mitigation but rather to reduce deep percolation and groundwater return flows from agricultural lands that mobilize salts into the Colorado River and its tributaries (Reclamation, 2011).

Reductions in total irrigation diversions at a field scale were estimated by comparing typical on-farm irrigation efficiency levels. Using an average flood irrigation efficiency level of 70 percent and assuming that center pivot irrigation and drip irrigation could achieve an efficiency level of 87 percent (WDOE, 2005), the assumed reduction in total diversion is 20 percent. Assuming that 10 percent of irrigated land outside of the Basin is converted from flood to drip and 20 percent from flood to sprinkler (pivot), this option may reduce agricultural consumptive use by up to 490,000 afy. However, 270,000 afy of these potential savings occur in Colorado, where current administrative practice does not allow reallocation of water saved due to improved efficiency (Colorado Agricultural Water Alliance, 2008).

This option requires a flow meter to be installed and the grower to follow an irrigation water management plan written for operations of the revised system in order for savings to be realized. The option may also require controls that limit the effective irrigated area to no greater than historical effective irrigated areas considering distribution uniformity effects.

## 6.5 Conveyance System Efficiency Improvements

Conveyance system efficiency improvements were estimated by considering the potential for canal lining, canal to pipe conversion, improved canal control and/or construction of regulation reservoirs to reduce canal operational spills, and system-wide implementation of drainwater or tailwater recovery systems in order to reduce evaporation, seepage, operational spills, and phreatophyte evapotranspiration losses. The majority of water savings through these actions simply change the redistribution of water because the seepage and other surface return flows often become supply for other water uses in the Basin. Ignoring surface and groundwater recharge losses to saline sumps or bodies of water, reductions in direct canal evaporation and phreatophyte evapotranspiration losses along canals, drains, and wasteways are the only effective mechanisms for reducing consumptive use for in-Basin agricultural water savings through this method.

Potential water savings through conveyance system efficiency improvements will vary widely from project to project depending upon the baseline system infrastructure and operations. Systems that have already undergone significant conveyance system efficiency projects will have less potential to yield additional water savings than those continuing to operate with older and less-advanced systems. For the basis of making potential water savings estimates, system-wide water budget estimates from the *Imperial Irrigation District Efficiency Conservation Definite Plan* (IID, 2007) were used. For an improvement project that eliminated main canal and lateral spill, canal seepage and net evaporation and reduced on-farm tailwater by 80 percent, the potential reduction in water diversions is estimated at 20 percent and the reduction in consumptive use through eliminating canal evaporation is 1 percent of water diversion. Assuming that half (50 percent) of the irrigation systems receiving Colorado River water outside the Basin could achieve this level of reduction, the potential water savings of this option has been estimated at approximately 820,000 afy. However, 450,000 afy of these potential savings occur in Colorado, where current administrative practice does not allow reallocation of water saved due to improved efficiency (Colorado Agricultural Water Alliance, 2008).

## 6.6 Controlled Environment Agriculture

Water savings in controlled environment agriculture are largely achieved by recirculating water within the greenhouse environment and by producing higher yield per unit of cropped area. However, greenhouse production is expensive and has been demonstrated to be commercially viable only for horticultural crops such as fresh market vegetables and nursery plants. Further, commercial viability depends on either producing superior quality crops or bringing crops to market during times of year when field production is not feasible. Capital costs can exceed $200,000 per acre (Tatum and Hood, 2009), compared to less than a tenth of that for facilities to support field production. Estimates of water savings vary widely. On the low end, there are estimates of greenhouse water use being 5 percent of outdoor water use on a volume used per unit crop output basis (Sandia, 2005); however, these estimates are from short field studies during cool times of the year and do not capture a full annual cycle. Estimates of water use for greenhouse produced tomatoes were about 17 percent of outdoor water use, calculated as volume used per pound of crop produced (Sandia National Labs, 2005). However, other studies comparing monitored greenhouse water use with outdoor cultivation water use (e.g., Mpusia, 2006) showed greenhouse water use as 65 percent of that for outdoor cultivation. For the purposes of the Study, a water savings of 50 percent over traditional outdoor cultivation was assumed for controlled environment agriculture.

2007 census data for the Basin States indicate that vegetable acreage ranges from about 0.1 percent to over 4 percent of crop acreage, depending on the state (USDA, 2007). Applying a 2 percent vegetable crop acreage to estimated irrigated acreage, land potentially suitable for greenhouse production is estimated to be about 42,000 acres within the Basin and 50,000 acres out of the Basin. Much of this land both in and out of the Basin is in warm winter areas that already enjoy significant cost and market advantages for field production; growers in these areas would have limited incentive to incur the significant cost for greenhouse production except on a limited basis. Assuming that about 10 percent of the vegetable acreage irrigated with Colorado River water (9,000 acres) could be profitably converted to greenhouse production, and that the total water consumption could be reduced by 50 percent, the total amount of water saved would be approximately 13,000 afy. Based on estimates from the University of Arizona (Controlled Environment Agriculture Center, 2012), the total area under greenhouse production across the entire United States is currently about 21,000 acres. Consequently, this effort would involve increasing the U.S. greenhouse production by more than 40 percent from current levels.

## 6.7 Irrigated Lands Fallowing

Irrigated lands fallowing is one of the most direct and simple methods of irrigation water conservation in terms of water accounting and accepted legal frameworks allowing reallocation of conserved water. However, this practice can have significant impact on local economies where implemented. Examples of significant fallowing programs for water conservation can be found in the IID and the Klamath Basin, among others.

The most common application of this water conservation method is with annual crops. However, temporary fallowing and split-season leasing of water rights for permanent forage crops such as irrigated pasture have also been implemented with varying degrees of success. The Klamath Basin Rangeland Trust (KBRT) has an active split-season leasing program focused on curtailing water deliveries to irrigated pasture in the mid- to late- summer irrigation period (KBRT, 2011).The Colorado water bank has also considered split-season fallowing for irrigated pasture and hay production, but several operational and perception challenges need to be overcome with participants, as presented by Gangwer (2011).

The amount of conserved water yielded from fallowing can vary widely depending upon the crop, season of fallowing, and site climate and soil/groundwater conditions. For summer annual crops in dry regions with little summer rainfall or access to shallow groundwater, the consumptive use savings can be nearly 100 percent of the consumptive use under irrigated conditions. For permanent crop applications with access to shallow groundwater, the savings can be far lower. For example, measured consumptive use on irrigated and non-irrigated grass pasture in the Klamath Basin has demonstrated a reduction in consumptive use of about 1 mafy (KBRT, 2005) in a location where the annual consumptive use under irrigation is approximately 2.58 mafy, for a savings of 39 percent of irrigated consumptive use. For this reason, the potential water savings have been estimated as 40 to 100 percent of consumptive use within the Basin and up to 100 percent of total diversions.

This option has been conceptualized as an overall Basin-wide program (or a set of planning area programs) consisting of rotational or permanent fallowing. Such a program would be scalable over time and could be sized to achieve any level of reduction in consumptive use. Constraints on the size of the program would likely be influenced primarily by economic considerations; for example, the level of reduction in consumptive use in a particular planning area could be scaled to maintain a viable agricultural economy and avoid unacceptable impacts on jobs. For planning purposes, the amount of savings is assumed to be up to 10 percent of the irrigated lands and 10 percent of the agricultural consumptive use in the water demand scenarios. Applying this reduction percentage to the 7.2 mafy consumptive use within the planning area, it was assumed that up to 720,000 afy of water savings could be generated from fallowing measures, but this would be limited to water transfer programs with legal transfer of water or water rights (temporary or permanent).

As noted above, in areas in the Upper Basin and adjacent areas that experience significant physical supply shortages, irrigated lands fallowing is not expected to result in reduced Basin water consumption or need for Colorado River water because under existing state water laws additional water will be available to reduce shortages to other Basin water users. Therefore, when this option is included in a portfolio, the portion of the 720,000 af water savings in the Upper Basin will be used directly to reduce other Upper Basin users' shortages, both within the Basin and in adjacent areas.

## 6.8 Water Yield Summary

As discussed previously, all of the agricultural water conservation measures have been conceptualized into two implementation approaches: 1) incentive-based programs and 2) water transfers. Because the conservation measures could produce different amounts of savings depending on the location in the Basin, implementation approach, and combination of conservation measures, the total quantities were estimated as an aggregate for each implementation approach rather than a summation of individual conservation measures. Up to 1 mafy of potential savings by 2060 was considered for both approaches combined with potential of roughly 500,000 afy under each approach category. By comparison, the summation of potential water savings for each conservation measure totals 2.44 mafy when accounting for non-consumptive use savings outside the Basin and ignoring return flow impacts, and is reduced to 833,000 afy when only consumptive use savings are considered under each approach category. Table F10-2 summarizes the potential agricultural water conservation savings by measure and implementation method.

TABLE F10-2
Estimated Potential Water Savings at the Farm Scale for Each Agricultural Water Conservation Measure

| Water Conservation Measure | Reduction in Consumptive Use (afy) | Reduction in Total Diversion (afy) |
|---|---|---|
| Advanced Irrigation Scheduling | 0 | 270,000 |
| Deficit Irrigation | 100,000 | 130,000 |
| On-Farm Irrigation System Improvements | 0 | 490,000 |
| Conveyance System Efficiency Improvements | 0 | 820,000 |
| Controlled Environment Agriculture | 13,000 | 13,000 |
| Irrigated Lands Fallowing | 720,000 | 720,000 |
| **TOTAL** | **833,000** | **2,443,000** |

# 7.0 Timing of Option Availability

Because the agricultural water conservation options would be ramped over time, it was considered that the improvements to irrigation management, on-farm irrigation improvements, and changes in crop consumptive use could occur in as early as 10 years. Large infrastructure projects, including conveyance system efficiency improvements and controlled environment agriculture, were estimated to require at least 15 years before full implementation due to the planning, permitting, design, and construction needs.

# 8.0 Costs

Costs for implementing agricultural water conservation measures would vary regionally and with different levels of conservation programs. Costs were estimated based on review of existing programs implementing such measures. Important sources of cost estimates for on-farm irrigation improvements and conveyance system improvements included Cooley et al. (2010); IID (2007), and engineering estimates using Natural Resource Conservation Service cost bases. All costs were translated into net annualized costs over the life of the improvement. When possible, capital cost amortization used the 2011 discount rate for water-related projects of 4.125 percent. IID (2007) used a rate of 4 percent to amortize capital costs of irrigation system components over their expected useful lives.

Based on the estimates reported by Cooley et al. (2010), the unit annual costs for improved irrigation scheduling and deficit irrigation were approximately $100 per afy and $43 per afy and the unit annual cost of on-farm irrigation efficiency improvements was $390 per afy. These estimates were based on total water savings, not reduction in consumptive use.

Reductions in consumptive use through rotational or permanent fallowing were estimated based on existing fallowing programs and administration costs. The IID has recently offered $125 per afy to growers for fallowing fields to provide water for transfer and for Salton Sea flows (IID, 2012). This price applies to the full reduction in applied water. The effective price per afy of reduced consumptive use would be substantially higher. A study by Pritchett et al. (2008) reported survey responses to the price to forgo 1 year of irrigation as ranging from about $200 to $750 per acre with a minimum of $50 and a maximum of $1,800 per acre.

Costs for conveyance system efficiency improvements vary substantially depending on the characteristics of the existing delivery system. System improvement options developed for the IID Efficiency Conservation Plan (2007) ranged from $140 to $800 per afy of reduced diversion.

Controlled environment agriculture costs vary by crop type, hydroponic or aquaponic system, and installation technique. Initial capital costs are more than 10 times higher than traditional agricultural operations, with construction costs of $3 to $7 per square foot reported for relatively large-scale greenhouses (USDA, 2003; Mississippi State University Extension Service, 2009). Based on an assumed 1.5 afy savings, unit annual costs are likely approaching $6,000 per af. This cost would be offset to some extent by improved crop yield, quality, and price, but these benefits are highly dependent on market conditions. Table F10-3 presents the estimated costs by measure

TABLE F10-3
Estimated Potential Water Savings at the Farm Scale for Each Agricultural Water Conservation Measure

| Water Conservation Measure | Cost (dollar per af) |
|---|---|
| Advanced Irrigation Scheduling | 100 |
| Deficit Irrigation | 43 |
| On-farm Irrigation System Improvements | 390 |
| Conveyance System Efficiency Improvements | 140-800 |
| Controlled Environment Agriculture | 6,000 |
| Irrigated Lands Fallowing | 125-700 |

In general, it is anticipated that agricultural conservation programs would be implemented in order from least costly to more costly and that these costs would vary somewhat by the program implemented and specific best management practices considered. It is assumed that "Conservation" is more focused on on-farm and delivery system improvements, whereas "Conservation with Transfer" is more focused on fallowing. Table F10-4 presents the estimated costs for about 1 mafy of savings when 200,000-afy increments are considered. Note that the initial level of "Conservation" is dominated by on-farm conservation, with other measures such as system conservation and fallowing being implemented in greater proportions in subsequent steps. Whereas, when transfers are considered, fallowing is the dominant measure. In both cases, costs increase with increasing yield requirements.

TABLE F10-4
Agricultural Conservation Annual Costs per af of Savings by Implementation Type

| | Savings (mafy) | Conservation[1] | | Conservation with Transfer[2] | |
|---|---|---|---|---|---|
| Step 1 | 0.2 | On-Farm | $150 | Fallowing | $250 |
| Step 2 | 0.4 | | $300 | | $400 |
| Step 3 | 0.6 | System | $500 | System | $500 |
| Step 4 | 0.8 | | $600 | | $600 |
| Step 5 | 1.0 | Fallowing | $750 | On-Farm | $750 |

[1] Begins with programs more heavily weighted toward On-Farm Measures (Deficit Irrigation, Advanced Irrigation Scheduling, On-Farm System Improvements) but includes some portions of System Improvements and Fallowing in subsequent steps.

[2] Begins with programs more heavily weighted toward Fallowing but includes some portions of System Improvements and On-Farm in subsequent steps.

# 9.0 Other Key Criteria

In addition to yield, timing, and cost, the agricultural water conservation options were characterized against several other criteria. A summary of the findings for all criteria is shown in table F10-5. In general, these options are technically feasible, and there are examples in areas of the Southwest and in other arid regions of the world. Controlled environment agriculture is unlikely to be economically feasible on a large scale under foreseeable circumstances. Irrigation management and efficiency improvement programs have been undertaken at district and state levels, but have not been demonstrated on basins of the scale of the Colorado River in North America. It is not anticipated that significant permitting issues or legal changes will be required to implement these options. However, these options will affect diversion patterns, return flow quantities and locations, and groundwater recharge. These changes could generate legal challenges. Policy concerns could arise with large-scale agricultural water transfers as public discourse on the maintenance of agricultural economies and effects to rural communities continues. Coupling agricultural conservation with a transfer mechanism can have varying degrees of political and legal complexities depending on the nature of the transfer. For example, an Upper Basin banking concept is explored in the Study that assumes water generated through agricultural conservation is transferred to a downstream conceptual water bank near Lake Powell. Transfers of this nature would have significant policy and legal challenges. The characterization ratings shown in table F10-5 assume all saved water in the Upper Basin states is made available to local water users within the priority system.

All options have some implementation risk in that yields will fluctuate over time and programs will require continuous funding to maintain overall results. Controlled environment agriculture has additional risk from the very large capital requirements: at an average $5.43 per square foot (Mississippi State University, 2009), more than $2.6 billion would be required to construct the facilities for 11,000 net acres of production. Additional long-term risks would include maintaining sufficient revenue to pay the debt service and operations. For the other options, once savings are realized they can be maintained, resulting in long-term viability.

The non-structural options were rated high with respect to operational flexibility because the programs can be stopped at any time without incurring significant debt service or resulting in stranded assets. However, structural (including irrigation infrastructure) options do not have high operational flexibility. Non-structural agricultural water conservation options do not require energy, but on-farm irrigation improvements generally will require energy for pressurizing sprinkler and drip systems or for pumping recycled tailwater. Greenhouses require pressurized irrigation and may require heating and cooling systems, depending on location and season of operation. Agricultural water quality issues primarily relate to fertilizers and pesticides in return flows to surface or groundwater. All of the options reduce return flows and therefore could have positive effects on water quality. All options would likely have generally positive or neutral impacts on hydropower and recreation. Impacts on other environmental factors are uncertain. In some cases, the lower diversions could be positive by leaving additional flow in streams; in other cases, reduced return flows could affect environmental resources such as riparian vegetation along canals and drains that have come to rely on the return flow. Structural options such as system conveyance improvements and controlled environment agriculture would have construction-related impacts.

All of the options would require some additional spending in local communities to implement, and would therefore support local economic activity. Only the reduced consumptive use options were rated low on socioeconomics because of their potential effect on agricultural communities under long-term fallowing and reduced crop production. It is possible that these effects can be mitigated by taking a Basin-wide rotational approach to this option such that individual communities do not experience the impacts in a sustained manner.

# 10.0 Characterization Results

A summary of the characterization findings are shown in table F10-5. The top portion of the table shows the estimated quantity of yield, earliest timing of implementation, and estimated cost. The bottom portion of the table shows the 17 criteria and associated ratings ("A" through "E") and is color-scaled. In general, "C" is typically designated as mostly neutral (yellow); "A" is largely positive (green); and "E" is largely negative (red) or more difficult to accomplish. Refer to appendix F3 for specific criteria descriptions and rating scales.

# 11.0 References

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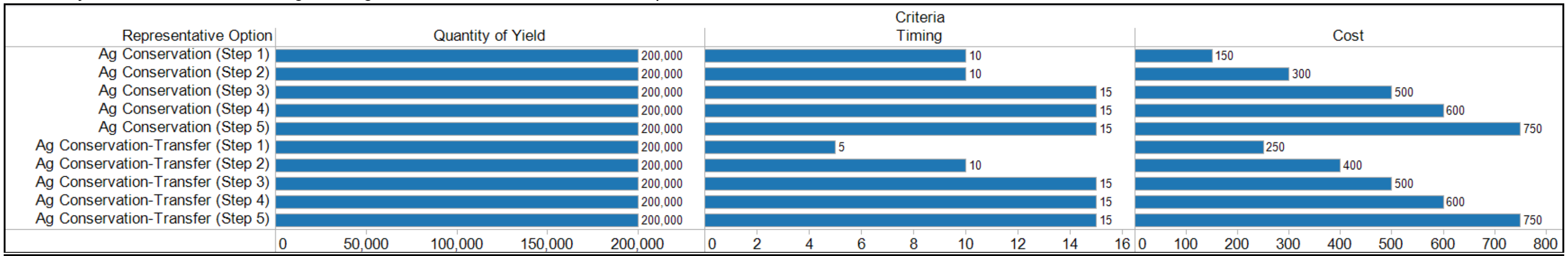
TABLE F10-5
Summary Characterization Ratings for Agricultural Water Conservation Options




| Representative Option | Quantity of Yield | Timing | Cost | Technical Feasibility | Implementation Risk | Long-Term Viability | Operational Flexibility | Permitting | Energy Needs | Energy Source | Other Environmental | Recreation | Socioeconomics | Policy | Legal | Hydropower | Water Quality |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ag Conservation (Step 1) | D | B | A | B | B | D | E | B | A | A | B | A | B | A | B | B | A |
| Ag Conservation (Step 2) | D | B | A | B | B | D | E | B | A | A | B | A | B | A | B | B | A |
| Ag Conservation (Step 3) | D | C | A | B | B | D | E | B | A | A | B | A | B | A | B | B | A |
| Ag Conservation (Step 4) | D | C | A | B | B | D | E | B | A | A | B | A | B | A | B | B | A |
| Ag Conservation (Step 5) | D | C | A | B | B | D | E | B | A | A | B | A | B | A | B | B | A |
| Ag Conservation-Transfer (Step 1) | D | A | A | B | C | C | A | B | A | A | B | A | D | C | B | C | A |
| Ag Conservation-Transfer (Step 2) | D | B | A | B | C | C | A | B | A | A | B | A | D | C | B | C | A |
| Ag Conservation-Transfer (Step 3) | D | C | A | B | C | C | A | B | A | A | B | A | D | C | B | C | A |
| Ag Conservation-Transfer (Step 4) | D | C | A | B | C | C | A | C | A | A | B | A | D | C | C | C | A |
| Ag Conservation-Transfer (Step 5) | D | C | A | B | C | C | A | C | A | A | B | A | D | C | C | C | A |

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