Agricultural Water Conservation in the Colorado River Basin: Alternatives to Permanent Fallowing Research Synthesis and Outreach Workshops

Part 1 of 5

Executive Summary

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December 2017

CWI Completion Report No.232
Acknowledgements

First, Greg Peterson and I thank the Walton Family Foundation for making this project possible. Without their funding and support, the project would not have happened.

Many people assisted with this project by reading and providing comments on drafts. We want to especially thank Perri Benemelis, Mike Bernardo, Perry Cabot, Aaron Citron, Michael Cohen, Bonnie Colby, Terry Fulp, Robert Glennon, Bill Hasencamp, Chuck Howe, Carly Jerla, Dave Kanzer, Doug Kenney, Kelsea MacIlroy, Jan Matusak, Sharon Megdal, Peter Nichols, Wade Noble, Michael Ottman, Ron Raynor, Adam Schempp, Tina Shields, MaryLou Smith, Pete Taylor, Reagan Waskom, John Wiener, and Scott Wilbor. Paul Kehmeier contributed a lovely photograph and important story. The final product was much improved by these insightful comments. It must be noted that any mistakes are solely mine.

Nancy Grice at the Colorado Water Institute provided critical support with financial reporting, travel assistance and working with Colorado State University. MaryLou Smith was instrumental in organizing and chairing the outreach workshops. Reagan Waskom provided much needed intellectual support throughout the project. Beth Lipscomb assisted with overall editing at the end. Finally, a very special thanks goes to my co-author, Greg Peterson, who did much of the early, difficult research and writing. Much of the value of this project is in the extensive bibliographies that Greg created by painstakingly acquiring, reading and summarizing hundreds of documents.

We thank Senator Michael Bennet and his staff for acquiring a room at the Capitol Visitor Center for the DC event. Finally, we extend our sincere appreciation to the approximately 100 participants who shared their precious time to join us for our outreach workshops. Thank you, all.

Brad Udall

This report was financed in part by the U.S. Department of the Interior, Geological Survey, through the Colorado Water Institute. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

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1 Project Overview

The Colorado River Basin has been under substantial stress since 2000. Growing cities, the Lower Basin’s Structural Deficit\(^1\), the ongoing, unprecedented 17-year-long drought, and recently recognized environmental flow needs are at the root of this stress. The high likelihood of long-term flow declines due to climate change is also forcing serious re-thinking of the long-term sustainability of the basin’s water demands and supplies. All of these issues were identified in the long-term supply-demand imbalance identified by Reclamation’s Basin Study in 2012 that projected a potential 3 million acre-feet/year gap by the year 2060. As increasing water scarcity occurs in the Colorado River Basin, water users looking for new sources of supply have focused on the largest water user in the basin, agriculture.

The default solution to many of these problems is to transfer water from the cheapest and most plentiful source — agriculture — to supply new water demands in the region. However, if pursued in haste, and without sufficient information, the likely outcome may be permanent fallowing, along with serious economic disruption to agricultural communities, loss of valuable farmland, loss of important amenity values, and a loss of a sense of place in many rural communities within the basin.

In 2015 the Colorado Water Institute undertook a Walton Family Foundation funded project entitled “Agricultural Water Conservation in the Colorado River Basin: Alternatives to Permanent Fallowing Research Synthesis and Outreach Workshops”. This project was undertaken to explore ways to minimize harm to agriculture if transfers occur. Four detailed synthesis reports of the four common methods used to temporarily transfer water from agriculture were produced by the project. The water saving methods covered by the reports are:

- Deficit irrigation of Alfalfa and other forages
- Rotational fallowing
- Crop switching
- Irrigation efficiency and water conservation

After the reports were drafted, three workshops were held, one in the Upper Basin located in Grand Junction, Colorado on November 4, 2016, one in the Lower Basin in Tucson, Arizona on March 29, 2017, and one in Washington, D.C. on May 16, 2017 to disseminate the findings. Over 100 people attended these workshops.

This document summarizes the most important findings from the individual reports on the four water saving options. Each report offers an up-to-date synthesis and analysis regarding the best-known and most promising methods of agricultural water savings along with case studies. The complete reports are available on the Colorado Water Institute’s website (http://cwi.colostate.edu/).

2 Deficit Irrigation Summary

Irrigation is generally designed to meet the full water requirements of crops. **Deficit irrigation** is the generic term for applying less water than the full needs of a crop; it can take many forms. It can be a

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\(^1\) The Structural Deficit is a 1.2 million acre-feet/year imbalance between the average flow into Lake Mead and the average flow out of Lake Mead. This imbalance drives Lake Mead lower by about 12 feet per year. It also serves to drive Lake Powell lower through complex rules that attempt to balance the contents of the two reservoirs.
planned, sophisticated strategy or an unplanned, natural consequence when water scarcity arises. Planned deficit irrigation is widely used with grapes to improve quality. Unplanned deficit irrigation occurs commonly on forage crops that depend on diversions from mountain streams as the runoff pulse declines in late summer.

2.1 Different Methods of Planned Deficit Irrigation

Regulated Deficit Irrigation (RDI) is the term used to apply less water than needed during less critical life stages, with the general goal of improving the quality of the crop. RDI is practiced widely on certain crops like fruit and nut trees.

Another planned deficit irrigation strategy is used with perennial hay crops, especially alfalfa. By completely ceasing water application for part of the year, some perennial crops can be forced to enter dormancy and thus survive a lack of water. This method has been most consistently called “split season” deficit irrigation.

2.2 Why Alfalfa and Deficit Irrigation?

Alfalfa, because of its large consumptive use relative to other crops, its extensive acreage in both the Lower and Upper Basins, and its ability to go dormant when water is removed, is an obvious candidate for saving water through deficit irrigation. Although it is also possible to partially irrigate alfalfa throughout the growing season, split season irrigation results in higher relative yields, better quality, and lower labor than other forms of deficit irrigation, and thus has been the focus of almost all deficit irrigation studies.

2.3 Alfalfa’s Importance in the Colorado River Basin

Alfalfa, when combined with all hays, is the nation’s third largest crop by production value. It is very commonly grown in the West, where nearly 40% of the nation’s alfalfa hay is produced from 11 western states. Because it is an animal food, it is sometimes called the “corn and soybeans” of the West. It is a major crop in each of the Colorado River Basin states and is 28% of the total acreage in the basin in these states. In most years, it makes up more acreage than any other crop in the Imperial and Palo Verde Valleys of California. Alfalfa is an important crop in a rotation because it is a nitrogen-fixing legume.

2.4 Critical Alfalfa Facts

Alfalfa yields range from under two tons per acre in the high mountain valleys of Colorado and Wyoming where only one cut is done, to over 10 tons per acre with 10 cuts per year in the low deserts of the Colorado River Basin. Harvesting and field drying is the one area where alfalfa has elevated risk for the grower because for storage, the hay must be dry. The plants last for several years in the field, especially if a dense stand with little room for weeds is established. Few pesticides and herbicides are used. The soil is left unplowed several years, for a positive effect on soil health. Alfalfa fixes nitrogen and thus the crop rarely needs nitrogen and it also provides nitrogen for the next crop. Because alfalfa fields are left undisturbed for years, they have significant wildlife benefits not present with annual row crops. Alfalfa is very easy to grow. It is adaptable to different climates from sweltering deserts to the highest mountain valleys, and can be planted at different times of the year.
Alfalfa is a cool season crop, meaning it is optimized to grow in the colder parts of the year. The spring and fall generate the highest yields, and the highest nutritional content. In Arizona, the term “summer slump” historically was used to mean the period in July and August when alfalfa generated little yield while using lots of water. In the 1960s before laser leveling, it was common to deficit irrigate during this period to save water (“summer dry down”), and to avoid root scalding from water ponding in fields when temperatures are above 100 degrees Fahrenheit.

2.5 Alfalfa’s Important Ties to the Beef and Dairy Industries

Alfalfa is a critical input to the beef and dairy industries. Since 1970, the dairy industry in the West has grown enormously, and alfalfa production has commensurately increased. The number of dairy cattle has increased significantly in California, central Arizona, southeastern New Mexico, and the Front Range of Colorado. In California, alfalfa is a $1B/year crop feeding a $5B/year dairy industry, the largest agricultural sector in the state. California is now the number one dairy state, while New Mexico (#9), Arizona (#13), Colorado (#15), and Utah (#21) are also key national dairy producers. Alfalfa is grown where it is used because it is bulky and hence has a relatively high cost of transportation. It provides significant nutritional advantages compared to other forages with its high protein content.

2.6 Alfalfa Deficit Irrigation Studies

There have been numerous studies on deficit irrigation of alfalfa dating to the 1960s. Alfalfa has a natural ability to go dormant when water is reduced or cut off. Stand loss, the loss of some of the plants, has occurred in a few studies. Stand loss is especially related to sandy soils with little water holding capacity, and lengthy deficit irrigation periods during very high temperatures. In general, yield returns quickly once irrigation resumes and the hay quality does not appear to be affected. Deeper soils are generally better when water is cut off as they hold more water. Alfalfa’s deep taproot can often obtain at least some water to keep the plant alive with deep soils.

2.7 Deficit Irrigation of Pasture

Irrigated pasture makes up approximately 15% of all irrigated lands in the 11 Western states. There is very little research on deficit irrigation of the grasses present in these pastures. Cow-calf operators are highly dependent on this resource. Grasses can also go dormant, but have much shallower root systems and are thus unable to tap deep moisture like alfalfa.

2.8 Case Studies

There are several recent case studies on deficit irrigation in the Colorado River Basin. The Colorado Water Trust has been pursuing its use in southwestern Colorado. The Colorado Compact Water Bank workgroup has been studying this issue as a way of saving water for post compact water rights in the event of an Upper Basin “compact call”. Additionally, the recent Colorado River System Conservation Pilot Program has utilized deficit irrigation in the Upper and Lower Basins. Colorado State University has

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2 The Colorado River Compact contains a provision stating that the Upper Basin shall not deplete the flows of the river below 75 million acre-feet every ten running years. Were this to occur, the Upper Basin would have to reduce consumption and this reduction has been likened to an in-state river “call”. In a river call, diversions from junior users are reduced in order to supply water to more senior users. Upper Basin “post compact” water rights – those with priority dates after the compact – would in theory be subject to curtailment under this “compact call” scenario.
studied this issue in both the Colorado’s Arkansas and South Platte Basins, and studies are ongoing in the Colorado River Basin.

3 Rotational Fallowing Summary

Rotational fallowing, also known as lease-fallowing, is the act of temporarily fallowing farm land to save water for other purposes. Rotational fallowing has been used for more than 25 years in the Colorado River Basin. Unlike some of the other methods of saving water, such as crop switching and deficit irrigation, temporary land fallowing is a proven, successful strategy for conserving significant amounts of water with a long history of on-the-ground projects in the Colorado River Basin. Although there can be significant issues with quantifying the actual water savings from fallowing, there is little doubt that fallowing does save water.

3.1 Negotiations are Complex

Leasing-fallowing negotiations often take a long time before finding a successful combination of price, land, water amounts, agreement length, and other terms. These agreements are three-party agreements with each party -- the buyer, the sellers, and the irrigation district – having distinct needs. The Metropolitan Water District of Southern California (MWD) – Palo Verde Irrigation District (PVID) agreement in 2004 was preceded by a two-year trial, nearly ten years earlier. Persistence has been key for the Colorado’s Lower Arkansas Valley Super Ditch3 which suffered several false starts but now has on-the-ground projects. Fallowing in the Imperial Irrigation District was part of the larger California Quantification Settlement Agreement in 2003. The agreements are unique to each area and cannot easily be replicated. Efforts generally require complex negotiations, multiple studies on environmental and tax consequences among others, and complicated legal documents to enact.

3.2 Impacts to Nearby Communities

Fallowing agreements need to consider the impact to nearby communities. Agricultural communities and irrigation districts have important economic ties and the impacts of fallowing go beyond the irrigation district and individual farmers. Local agricultural suppliers can suffer from decreased purchases of crop inputs and services, as well as the displacement of jobs associated with the fallowed fields. Other, broad third-party impacts are also in play, including decreased retail sales, sales taxes, and property taxes, which can negatively impact and harm the overall community. In some recent fallowing agreements, relatively large community funds provided by the purchaser have been a part of the arrangement to provide economic support and mitigation for displaced individuals and businesses.

3.3 Agronomic Advantages and Disadvantages of Rotational Fallowing

Rotational fallowing to conserve water should provide many of the benefits of traditional land fallowing for soil health, future yield increases and pest management. These benefits, however, have been much less studied than the water conservation savings, and remain mostly unquantified. Rotational fallowing could be part of a larger, purposeful crop rotation plan to provide these additional benefits, while producing income for a farmer from a fallowed field.

One negative soil impact seems clear. In areas with salty subsurface moisture, which includes most areas

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3 The term “Super Ditch” implies a single physical ditch. The program is, in fact, a joint effort of shareholders on multiple existing ditches in the region.
in the Colorado River Basin, capillary action can move subsurface salt to the soil surface during fallowing and hence a pre-planting leaching irrigation to remove these salts following the fallowing period is often necessary. This leaching water reduces the water savings from fallowing, to the extent that it was not otherwise needed.

3.4 Field Management Issues

All fallowing programs require that bare fields be managed to prevent weeds, avoid topsoil erosion, and control dust. Most agreements require the landowners to sign documents stating that they will perform this work at their cost, or else fallowing payments will be either reduced or withheld. Monitoring efforts need to make sure that the enrolled fields are actually fallowed, and that proper land management activities are undertaken.

3.5 Quantification of Water Savings

Quantifying the water savings of fallowing can be complicated. Several different approaches have been used. A generic, but difficult approach, would be to make assumptions about the exact crop that would have been grown, its expected yield (thus, total crop consumptive water use) reduced by precipitation supplied by nature. In small fallowing arrangements, a per-acre water savings has often been stipulated. In large irrigation districts with substantial acreage devoted to fallowing such as PVID, the difference in headgate diversions in fallowed years versus non-fallowed years, minus assumed return flows, can be used as an approximation.

In Colorado’s Arkansas River Basin, the State Engineer developed a spreadsheet-based tool to perform calculations on each enrolled tract to determine consumptive use, and the return flows needed to keep downriver users whole.

3.6 Case Studies

Rotational Fallowing was originally pursued by the Metropolitan Water District of Southern California in the Palo Verde Irrigation District in the early 1990s. This test case led to a 35-year agreement signed in 2004. Total fallowed acreage has ranged from 6500 to almost 40,000 acres with water savings ranging from 25,000 to almost 120,000 acre-feet per year. Metropolitan has more recently pursued a small test summer fallowing with the Bard Irrigation District near Yuma. As part of its agreement with the San Diego County Water Authority, since 2003 the Imperial Irrigation District has also been fallowing lands to provide mitigation flows into the Salton Sea with over 700,000 acre-feet generated for the Sea and another 700,000 acre-feet for municipal purposes. This fallowing ends in 2017, with further municipal deliveries to San Diego provided by efficiency improvements. In Colorado, the SuperDitch, a collection of ditches, has been created by farmers in the Arkansas River valley to provide income for farmers and water for cities. In 2004, the City of Aurora, Colorado successfully pursued fallowing in the Arkansas Basin in the midst of a severe drought to provide about 7500 acre-feet for emergency supplies. In 2005, Colorado Springs joined with Aurora to extend the agreement for an additional year. The extension was used to refill depleted reservoirs with about 10,000 acre-feet of water.

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4 The 2004 agreement only allows for a maximum of 26,000 fallowed acres. A later additional emergency fallowing agreement increased this amount by an additional 13,000 acres in one year.
4  Crop Switching Summary

Crop switching has been proposed as a way to save large amounts of water in the West, including the Colorado River Basin. While in theory this technique is appealing as a way to save water, numerous studies and publications have shown that crop switching is difficult to implement because there are many complicated and potentially expensive issues to resolve. For a farmer, crop switching implies modifying much of what they depend upon to generate income.

4.1  Calls for Crop Switching Often Ignore Larger Economic and Market Forces

Large economic and market forces encourage farmers to produce many traditional, water-intensive crops. These crops have an entire production and risk management system built around them.

4.2  The Lower Basin Has More Crop Switching Opportunities

For crop switching to work, the new crop must offer lower water usage, relative to the old crop. Unfortunately, the consumptive-use difference between crops in the Upper Colorado River Basin is often relatively small, because the Upper Basin has lower evapotranspiration due to cooler temperatures and a shorter growing season. This decreases the crop-switching advantages in the Upper Basin. A few locations in the Upper Basin, such as the Uncompahgre and Grand Valleys in Colorado, do have climates that allow for many different crops. There are more crop-switching options in the Lower Basin because the climate there allows for greater crop selection, and because the longer growing season increases the water-use difference between high- and low-consumptive-use crops.

4.3  Farm Level Concerns

Soils, irrigation systems, farm equipment, labor and risk management instruments are all farm-level issues that must be surmounted in order to switch crops. These are discussed below.

   a.  Climate and Soils Constrain Crop Selection.

In the West, alternative crops must be able to survive, and even thrive in extreme conditions, including aridity, wind, hail, maximum and minimum temperatures, and other unusual weather. Compared to alfalfa and other forage crops, vegetables and fruits are only suitable for certain soils, and are generally less resilient to weather extremes. The risks from insect pests, crop diseases, and weeds are often tied to soils and climate, and with new crops these risks are not well understood.


With a switch to vegetables, either a new source of water may be necessary, or investments may be needed to improve the quality of the water being used.

   c.  Water-Delivery Methods May Need to Change.

To shift crops to orchards and vineyards, a farmer may need to invest in micro-irrigation. Micro-irrigation and sprinklers require clean water and a pressurized delivery system.
d. **Crop Switching Can Reduce Drought Resiliency**

Perennial tree and vine crops, unfortunately, require consistent irrigation and cannot be fallowed or reduced in acreage in times of drought like forages. Switching to these crops can thus reduce resiliency when a drought occurs. This can impact the individual farmer as well as entire basins if large transitions to these crops occur. This has been the case in California with the large-scale switch to highly profitable nut trees.

e. **Farming is Very Specialized and New Knowledge May Be Necessary.**

In many headwater streams, ranching is the predominant activity, with irrigation used to grow grass forages. Even if the climate allowed it, asking ranchers to transition to growing crops is extremely unlikely and would represent a dramatic shift in their agronomic knowledge. Acquiring the knowledge and skills to grow a new crop requires a significant investment. There needs to be an effective network, including extension services, to disperse and share knowledge on any new crop.

f. **Significant On-Farm Investment May Be Needed for New Equipment and Inputs.**

Ideally, with crop switching farm investments would be minimal. Especially compared to alfalfa and other forages, the most common crops in the Colorado River Basin, most crops require more fertilizers, herbicides, pesticides, and/or other inputs, thus raising farm operating costs.

g. **Labor Needs May Change, Impacting Costs.**

Most high-value crops like lettuce require intensive labor, unlike forage crops. Production of labor-intensive crops in some parts of the basin may not be competitive due to the lower cost of labor in countries like Mexico. On the other hand, transitioning from an existing, labor-intensive crop can reduce rural labor demand, depress rural wages, and threaten agricultural households and communities.

h. **Financial Risk Management Mechanisms, Such as Insurance May Not Be Available.**

The supporting bank will want to know that the farmer has the necessary knowledge to plant, harvest, and market a crop. The ability to store the crop before shipment, if needed, may be important. Knowledge of how markets might affect the final price is necessary, as are hedging mechanisms for that price.

i. **Alfalfa, Often the Crop to Replace, Has Significant Benefits**

Alfalfa consistently has the highest consumptive use of any crop in the basin. For this reason, it is often a target for replacement. By switching out of alfalfa, however, farmers forego significant benefits. Alfalfa is planted once and lasts for several years, thereby reducing annual input costs. Pesticides and herbicides are often not used. As a nitrogen-fixing legume, it can be an important crop in a rotation, and it does not require nitrogen fertilization. It is relatively easy to grow, and is robust to varying weather and climate conditions. It is drought-tolerant.

Because humans do not consume it, alfalfa is less susceptible to quality concerns, although these can certainly affect its market price. It can be readily stored and sold later when prices are high. It has a widely available and growing market, thanks in part to the emergence of a strong dairy sector in the
West. Until recently, prices have been high. In short, farmers know how to grow this crop, it is relatively low risk, and it provides decent, reliable returns. Any other crop can look risky by comparison.

It seems unlikely that unknown non-forage niche crops will replace alfalfa, at least in the short term. A better strategy might be to replace one forage (alfalfa) with another, less water intensive forage, such as forage sorghum. This approach would affect the overall forage market less by providing a substitute crop. Were large declines to occur in alfalfa production, surely alfalfa prices would rise, thus encouraging more alfalfa production.

4.4 Broad Scale, Off-Farm Issues

There are also significantly larger economic, political, and business factors that can limit a farmer’s options of what to grow. Even though switching to low-water-use crops may conserve water, such a change may be economically unviable due to these off-farm issues.

a. Large Shifts in Output May Impact Prices, Farmers’ Incomes and Other Agricultural Sectors

One proposal to shift a significant amount of acreage from alfalfa to fresh tomatoes in California would likely have a dramatic effect on prices. Processing facilities and a market for the new crop need to exist. The market for vegetables and high-value crops can also be much more volatile, with more market fluctuations in price than traditional crops.

b. Politics and International Competition are Significant Factors in Crop Selection

There is also a competitive disadvantage for U.S. growers for produce that can be grown less expensively in other countries. Many areas in the Colorado River Basin are well-suited economically for alfalfa and forage production, but cannot compete with the low-cost production of certain crops in other countries, thus encouraging continuation of current cropping patterns

c. Subsidies May Constrain Changes in Crop Production

Cotton, a crop with high consumptive water use, has been supported by federal subsidies. These subsidies encourage production and discourage switches to alternative crops.

d. An Entire Supporting Infrastructure Often Has to Be Built Around New Alternative Crops.

This new business infrastructure includes seed and fertilizer supplies, marketing and distribution networks, and even processing and storage facilities. Plus, processing a crop often requires a certain amount of crop to justify the investment in processing and storage facilities.

e. Water Law Disincentives

In most Western states, there are strong water law disincentives against switching crops to save water. The key disincentive is the loss of historical crop consumptive use when switching to a crop that uses less water. When selling a water right, an historical consumptive-use analysis, based on the actual crops grown, determines how much water can be transferred. Only this historical consumptive use can be sold, not the far larger decreed headgate diversion amount. This, unfortunately, provides a strong incentive for growing crops with large consumptive water use.
Colorado farmers know that alfalfa uses lots of water, and they believe that growing it will preserve their water rights and maximize their return in a future sale. If a farmer wanted to monetize the water savings from crop switching, the savings would need to legally quantified and transferred at the time of the switch, not later when lower consumptive use numbers would apply. Finally, a farmer’s water rights are his or her most valuable asset, and selling these assets are often the only retirement plan the farmer has; this fact further encourages maximum use.

4.5 Case Studies

There are very few cases of switching crops to save water. The Walker River Basin in Wyoming is one case, although this example was funded by the federal government in an unusual experiment. There are many cases of crop switching encouraged by market forces. Avocados took decades to become a mainstream crop. Nuts, on the other hand, became a very large and valuable crop in California in about two decades. Both provide interesting lessons. Since the mid-1970s, growers in the Yuma area have switched from citrus, cotton and other crops into more sophisticated multi-cropping oriented around very profitable winter vegetables, saving about 250,000 acre-feet per year. Some of the Yuma savings also arise from irrigation efficiency improvements.

5 Irrigation Efficiency and Water Conservation Summary

Two related ideas, irrigation efficiency and water conservation, can be used to obtain water from agriculture for other purposes. These concepts are related, because improving irrigation efficiency and improving water conservation can both lead to reductions in water use. The two terms as defined herein, however, deal with distinctly different kinds of reductions in water use. Each concept has different physical and legal ramifications, especially in terms of how they affect other uses and users. Both concepts can potentially provide water for municipal or environmental purposes from agriculture.

5.1 Key Definitions

Consumptive use is defined as liquid water that has been converted to water vapor, by either evaporation or plant transpiration. It is therefore no longer available for use. In some limited cases, water can also be considered “consumed” if liquid fresh water flows to a salty water body. This also makes it unavailable for crop and most human uses. It is still available for environmental purposes, however. Water that is diverted but not consumptively used becomes return flows, liquid water that returns either immediately to the stream as surface runoff, or as delayed groundwater. Return flows are heavily relied upon by downstream diverters in the West. In many basins in the West, the total diversions vastly exceed the total flows in the river, which provides strong evidence for how important return flows are.

Improving irrigation efficiency refers to the act of saving non-consumptive-use water, sometimes called “saved water.” This might typically occur by reducing ditch conveyance losses, which would allow for smaller headgate diversions for the same volume of water reaching the field at the end of the ditch.

Water conservation, by contrast, is the act of saving consumptive-use water. Water conservation is further broken into two types. Savings from reducing non-productive consumptive use such as occurs by phreatophytes is called ‘salvage water’ under Colorado law. It might have different names in other states. This water in most states is not legally transferrable and thus there is little incentive to reduce this use. In addition, the generation of salvage water can impact amenity values including mature trees.
on ditches. By contrast, **conserved consumptive use water** comes from reductions from crop consumptive use or ancillary consumptive use necessary to get water to crops such as evaporation from canals. This water is generally legally transferrable.

In general, greater quantities of **saved water** can be created than water saved from reducing **consumptive use**, in large part because in flood irrigation, the most common form, 50% of the diverted water is not consumed and becomes return flows. A farmer can generate significant saved water without affecting consumptive use, a key driver of crop yields. On the other hand, reducing conserved consumptive use leads to crop yield reductions and therefore has economic impacts. Reducing consumptive use affects fewer water users because this water was already used, and not available for reallocation via return flows.

### 5.2 Understanding Irrigation Efficiency

The term “**irrigation efficiency**” is most commonly defined as a percentage:

\[
\text{Irrigation Efficiency} = \frac{\text{Crop Consumptive Use}}{\text{Total Stream Diversions}}
\]

This definition leads to misunderstandings because in most engineering fields, efficiencies of less than 100% imply a loss or waste, such as wasted heat in energy applications. In water, however, the loss or “waste” is still liquid water that will ultimately be recycled as a return flow at some point in space and time. Return flows are highly valuable, and should not be considered “waste.”

### 5.3 Critical Nature of Return Flows

Return flows provide water supplies for many downstream users and thus are important in many river basins in the West. Farms using flood irrigation are often only 50% efficient, meaning that 50% of their diversions return to the river for recycling. Because of recycling, “stacked” farms that rely on irrigation return flows can obtain high collective efficiencies, a feature sometimes known as the “basin approach.” Sprinklers and drip can reach 80 to 90% efficiency with commensurate reductions in return flows.

A water mass balance, which is merely the application of the law of conservation of mass\(^5\) to a suitably large geography and time period to account for all the consumed and non-consumed flows of water (both liquid and vapor), can help to understand how water is being used. Mass balances can indicate the importance of return flows, among other purposes. Sometimes, return flows can “stack” in the basin, helping to achieve high efficiency. Sometimes, even with a low efficiency, a high return flow rate can be achieved.

There is a vigorous debate over whether return flows are good or bad — and implicitly, whether efficiency improvements (which almost always change return flows) are good or bad. The answer depends on the soil, runoff contaminants, if any, water temperatures, changes to the natural hydrograph, local geography, the location, and priorities of other diverters, and even the values of the observer. When return flows change, there are often winners and losers, including nature, which also influences the answers to this question.

---

\(^5\) The law of conservation of mass says that matter can neither be created nor destroyed. It is a fundamental tool used in almost all engineering and physics studies.
5.4 On-farm vs. District-Wide Efforts to Improve Efficiency

Irrigation efficiency improvements can be broken into on-farm and district-wide efforts. On-farm efforts include increasing the delivery efficiency from headgate to field by lining or piping canals and increasing the field application efficiency, defined as the amount of water consumed by crops divided by the total amount applied to the field. Field application efficiencies can be increased by laser leveling, tailwater recovery (capturing water at the end of the field and reusing it), and installing sprinklers, or drip and other methods. Irrigation scheduling can increase efficiency by only applying water when it is needed, which can reduce unnecessary soil evaporation.

District-wide efficiency measures include similar actions to on-farm measures but done on a larger scale, such as canal lining. With large systems involving tens of miles of canals and many hours of water travel times, keeping canals full, especially near the end of the canal after many laterals have withdrawn water, has historically been challenging. Operators would often rather spill water from the tail end of the canal than run short, which has meant that the river segment between the headgate and the tail end of the canal has had less water than it might. Computerized canal check structures -- small movable, vertical dam-like structures within a canal -- can keep canals full when they have less water, while reducing spills at the end of the canal. Small operational reservoirs, often near the end of a lengthy canal, can capture and allow reuse in the difficult-to-serve lower canal reaches.

5.5 Co-Benefits of Increasing Irrigation Efficiency

Co-benefits of irrigation efficiency improvements that reduce diversions are important. These benefits include increased water quality due to reductions in saline or chemical-laden farm runoff, less groundwater pumping in groundwater dependent systems, and higher reliability of diversions due to the need for less carriage water. Increased efficiencies can increase productivity, yields, and economic gain. In the 21st century these improvements can be as important as considerations of total water quantity, which has heretofore dominated water supply conversations.

Many irrigation systems are decades old, and in need of infrastructure maintenance and improvements. Efficiency improvements generally provide modern automated management, which reduces labor and increases flexibility. This is another co-benefit.

5.6 Increased Consumptive Use From Improved Irrigation Efficiency

Improving irrigation efficiency often has the paradoxical effect of increasing consumptive use. This has been known for many years and proven in many field-level and modeling studies, yet it is frequently misunderstood by the public. Technologies that improve field application efficiency apply water more uniformly in space, and often remove a time and labor constraint associated with flood irrigation. By flipping a switch, crops on sprinklers or drip can receive water whenever needed, not just on a set schedule dictated by canal capacity and/or labor. Many farm operations are constrained by delivery capacities (i.e., are “water-short”); improvements allow more diverted water to be applied to the crop rather than lost as a return flow. In these water short systems, yields and consumptive use can go up because more of the diverted water makes it to the crops that were previously unintentionally deficit irrigated. Increased consumptive use thus means fewer return flows for use by downstream diverters.

Improved irrigation efficiency is often portrayed as leaving more water in the stream, downstream of the headgate of the improver. While this is one outcome, others are possible. The efficiency improvement can lead to the same diversions, more consumptive use, and less return flow as described
above. Under another scenario, if the saved water is not diverted, under prior appropriation the next-in-line diverter may be upstream, not downstream. In this case, there will be a reduction in flow from the next-in-line diverter’s headgate down to the headgate of the diverter installing the efficiency improvement. This is a paradoxical outcome that is rarely mentioned, and one that is not often envisioned by the promoters of irrigation efficiency.

5.7 Water Conservation Opportunities

Water conservation measures include reducing non-beneficial consumptive use, reducing crop and non-crop transpiration, reducing runoff into saline water bodies, and utilizing rainfall more effectively. Several studies suggest that savings from reducing non-beneficial evaporation from soil can be from 20 to 40%. Reducing other forms of non-beneficial evaporation such as phreatophyte removal may harm amenity values associated with trees and other vegetation. Reducing crop transpiration will reduce yields. Reducing weeds can provide additional water.

Reducing runoff to saline water bodies is a different kind of consumptive use reduction. Most consumptive use occurs when liquid water is evaporated or transpired to water vapor. This method, however, involves stopping fresh liquid water from being converted to unusable saline water. In arid areas throughout the world, saline water bodies can support important biological activities and thus this kind of consumptive use reduction impairs the environmental values of the saline body. Mono Lake, Owens Lake and the Salton Sea are three examples in the Western United States and there are many elsewhere around the world. There is little opportunity for more effective rainfall utilization in the West as rainfall provides only a small portion of crop water needs in many of the most important irrigation areas.

Some projects that have focused on salinity control such as canal lining efforts are also irrigation efficiency projects. While these improvements can lead to higher consumptive use, they also improve the quality of agricultural runoff and hence enhance stream water quality for downstream users.

If changes in return flows are a concern, one solution is to make efficiency improvements at the end of a river first, and then work up-river. This approach minimizes return flow impacts to downstream diverters, while potentially improving instream flows and water quality downstream of the improvements, provided that saved flows can be “shepherded” downstream rather than being taken by upstream next-in-line diverters.

5.8 Case Studies

There are many cases of irrigation efficiency improvement projects in the West. The Metropolitan Water District on Southern California has an on-going program at the Imperial Irrigation District to save approximately 100,000 acre-feet of water every year. The Yuma area in Arizona has used about 250,000 less acre-feet per year, in part due to different crops and in part due to sprinklers, high flow turnouts, laser leveling and other efficiency methods. In Colorado, one large irrigation district near Grand Junction saved nearly 40,000 acre-feet per year in some years by lining canals, automating gates, installing check structures, and using a reservoir near the end of a long canal with no loss of agricultural output.
Agricultural Water Conservation in the Colorado River Basin: Alternatives to Permanent Fallowing Research Synthesis and Outreach Workshops

Part 2 of 5

Deficit Irrigation of Alfalfa and Other Forages in the Colorado River Basin: A Literature Review and Case Studies

Brad Udall
Greg Peterson

Colorado Water Institute
Colorado State University

December 2017

CWI Completion Report No.232
Acknowledgements

This report was financed in part by the U.S. Department of the Interior, Geological Survey, through the Colorado Water Institute. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

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Project Background

This document is one of four separate reports created under a grant from the Walton Family Foundation to investigate ways to minimize harm to agriculture as water scarcity in the Colorado River Basin forces growing municipal and environmental water users to look at existing uses as potential sources of supply. Agriculture, the largest water user in the basin, is a frequent target in these efforts. The project, “Agricultural Water Conservation in the Colorado River Basin: Alternatives to Permanent Fallowing Research Synthesis and Outreach Workshops” was undertaken to create detailed reports of the four common methods used to temporarily transfer water from agriculture to other purposes. The four reports consider the following methods:

- Deficit Irrigation of Alfalfa and other Forages
- Rotational Fallowing
- Crop Switching
- Irrigation Efficiency and Water Conservation

After the reports were drafted, three workshops were held, one in the Upper Basin in Grand Junction on November 4, 2016, one in the Lower Basin in Tucson on March 29, 2017, and one in Washington, DC on May 16, 2017. All of the reports are available from the Colorado Water Institute website.

Acknowledgements

First, Greg Peterson and I thank the Walton Family Foundation for making this project possible. Without their funding and support, the project would not have happened.

Many people assisted with this project by reading and providing comments on drafts. We want to especially thank Perri Benemelis, Mike Bernardo, Perry Cabot, Aaron Citron, Michael Cohen, Bonnie Colby, Terry Fulp, Robert Glennon, Bill Hasencamp, Chuck Howe, Carly Jerla, Dave Kanzer, Doug Kenney, Kelsea MacIlroy, Jan Matusak, Sharon Megdal, Peter Nichols, Wade Noble, Michael Ottman, Ron Raynor, Adam Schempp, Tina Shields, MaryLou Smith, Pete Taylor, Reagan Waskom, John Wiener, and Scott Wilbor. Paul Kehmeier contributed a lovely photograph and important story. The final product was much improved by these insightful comments. It must be noted that any mistakes are solely mine.

Nancy Grice at the Colorado Water Institute provided critical support with financial reporting, travel assistance and working with Colorado State University. MaryLou Smith was instrumental in organizing and chairing the outreach workshops. Reagan Waskom provided much needed intellectual support throughout the project. Beth Lipscomb assisted with overall editing at the end. Finally, a very special thanks goes to my co-author, Greg Peterson, who did much of the early, difficult research and writing. Much of the value of this project is in the extensive bibliographies that Greg created by painstakingly acquiring, reading and summarizing hundreds of documents.

We thank Senator Michael Bennet and his staff for acquiring a room at the Capitol Visitor Center for the DC event. Finally, we extend our sincere appreciation to the approximately 100 participants who shared their precious time to join us for our outreach workshops. Thank you, all.

Brad Udall
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1 Summary

Irrigation is generally designed to meet the full water requirements of crops. *Deficit irrigation* is the generic term for applying less water than the full needs of a crop; it can take many forms. It can be a planned, sophisticated strategy or an unplanned, natural consequence when water scarcity arises. Planned deficit irrigation is widely used with grapes, to improve quality. Unplanned deficit irrigation occurs commonly on forage crops that depend on diversions from mountain streams as the runoff pulse declines in late summer.

1.1 Different Methods of Planned Deficit Irrigation

*Regulated Deficit Irrigation (RDI)* is the term used to apply less water than needed during less critical life stages, with the general goal of improving the quality of the crop. RDI is practiced widely on certain crops like fruit and nut trees.

Another planned deficit irrigation strategy is used with perennial hay crops, especially alfalfa. By completely ceasing water application for part of the year, some perennial crops can be forced to enter dormancy and thus survive a lack of water. This method has been most consistently called “split season” deficit irrigation.

1.2 Why Alfalfa and Deficit Irrigation?

Alfalfa, because of its large consumptive use relative to other crops, its extensive acreage in both the Lower and Upper Basins, and its ability to go dormant when water is removed, is an obvious candidate for saving water through deficit irrigation. Although it is also possible to partially irrigate alfalfa throughout the growing season, split season irrigation results in higher relative yields, better quality, and lower labor than other forms of deficit irrigation, and thus has been the focus of almost all deficit irrigation studies.

1.3 Alfalfa’s Importance in the Colorado River Basin

Alfalfa, when combined with all hays, is the nation’s third largest crop by production value. It is very commonly grown in the West where nearly 40% of the nation’s alfalfa hay is produced from 11 western states. Because it is an animal food, it is sometimes called the “corn and soybeans” of the West. It is a major crop in each of the Colorado River Basin states and is 28% of the total acreage in the basin in these states. In most years, it makes up more acreage than any other crop in the Imperial and Palo Verde Valleys of California. Alfalfa is an important crop in a rotation because it is a nitrogen-fixing legume.

1.4 Critical Alfalfa Facts

Alfalfa yields range from under two tons per acre in the high mountain valleys of Colorado and Wyoming where only one cut is done, to over 10 tons per acre with 10 cuts per year in the low deserts of the Colorado River Basin. Harvesting and field drying is the one area where alfalfa has elevated risk for the grower because for storage the hay must be dry. The plants last for several years in the field, especially if a dense stand with little room for weeds is established. Few pesticides and herbicides are used. The soil is left unplowed several years, for a positive effect on soil health. Alfalfa fixes nitrogen and thus the
crop rarely needs nitrogen and it also provides nitrogen for the next crop. Because alfalfa fields are left undisturbed for years, they have significant wildlife benefits not present with annual row crops. Alfalfa is very easy to grow. It is adaptable to different climates from sweltering deserts to the highest mountain valleys, and can be planted at different times of the year.

Alfalfa is a cool season crop, meaning it is optimized to growing in the colder parts of the year. The spring and fall generate the highest yields, and the highest nutritional content. In Arizona, the term “summer slump” historically was used to mean the period in July and August when alfalfa generated little yield while using lots of water. In the 1960s before laser leveling, it was common to deficit irrigate during this period to save water ("summer dry down"), and to avoid root scalding from water ponding in fields when temperatures are above 100 F.

### 1.5 Alfalfa’s Important Ties to the Beef and Dairy Industries

Alfalfa is a critical input to the beef and dairy industries. Since 1970, the dairy industry in the West has grown enormously, and alfalfa production has commensurately increased. The number of dairy cattle has increased significantly in California, central Arizona, southeastern New Mexico, and the Front Range of Colorado. In California, alfalfa is a $1B/year crop feeding a $5B/year dairy industry, the largest agricultural sector in the state. California is now the #1 dairy state, while New Mexico (#9), Arizona (#13), Colorado (#15), and Utah (#21) are also key national dairy producers. Alfalfa is grown near where it is used because it is bulky and hence has a relatively high cost of transportation. It provides significant nutritional advantages compared to other forages with its high protein content.

### 1.6 Alfalfa Deficit Irrigation Studies

There have been numerous studies on deficit irrigation of alfalfa dating to the 1960s. Alfalfa has a natural ability to go dormant when water is reduced or cut off. Stand loss, the loss of some of the plants, has occurred in a few studies. Stand loss is especially related to sandy soils with little water holding capacity, and lengthy deficit irrigation periods during very high temperatures. In general, yield returns quickly once irrigation resumes and the hay quality does not appear to be affected. Deeper soils are generally better when water is cut off as they hold more water. Alfalfa’s deep taproot can often obtain at least some water to keep the plant alive with deep soils.

### 1.7 Deficit Irrigation of Pasture

Irrigated pasture makes up approximately 15% of all irrigated lands in the 11 Western states. There is very little research on deficit irrigation of the grasses present in these pastures. Cow-calf operators are highly dependent on this resource. Grasses can also go dormant, but have much shallower root systems and are thus unable to tap deep moisture like alfalfa.

### 1.8 Case Studies on Deficit Irrigation

There are several recent case studies on deficit irrigation in the Colorado River Basin. The Colorado Water Trust has been pursuing its use in Southwestern Colorado. The Colorado Compact Water Bank workgroup has been studying this issue as a way of saving water for post compact water rights in the
event of an Upper Basin “compact call”\(^1\). Additionally, the recent Colorado River System Conservation Pilot Program has utilized deficit irrigation in the Upper and Lower Basins. Colorado State University has studied this issue in both the Colorado’s Arkansas and South Platte Basins, and studies are ongoing in the Colorado River Basin.

2 Introduction

Irrigation is generally designed to meet the full water requirements of crops\(^2\). Irrigators, however, may under-irrigate crops when water is scarce, or over-irrigate when water is plentiful or inexpensive. Deficit irrigation is the generic term for applying less water than the full needs of a crop and can take many forms. It can be a planned, sophisticated strategy or an unplanned fact of life when water scarcity arises. Planned deficit irrigation is widely used with grapes to improve quality. Unplanned deficit irrigation occurs widely on hay crops that depend on diversions from mountain streams as the runoff pulse declines in late summer. Planned deficit irrigation has made it possible for many farmers around the world to increase water productivity and profits (Elias Fereres & Soriano, 2007; Geerts & Raes, 2009).

Depending if land or water is limited, deficit irrigation can increase profits depending on the price of crops and water (Marshall English & Raja, 1996). Deficit irrigation has been investigated because economists have long known that maximizing crop yield is not the same as maximizing profits. Applying less water could result in financial savings on labor, water, and other inputs, assuming that there is a charge for water. In theory, a farmer could increase profits by optimizing the use of all of these inputs (M. English, 1990). In recent years, deficit irrigation has been studied because of water scarcity issues, not profit maximization (E. Fereres & Soriano, 2006; R. B. Lindenmayer, Hansen, Brummer, & Pritchett, 2011a; Pritchett, Thorvaldson, & Frasier, 2008).

There are different methods of planned deficit irrigation. Regulated Deficit Irrigation (RDI) is the term used to apply less water than needed during less critical life stages with the general goal of improving the quality of the crop. RDI is practiced widely on certain crops like fruit and nut trees including almond, peaches, pistachio, citrus, apple, apricot, wine grapes, and olives. RDI can also be used to save water with the goal of not damaging the yield or crop quality. Different plants have different tolerances for reductions in water depending on their life cycle.

Another planned deficit irrigation strategy is used with perennial hay crops, especially alfalfa. By completely ceasing water application for part of the year, some perennial crops can be forced to enter dormancy and water can be saved. This method has been most consistently called split season irrigation

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\(^1\) The Colorado River Compact contains a provision stating that the Upper Basin shall not deplete the flows of the river below 75 million acre-feet every ten running years. Were this to occur, the Upper Basin would have to reduce consumption and this reduction has been likened to an in-state river “call”. In a river call, diversions from junior users are reduced in order to supply water to more senior users. Upper Basin “post compact” water rights – those with priority dates after the compact – would in theory be subject to curtailment under this “compact call” scenario.

\(^2\) Agronomists define full irrigation as “when irrigation water is applied to completely meet crop water demand or evapotranspiration (ET) that is not supplied by natural precipitation and soil water storage”.


although other names have been used as well\textsuperscript{3}. Although it is also possible to partially irrigate alfalfa throughout the growing season, split season irrigation results in higher relative yields and better quality than partial irrigation the entire season and thus is the focus of this chapter. Most studies of deficit irrigation for alfalfa have promoted split season irrigation for these very reasons. (S. Orloff, Putnam, Hansen, & Carlson, 2014).

Despite RDI’s success with crops like grapes, the real opportunity in the Colorado River Basin to utilize deficit irrigation to save water is with alfalfa, because of its large water consumption, its widespread cultivation, and its ability to tolerate water reductions. Deficit irrigation of alfalfa is currently being used in Reclamation’s System Conservation Pilot Projects (see Carpenter Ranch Case Study below) and is also a key feature of Colorado’s Compact Water Bank studies. Deficit irrigation of alfalfa may be a helpful tool to address potential compact curtailments in the Upper Basin and the structural deficit in the Lower Basin. Deficit irrigation generally limits the amount of biomass production, thus reducing the yield of forage crops like alfalfa and hence farmer profits (S. Orloff, Putnam, et al., 2014). Thus, any plan to utilize deficit irrigation with alfalfa would have to compensate growers for lost profits.

Even though deficit irrigation has not yet been used on a wide scale to conserve water, there is considerable research on the topic that could prove invaluable. Research conducted in the basin states over the last 50 years shows that deficit irrigation is a viable option although there are numerous hurdles to its successful widespread implementation\textsuperscript{4}. This chapter surveys the current research and issues related to DI, especially concerning its use with alfalfa. The chapter concludes with three cases of actual deficit irrigation in the Basin.

### 3 Alfalfa Overview and Deficit Irrigation

Alfalfa is a major cash crop in every western state and the nation’s fourth largest crop commodity (Putnam et al., 2000). In 2014, alfalfa made up almost 80 percent of crop value of production of all hay crops. Alfalfa by itself is only behind corn, soybeans, and wheat in total value of U.S. production (USDA Crop Summary, 2015). Nationally, there are 23 million acres of the crop. Combined with all other hay crops, it is the third highest crop in value after corn and soybeans, a position it has held for years (NASS, 2016).

Alfalfa is the Western equivalent of corn and soybeans. Its widespread production in the United States, and especially in the West, reflects the preferences of American consumers to eat beef and dairy products. It grows in many regions and climates. Deficit irrigation of alfalfa provides opportunity for

\textsuperscript{3} Some of these terms are summer fallow, partial-season irrigation, early irrigation, summer dry-down, or even “cold turkey cutoff”.

\textsuperscript{4} This chapter is concerned with agronomic issues of deficit irrigation. There are also significant legal hurdles associated with the use of deficit irrigation to move saved water to another user. In both the Upper and Lower Basins, for example, the doctrine of prior appropriation means that water not used is legally available to the next in priority diverter. Legal methods to ‘shepherd’ the water saved from deficit irrigation to its intended target use around potential next in priority diverters (who can be located upstream as well as downstream) would be needed for deficit irrigation to be a success. Although critical, these are not a focus of this document.
significant water savings because of its widespread cultivation, because of its significant water use, and because of the drought tolerance of the plant.

3.1 History

Alfalfa originated in the Middle East more than 4000 years ago. The name is said to mean “best horse fodder.” From the Middle East, it spread to Greece and other Mediterranean locations. In Europe it was named “lucerne” and that name is currently still used in many counties (Putnam, Summers, & Orloff, 2007). Within the U.S. it first appeared in Georgia in 1736 but these early efforts in the East were mostly unsuccessful. Alfalfa was likely brought to California from Chile during the Gold Rush (1849-1852) at a time when everything was animal-powered and cattle were the focus of western ranching. With irrigation, it thrived in the hot and dry climate of California, and it had a ready local market for high-quality forages. Unlike other California crops that had to be shipped far away, it was sold as a cash crop locally used (Putnam et al., 2000). From California, it spread east to other Western states where it also grew well. Its movement from West to East in the United States is highly unusual for a crop.

![Figure 1: Locations where alfalfa is grown in the United States. Source: NASS (2012).](image)
3.2 Alfalfa Agronomic Studies

There are hundreds of studies and even complete books on alfalfa production dating back to the early 1900s (Coburn, 1908; S. B. Orloff, Carlson, & Teuber, 1997; Peterson, 1972; Stanberry, 1955; Summers, Charles G. & Putnam, Dan, 2007; Undersander, Dan J. et al., 2000; Wing, 1909). Researchers from agricultural colleges and the USDA Agricultural Research Service have analyzed all aspects of its production including water consumption, yield, quality, differences among cultivars, irrigation practices, drought tolerance and many other plant characteristics throughout the United States, including the Northeast and Southeast. Most of these studies, however, have taken place in western states where alfalfa thrives like Nebraska, Texas, Colorado, Nevada, Oregon, Arizona, and especially California. Alfalfa is widely grown throughout the world and studies have also been conducted in Lebanon, Israel, Cyprus, and Spain among other international locations.

Considerable knowledge on alfalfa has come from state extension services and unpublished conference papers although there are also numerous peer-reviewed papers. Since 1971, the California Alfalfa and Forage Symposium (now the Western Alfalfa & Grains Symposium) has produced a multitude of reports on alfalfa that range from deficit irrigation to nutritional quality to the economic impact of alfalfa production (“Alfalfa Symposium Proceedings,” 2016). Most Extension Services have multiple publications to assist growers (“Alfalfa Symposium Proceedings,” 2016; S. B. Orloff et al., 1997; Summers, Charles G. & Putnam, Dan, 2007; Undersander, Dan J. et al., 2000). A list of the studies surveyed in this effort is included as an appendix to this chapter. In recent years, due to drought and competition for water, many of these studies have focused on deficit irrigation field trials as a way of saving water. Most of these field trials provide support to the idea that split season deficit irrigation can save water and can be done without long-term harm to the crop, with some caveats pertaining to groundwater use, overly long termination, and suitable soils (T. Bauder, Hansen, Lindenmeyer, Bauder, & Brummer, n.d.; Frate & Roberts, 1988a; Hansen, 2008; B. Lindenmayer, Hansen, Crookston, Brummer, & Jha, 2008a; R. B. Lindenmayer et al., 2011a; S. B. Orloff, Putnam, Hanson, & Carlson, 2003).

3.3 Alfalfa Acreage and Production Value

Alfalfa’s total acreage and economic relationship with western livestock and dairy industries makes alfalfa one of the most important crops in the West. Nearly 40 percent of the nation’s alfalfa hay is produced in the 11 western states (Putnam et al., 2001). There are many other crops grown in the West, but none are produced on the same scale and with the same geographic range. In the West, alfalfa acreage is greatest in Montana, followed by Idaho, California, and Colorado. However, total production is greatest in California due to higher yields, where more than 80 percent of the hay is grown in areas that have 7-10 harvests (“cuttings”) a year (Putnam et al., 2000).

Areas that often have wet soil with high humidity show significant declines in alfalfa productivity. Diseases of the root and crown occur under excessively wet conditions (S. B. Orloff et al., 1997). The arid climate in the western United States is thus ideal for production.
Table 1: Forage and alfalfa acreage (1000s) in the Colorado River Basin. Source: Cohen et al. (2013).

<table>
<thead>
<tr>
<th></th>
<th>Total All Crops Harvested Acreage</th>
<th>Forage Harvested Acreage (includes alfalfa)</th>
<th>Forage Acreage as % of Total Harvested Acreage</th>
<th>Total Alfalfa Harvested Acreage</th>
<th>Alfalfa Acreage as % of Total Harvested Acreage</th>
</tr>
</thead>
<tbody>
<tr>
<td>AZ</td>
<td>754</td>
<td>307</td>
<td>41%</td>
<td>257</td>
<td>34%</td>
</tr>
<tr>
<td>CA</td>
<td>452</td>
<td>289</td>
<td>64%</td>
<td>181</td>
<td>40%</td>
</tr>
<tr>
<td>CO</td>
<td>641</td>
<td>332</td>
<td>52%</td>
<td>157</td>
<td>24%</td>
</tr>
<tr>
<td>NV</td>
<td>25</td>
<td>17</td>
<td>68%</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>NM</td>
<td>64</td>
<td>37</td>
<td>58%</td>
<td>29</td>
<td>45%</td>
</tr>
<tr>
<td>UT</td>
<td>277</td>
<td>124</td>
<td>45%</td>
<td>104</td>
<td>38%</td>
</tr>
<tr>
<td>WY</td>
<td>339</td>
<td>208</td>
<td>61%</td>
<td>55</td>
<td>16%</td>
</tr>
<tr>
<td>US Total</td>
<td>2555</td>
<td>1315</td>
<td>51%</td>
<td>783</td>
<td>31%</td>
</tr>
<tr>
<td>Mexico</td>
<td>443</td>
<td>79</td>
<td>18%</td>
<td>79</td>
<td>18%</td>
</tr>
<tr>
<td>CRB Total</td>
<td>3077</td>
<td>1394</td>
<td>45%</td>
<td>863</td>
<td>28%</td>
</tr>
</tbody>
</table>

Alfalfa is a major crop in all of the Colorado River Basin States, especially in states like Nevada and Utah, where alfalfa is approximately 54 percent of the total acreage of principal crops (Table 2). In the Colorado River Basin, alfalfa makes up more than one-quarter (26 percent) of all major crops in the basin. The acreage of alfalfa in the basin is highest in California and Arizona, where the long growing season and extensive acreage alfalfa contributes to its large total consumptive use.
Table 2: Alfalfa acreage compared to other principal crops in Colorado River Basin states. Note: Principal crops included in the area planted are corn, sorghum, oats, barley, rye, winter wheat, Durum wheat, other spring wheat, rice, soybeans, peanuts, sunflower, cotton, dry edible beans, sugar beets, canola, and proso millet. Harvest acreage is used for all hay, tobacco, and sugarcane in computing total area. Source: USDA June 30, 2015 Acreage Report.

<table>
<thead>
<tr>
<th>State</th>
<th>Alfalfa Area Harvested</th>
<th>Principal Crop Area</th>
<th>% of Principal Crop Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona</td>
<td>260</td>
<td>666</td>
<td>39.0%</td>
</tr>
<tr>
<td>California</td>
<td>820</td>
<td>3,086</td>
<td>26.6%</td>
</tr>
<tr>
<td>Colorado</td>
<td>700</td>
<td>5,986</td>
<td>11.7%</td>
</tr>
<tr>
<td>Nevada</td>
<td>240</td>
<td>445</td>
<td>53.9%</td>
</tr>
<tr>
<td>New Mexico</td>
<td>220</td>
<td>1,008</td>
<td>21.8%</td>
</tr>
<tr>
<td>Utah</td>
<td>510</td>
<td>944</td>
<td>54%</td>
</tr>
<tr>
<td>Wyoming</td>
<td>490</td>
<td>1,447</td>
<td>33.9%</td>
</tr>
</tbody>
</table>

Alfalfa is the single largest user of agricultural water in California, making up nearly 20 percent of applied water (S. Orloff, Putnam, et al., 2014). Most years, it makes up more acreage than any other crop in the Imperial and Palo Verde Valleys. The subtropical desert climate is ideal for growing alfalfa year-round. Sunlight occurs more than 90 percent of the possible hours every year and even in the winter sunshine exceeds 8 hours a day. In the low desert areas of California and Arizona, the consumptive use of alfalfa in the early to mid-1990s was approximately 1.8 maf annually because of extensive acreage and year-round production of the crop. This amount was 45 percent more than cotton, 65 percent more than wheat, 66 percent more than sorghum, 89 percent more than lettuce, and 75 percent more than cantaloupe (Takele & Kallenbach, 2001a).

In California, alfalfa is worth over $1 billion/year and is a fundamental input to California’s large dairy and beef industries. The dairy and beef cattle industries are reliant this locally-grown alfalfa. Unlike other crops like cotton, it receives no crop subsidy. Comparatively, these industries provide more jobs and economic activity than TV and movies and the wine industry in California. Often, alfalfa is compared to high-value crops that generate more value per acre. Even though the value of alfalfa produced from an acre is less than other crops, the overall value of the downstream uses of alfalfa is comparable. For example, almonds are a high-value crop with water use per acre similar to alfalfa. The dry matter yields of alfalfa are six times greater than that of almonds. The value of consumer products produced per acre is only marginally better for almonds (alfalfa can produce 2,459 gallons of milk/acre and an almond orchard makes 1,464 cans of nuts/acre) (Putnam, 2010). This hidden value of alfalfa is a necessary part of the understanding the crop’s significance in the region.

3.4 Connection to Dairy and Beef Industries

Alfalfa is a critical input into the dairy and beef industries and cannot be separated from this value chain. Farmers will grow alfalfa if these industries continue to demand the crop. In just the last few decades, alfalfa production has changed dramatically. “It has gone from a relatively low-value rotation and pasture crop grown largely to feed dairy cows on-farm, to a cash hay business, being grown and managed professionally, shipped long distances, even overseas, to multiple markets, with exacting
demands on quality factors. It has risen from a “Rodney Dangerfield” of crops (“don’t get much respect”), to a crop which can effectively compete economically with a wide range of irrigated crops in the West, including potato, tomato, and some specialty crops, as well as corn, grains, and oilseeds” (Putnam, 2009).

As many western states have expanded their dairy industries, the need for high quality hay has also increased significantly. The demand for alfalfa is mostly local and regional, not international, although some alfalfa is now being exported (Glennon, 2012; “My Turn”, 2015, “Saudi dairy company Almarai buys land in California to grow fodder”, 2016). Due to the expanding dairy industry in states like Idaho, New Mexico and California, and lack of profitable alternative crops, alfalfa acreage increased significantly around the year 2000 (Putnam et al., 2000). Growth of the dairy industry has been significant in Western states over the last 40 years. In 1970, the only Western states in the top ten of dairy production were California and Texas. By 2008, Idaho, New Mexico, and Washington were also top ten dairy states (Figure 1).

![Change in Dairy Production 1970 - 2016](image)

**Figure 2:** Top ten milk production states, plus CRB States, 1970 and 2016. National ranks shown at top of the column. Source: NASS (2017).

During this period, national milk cow numbers declined from 12 million to 9.3 million while western states added cows. (Production per cow during this period has significantly outpaced the decline in total cows and thus total milk production has increased). Alfalfa production has struggled to keep up and been outpaced significantly by demand. In California, about the same amount of alfalfa hay is produced
now as in 1970, but dairy production has quadrupled. Alfalfa is a preferred feeding ration for cows, especially young and lactating cows, comprising in some cases more than 25% of the diet (Foster, 1992; Robinson, 2014; Schoneveld, 1992). Dairies have found other ways to meet their demand for forage despite the lack of alfalfa production: increased use of corn and small grain silage, alfalfa by-products and fermentation by-products; and improvement of alfalfa quality factors that increase milk production. In addition, there has been a reduction in the amount of alfalfa fed to beef animals (Putnam, 2009).

Though dairies have found some solutions to meet the lack of alfalfa production, alfalfa provides significant nutritional advantages compared to other forages. Modern dairy production monitors the digestion (and rumen, especially) of cattle carefully. Exact percentages of crude protein, fiber, and other plant nutrients are required to maintain the pH in a cow’s stomach for optimum milk production and prevent rumen acidosis, a decline in the rumen pH that can cause depression, lack of appetite, elevated heart rate, diarrhea, and death in animals. Compared to corn and cereal silages, alfalfa has much better nutritional qualities like high buffering capacity, chewing stimulation, and pectin, which all help regulate the pH in the rumen. Alfalfa is also closer to the ideal level of crude protein, which supports growth and milk production. Other important amino acids like lysine are higher in the alfalfa. Compared to silages, it also has more good ash (inorganic matter) like calcium (Robinson, 2014). Studies have shown that a diet that is two-thirds alfalfa is optimal for milk production. Higher alfalfa diets also produce less nitrogen excretion per unit of milk produced. Alternative diets with less alfalfa require expensive supplements to match the nutritional value of the crop (Martin, Brink, Hall, Shewmaker, & Undersander, 2006).

Since the dairy and livestock industry provides a consistent source of demand, alfalfa is a relatively low-risk crop choice for farmers with the ability to provide a reasonably stable income. Higher-value crops always have the risk of overproducing for narrow markets. (Putnam, 2010). Unlike most other crops, alfalfa can be harvested multiple times during the year, providing a dependable income stream. Alternatively, it can be stored onsite in simple structures to be sold when market conditions improve.

3.5 Agronomic Practices and Considerations

Alfalfa’s adaptability explains its widespread cultivation; no other U.S. crop can be grown in such diverse locations. It is grown throughout the western United States almost regardless of climate, elevation, and precipitation. Specialized cultivars exist for cool high mountain valleys and hot, dry deserts near sea level and it flourishes in both locations (Putnam, Orloff, & Teuber, 2007). It can grow in a wide array of soil types, from heavy clay soils to sandy soils, to organic or volcanic soils (S. B. Orloff et al., 1997; Putnam et al., 2000).

Alfalfa is a relatively easy crop to grow. In many Intermountain Regions, a seedbed can be prepared without plowing (S. B. Orloff et al., 1997). It requires much less labor compared to high value crops like vegetables and fruit trees. There is no ideal planting date; it can be planted successfully at several different times. Most often, planting occurs in the late-summer or early-spring (S. B. Orloff et al., 1997). Planting in the late-summer can take advantage of upcoming winter precipitation to help establish the plant. Often, when alfalfa is planted in the spring, an application of water is necessary after planting to support initial root growth (Guitjens, 1990; S. B. Orloff et al., 1997).

Throughout the growing season, alfalfa is irrigated 1-3 times between cuttings and the amount of water applied annually varies greatly from region to region, ranging from 2 af in cool mountain climates to 7-8 AF in the deserts per acre per year (Putnam et al., 2001). The growth process dictates when to harvest,
usually every 30 to 50 days. After a cutting, alfalfa relies on its root reserves for approximately 2 to 3 weeks (roughly 6 to 8 inches of plant height) after which it then adds surplus carbohydrates back to the roots (S. B. Orloff et al., 1997). Normally, irrigation is discontinued some time before cutting to allow equipment access to the field without compacting the soil or damaging the plants.

The post cutting drying of alfalfa requires several days without irrigation, too. Watering is resumed after the hay bales have been removed (Guitjens, 1990). The cutting schedule is adjusted based on the intended use of the alfalfa hay. Shorter cutting periods result in lower yields but higher quality hay, which is ideal for dairies, growing calves, or yearlings. Alfalfa harvested before bloom produces higher quality hay than after bloom (Putnam et al., 2001). Longer cutting periods will have higher yields but lower quality (Putnam, Robinson, & DePeters, 2007). This hay is better suited for beef cows and “hobby” horses (S. B. Orloff, 2007). Even though immature alfalfa may be the highest quality, the greatest financial return may be harvesting mature alfalfa to maximize yield, reduce harvest costs, or ensure stand survival (Mueller, 1992).

In general, alfalfa requires fewer chemical inputs than other crops (Table 3). Rarely does the crop need nitrogen application, and, because it fixes nitrogen like all legumes, it provides a significant source of the nutrient for subsequent crops (Putnam et al., 2001; Putnam, 2010; Wrona, 1992). It has also been used to mitigate contamination problems by absorbing nitrates from groundwater, recycling dairy or municipal waste, and mitigating industrial compounds that could contaminate groundwater (Putnam, 2010; Putnam et al., 2001). With more government regulations that require nutrient management plans for soils high in nitrate nitrogen and or phosphorus, crops that can remove excessive nitrate will become more important (Martin, Mertens, & Weimer, 2004). Finally, there are millions of acres of alfalfa in the US that do not receive any pesticides (Putnam et al., 2001).
Table 3: Alfalfa fertilizer and chemical inputs. Source: Orloff et al. (2007).

<table>
<thead>
<tr>
<th>Element Needed</th>
<th>Symbol</th>
<th>Fertilizer Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorus</td>
<td>P2O5</td>
<td>Frequently</td>
</tr>
<tr>
<td>Sulfur</td>
<td>S</td>
<td>Frequently</td>
</tr>
<tr>
<td>Boron</td>
<td>B</td>
<td>Less Frequently</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>Mo</td>
<td>Less Frequently</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe</td>
<td>Seldom</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N</td>
<td>Seldom</td>
</tr>
<tr>
<td>Calcium</td>
<td>Ca</td>
<td>Never</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Cl</td>
<td>Never</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Co</td>
<td>Never</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>Never</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg</td>
<td>Never</td>
</tr>
<tr>
<td>Manganese</td>
<td>Mn</td>
<td>Never</td>
</tr>
<tr>
<td>Nickel</td>
<td>Ni</td>
<td>Never</td>
</tr>
<tr>
<td>Zinc</td>
<td>Zn</td>
<td>Never</td>
</tr>
</tbody>
</table>

3.6 Harvesting and Yields

Compared to other crops, alfalfa is one of the most difficult to harvest. Not only must it be cut, but alfalfa must be dried to lower the moisture content from usually 75 to 85 percent to less than 20 percent before baling (S. B. Orloff & Mueller, 2007). To produce a ton of hay at 20 percent moisture, seven tons of water must be extracted from eight tons of fresh forage. Most of the moisture loss occurs from leaves through open stomata, representing 75 percent of the moisture loss during approximately 20 percent of the total drying time. Then the pores of the leaf and stem close, slowing the rate of drying considerably. There are many different management practices to speed up the second phase of the drying process. Mechanical methods can lightly crimp or crush the forage, breaking the stems and increasing water loss. Chemical drying agents allow moisture to exit more easily, but are not popular due to their cost and lack of effectiveness in cool weather when they are needed most. Having wider
and thinner windrows\(^5\) as opposed to conventional narrow thick windrows is another technique to decrease drying time. Wide windrows dry faster because more of the alfalfa is exposed to the sun (S. B. Orloff, 1992). The last step of the haying process is for the alfalfa to be baled and then collected for storage or shipping (S. B. Orloff et al., 1997).

The climatic variability in growing locations throughout the region is reflected in the yield, irrigation amount, cuts per year, fall dormancy and stand life of alfalfa (Table 4). Cooler regions with shorter growing seasons and higher precipitation like Wyoming, Utah and Colorado have lower yields, fewer cuttings per year, and alfalfa varieties that become dormant earlier in the fall and have delayed growth in the spring. Alfalfa stands in this environment can last up to eight years. In the hotter areas of southern California and Arizona, alfalfa requires more irrigation water, has higher yields, more cuttings per season, and many of the alfalfa cultivars are less fall dormant, which allows for a longer growing season. Unfortunately, stands must be replaced every 3-4 years in these climates.

Table 4: Alfalfa characteristics by state. Source: Summers et al. (2007).

<table>
<thead>
<tr>
<th>State</th>
<th>Average Yield (tons/acre)</th>
<th>Economic Rank in State</th>
<th>Acreage Under Irrigation</th>
<th>Cuts/Year</th>
<th>Fall Dormancy Classes</th>
<th>Stands Replaced Every</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona</td>
<td>7.9</td>
<td>-</td>
<td>98%</td>
<td>8-10</td>
<td>8-9</td>
<td>3 years</td>
</tr>
<tr>
<td>California</td>
<td>6.8</td>
<td>5-7</td>
<td>100%</td>
<td>3-10</td>
<td>3-10</td>
<td>3-4 years</td>
</tr>
<tr>
<td>Colorado</td>
<td>3.8</td>
<td>3</td>
<td>89%</td>
<td>1-4</td>
<td>2-4</td>
<td>3-8 years</td>
</tr>
<tr>
<td>Nevada</td>
<td>4.1</td>
<td>1</td>
<td>100%</td>
<td>3-4</td>
<td>3-5</td>
<td>8 years</td>
</tr>
<tr>
<td>New Mexico</td>
<td>5.2</td>
<td>3</td>
<td>90%</td>
<td>3-8</td>
<td>3-9</td>
<td>3-5 years</td>
</tr>
<tr>
<td>Utah</td>
<td>4.4</td>
<td>3</td>
<td>67%</td>
<td>3-5</td>
<td>3-6</td>
<td>3-5 years</td>
</tr>
<tr>
<td>Wyoming</td>
<td>2.7</td>
<td>-</td>
<td>68%</td>
<td>1-4</td>
<td>2-4</td>
<td>4 years</td>
</tr>
</tbody>
</table>

### 3.7 Dormancy

Alfalfa’s adaptability includes its ability to survive prolonged periods of drought. Alfalfa plants go into drought-induced dormancy and generally recover once moisture is returned (S. Orloff, Putnam, et al., 2014). Alfalfa is relatively drought tolerant because of its deep root system. It is able to access moisture lower in the soil profile that other crops cannot (S. Orloff, Putnam, et al., 2014). When alfalfa becomes drought-stressed, it will rely on the water deeper in the soil profile, if available. Roots can grow and penetrate soil to a depth of 9 meters (K. B. Jensen, Waldron, Peel, & Hill, 2007; Shewmaker, Allen, & Neibling, 2015). However, 60 to 70 percent of the total root mass is in the upper 15 cm of the soil;

\(^5\) A windrow is the gathered linear pile of cut alfalfa that is left to dry in the sun. “Make hay while the sun shines” could easily be “make windrows while the sun shines.”
keeping that section of the soil profile moist is important (K. B. Jensen et al., 2007). Approximately 70 percent of the water is extracted by the upper half of the root system (S. Orloff, Putnam, et al., 2014) (Colorado Water Conservation Board & Colorado Division of Water Resources, 2013; S. Orloff, Bali, & Putnam, 2014). In the fall, the plants enter dormancy when the days shorten and temperatures drop. The plants will begin to grow again when soil temperatures warm. While dormant, alfalfa is much less susceptible to cold and frost (S. B. Orloff et al., 1997).

Cutting management is the primary method for increasing stand health during drought periods. Starch stored in the crown and roots feed new branch and crown bud growth in the spring (Fransen & Kugler, 2003). This stored starch is also important during regrowth periods after cuttings. One extension study suggests that as long as the plant roots remain white, moist and pliable the plant can survive drought (McWilliams, 2002). A 1997 study in Tucson looked at crown moisture as a relatively easy way of predicting survivability during summer irrigation termination (SIT). At the end of an 84-day SIT, 42% crown moisture was identified as a critical threshold for crown survivability (Matthias Wissuwa, Smith, & Ottman, 1997).
Figure 3: Five-year-old alfalfa after two years of drought. Source: Orloff et al. (2014). Note: A field study on alfalfa in Five Points, CA was stopped after three years. In both 2013 and 2014 there was no water applied from April to November, but the stands mostly survived by relying on subsurface moisture.

3.8 Water Use Compared to Other Plants

The most often cited criticism of alfalfa is that it consumes more water than almost any other crop except rice when comparing consumptive use across different plants. The large water consumption is due to the long growing season of perennial crops (S. Orloff, Putnam, et al., 2014). Alfalfa provides a high tonnage of usable dry matter for the water applied (Putnam et al., 2001). In the Sacramento Valley
of California, the water use efficiency\(^6\) (WUE) of alfalfa compares well to other commonly grown and high-value crops in the same area (Table 5). Even though the biomass yield is not as high as other crops like corn and rice, alfalfa has a very high “harvest index”, the percentage of plant used for economic harvest. Its water use efficiency of biomass production is average, but the WUE of the harvested economic yield is higher than any of the other crops listed.

Table 1: Water use efficiency comparison of Sacramento Valley crops. Source: Putnam et al. (2001).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Duration(^1)</th>
<th>Applied Water(^2) (inches)</th>
<th>Biomass Yield(^3) (lb/acre)</th>
<th>Harvest Index(^4) (%)</th>
<th>Crop Economic Yield(^5) (lb/acre)</th>
<th>WUEh(^6) (lbs/acre inch)</th>
<th>WUEh(^7) (lbs/acre inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>Mar-Oct</td>
<td>42</td>
<td>12,833</td>
<td>100</td>
<td>12,833</td>
<td>306</td>
<td>306</td>
</tr>
<tr>
<td>Corn Grain</td>
<td>Apr-Aug</td>
<td>35</td>
<td>19,194</td>
<td>50</td>
<td>9,597</td>
<td>548</td>
<td>274</td>
</tr>
<tr>
<td>Wheat</td>
<td>Dec-Jan</td>
<td>19</td>
<td>10,055</td>
<td>45</td>
<td>4,525</td>
<td>529</td>
<td>238</td>
</tr>
<tr>
<td>Sugarbeet</td>
<td>Oct-Jun</td>
<td>43</td>
<td>18,529</td>
<td>43</td>
<td>8,005*</td>
<td>431</td>
<td>186</td>
</tr>
<tr>
<td>Rice</td>
<td>May-Oct</td>
<td>71</td>
<td>16,900</td>
<td>45</td>
<td>7,774</td>
<td>238</td>
<td>109</td>
</tr>
<tr>
<td>Dry Bean</td>
<td>May-Aug</td>
<td>28</td>
<td>4,382</td>
<td>40</td>
<td>1,753</td>
<td>156</td>
<td>63</td>
</tr>
<tr>
<td>Almonds</td>
<td>Mar-Oct</td>
<td>37</td>
<td>-</td>
<td>-</td>
<td>1,134</td>
<td>-</td>
<td>31</td>
</tr>
</tbody>
</table>

1. Normal growth duration for these crops.
2. Median of a range of estimated applied water (irrigation water required to produce a crop) for Sacramento Valley, CA; values from California Water Plan Update, DWR, 1994.
3. Biomass yields are based upon economic yields and Ht. Economic yields are a 3-year (1990-2000) mean from Agri. Commissioners Reports for 9 counties in the Sacramento Valley. *Sugarbeet yields are expressed as sucrose, based upon 15% sucrose in the root.
4. Harvest Index estimates are from published sources and by discussions with Cooperative Extension Specialists. Harvest Index = Percentage of plant used for economic harvest (above-ground except for sugarbeet). WUEh is the Applied Water-Use-Efficiency of biomass production (total above ground plant, except sugarbeet where roots are included). WUEh is the Applied Water-Use-Efficiency of the harvested economic yield.

3.9 Environmental Benefits

Alfalfa has some environmental benefits not present in other crops. Due to the long stand life of the plant, it provides habitat for wildlife and beneficial insects. Many animal species use alfalfa for reproduction, cover, or feeding (Putnam et al., 2001). Alfalfa improves the soil characteristics and contributes to less erosion due to its extensive root system and long life. Most alfalfa fields are not tilled for 3 to 6 years and the root structure helps maintain the soil in place. The thick canopy covers most of the soil and prevents water from loosening the soil (Putnam, 2010; Putnam et al., 2001). Many alfalfa fields are not sprayed with pesticides or herbicides.

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\(^6\) Water Use Efficiency is a measure of how well the plant generates biomass per unit of applied water. The biomass can be the total plant biomass, or the biomass of the economic part of the plant. Because the entire harvested amount of alfalfa is used, the plant scores high by this measure of water use.
3.10 Yield, Water Consumption, and Quality Relationships

There have been many studies on the relationship between alfalfa ET and yield in numerous locations around the country. Alfalfa yield has a linear relationship with evapotranspiration (ET). The more water is applied, the higher the yield until the full ET is reached. Consistently, yield increases with increased irrigation to the point of meeting maximum ET. (J. W. Bauder, Bauer, Ramirez, & Cassel, 1978; Carter & Sheaffer, 1983; Davis, Fry, & Jones, 1963; Donovan & Meek, 1983, 1984; Hanson, Putnam, & Snyder, 2007; E. H. Jensen, Miller, Mahannah, Read, & Kimbell, 1988). Even in locations like western New York that are not ideal for alfalfa growth, increased irrigation results in higher yields (Lathwell & Vittum, 1962). Other studies have shown that yield is also a function of growing degree-day accumulation, average daily solar radiation, year and harvest number within year, but ET is the most significant factor (Hanks, 1974; Smeal, Kallsen, & Sammis, 1991).

Deficit irrigation will reduce yield significantly because ET and yield are linearly related. Indeed, this result holds for all forms of deficit irrigation where biomass growth is the objective. Many studies (see appendix) have investigated the impacts of split-season deficit irrigation or continuous deficit irrigation on alfalfa yield. (Cohen, Bielorai, & Dovrat, 1972; Guitjens, 1990; Hugh Barret & Skogerboe, 1980; R. B. Lindenmayer, Hansen, Brummer, & Pritchett, 2011b; Retta & Hanks, 1980; Sammis, 1981; Smeal et al., 1991; Wright, 1988). All feature significant yield declines when the plants truly received less water; in some cases, the plants were able to access groundwater and thus show lower declines than would otherwise occur.

Interestingly, alfalfa that is water stressed often has improved quality because the plant is not as mature and contains a higher percentage of leaf material and fewer stems. Multiple deficit irrigation studies have found drought stressed alfalfa to be higher in crude protein and lower in non-digestible fiber, both desirable characteristics (Davis et al., 1963; Donovan & Meek, 1983, 1984; Hanson et al., 2007; E. H. Jensen et al., 1988; McWilliams, 2002; Mueller, 1992).

The relationship between ET and yield shifts depending on the climate (Figure 4). Hotter climates with more evaporative losses will produce significantly less alfalfa at the amount of ET than alfalfa grown in cooler climates, though the relationship is still linear. (Sanden, Klonsky, Putnam, Schwankl, & Bali, 2011).
Water applied in excess of water required by the crop does not produce extra yield (Shewmaker et al., 2015). Indeed, over-irrigation can lead to stand loss and declining yields (Rice, Quisenberry, & Nolan, 1989). Early in the irrigation season crop requirements can often be met with limited irrigation. Consistently, studies have found little response of alfalfa yield to applied water for the first cutting due to stored water in soil from normal winter and spring precipitation (Hanson & Putnam, 2000; Shewmaker et al., 2015).

Most studies have found very little difference in the relationship between yield and ET in different cultivars. A study in Bushland, Texas found little difference in yields between cultivars, but water use generally increased with yield (Undersander, 1987). In the San Joaquin Valley of California, one study found some differences between alfalfa varieties in the early spring and late summer, but total seasonal yields were not different among the cultivars (Grimes, Wiley, & Sheesley, 1992). In Logan, Utah, more variation in yield was documented between years than between difference cultivars (Retta & Hanks, 1980). However, some yield differences were found between seven cultivars grown in the Imperial Valley (Hanson & Putnam, 2000).

### 3.11 Seasonal Yield

Alfalfa consistently produces the highest yields of the best quality at the highest water use efficiency in the spring. This is why many emphasize split season deficit irrigation for alfalfa, terminating irrigation after most of the quality yield has been produced (S. Orloff, Putnam, Hanson, & Carlson, 2003a) (R. B. Lindenmayer et al., 2011a; S. Orloff, Putnam, Hanson, & Carlson, 2003b).
Yields throughout the West are often highest early in the season, making up a disproportionate amount of the total annual yield. Spring to early summer cuttings produce approximately two-thirds of the annual yield (Guitjens & Goodrich, 1994; S. Orloff, Putnam, et al., 2014). In Arizona, alfalfa is generally harvested from March 1st through November 1st, but 65 percent of the total production comes before mid-May (Husman, 1992). In North Dakota, yields declined with each successive harvest. That trend increases with magnitude for unirrigated alfalfa (J. W. Bauder et al., 1978). In Washington, in a four-cut harvest system, the first cutting usually makes up about 35 percent to 38 percent of the year’s total forage produced. In a five-cut harvest system, the first cutting yields are about 27 percent (Fransen & Kugler, 2003). In the Central and Imperial Valleys of California, about two-thirds of the annual production occurs by July. This increases to 75 percent in the Intermountain Regions of California (S. Orloff, Putnam, et al., 2014). In Idaho, the first cutting of a 4-cut system makes up 35-38 percent of the year’s total forage yield and in a 5-cut system the first cutting is about 27% of the total yearly yield (Shewmaker et al., 2015).

Orloff et al. (2014) documents the significant decline in yield as a percent of total production in two locations in California (Figure 5). In the Intermountain region, yields after the second cutting only make up 25 and 41 percent of the total annual yield in a three- and four-cut system, respectively. By the second cutting (when split-season deficit irrigation could occur), 75 and 60 percent of total alfalfa is harvested in a three- and four-cut system, respectively. In Fresno County, a region where seven harvests can occur in one season, production declines in late July and August.

Regardless of location or climate, alfalfa yields decrease during the hot summer season because it is a cool season crop. This occurs in all major production areas in North America, including the Colorado River Basin (Evans & Peadan, 1984). In some studies the amount of forage harvested from the midsummer cutting is 50 percent lower than the spring cutting, even with irrigation (Cohen et al., 1972). In Washington, over a two-year study the ratio of yield over the four harvests throughout the season was 37:27:24:12 (Evans & Peadan, 1984). In the Imperial and Palo Verde Valleys, summer yields drop to ½ to ¾ ton per cutting on a 24 to 28 day cycle (Wrona, 1992).

### 3.12 Seasonal Nutritional Characteristics

Alfalfa’s nutritional characteristics, especially its high protein and digestibility, make it the preferred forage for lactating dairy cows. One important factor affecting quality is the content of the cell wall. In high quality alfalfa, there is less cell wall material, making it more nutritious and digestible. With low-quality alfalfa, there is a higher proportion of cell wall material containing indigestible compounds like lignin. This “lignification” of the cell wall occurs as alfalfa plants mature (S. B. Orloff et al., 1997).

Spring is when the highest quality alfalfa is produced. This difference in quality is significant such that it is highly desired by dairy farmers and commands a higher price (Foster, 1992; S. Orloff, Putnam, et al., 2014; Robinson, 2014; Schoneveld, 1992). Forage quality declines after the first harvest. In some regions the decline can be severe (Martin et al., 2006), in part due to higher temperatures.

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7 Cool season crops are adapted to cool climates and are often less sensitive to frosts. When temperatures warm too much for the plant, they will produce flowers and seeds.
According to Mueller (1992), forage quality declines as the summer progresses and recovers in the fall. Alfalfa harvested in the spring or fall has a higher leaf and protein content than summer produced alfalfa. High temperature increases the rate of plant maturation and cell wall lignification (the strengthening of the plant vascular body). This causes structural components to form much faster at the expense of metabolites in the cell contents. Lignification of the cell wall is the primary factor limiting forage digestibility. During April and May, hay quality is excellent and prices are usually highest. In June, July, and August, alfalfa hay yields are high but quality is lower. The table below shows the change in yield and total digestible nutrients (TDN).

Alfalfa produced in the summer months brings a lower price due to its poor quality compared to spring or fall hay. Summer biomass created is thicker in the stem and not as digestible (T. Bauder, Hansen, Lindenmeyer, Bauder, & Brummer, 2014; Martin et al., 2006; S. Orloff, Putnam, et al., 2014; Wrona, 1992). This type of alfalfa is suited for dry cows, feedlot animals, or horses, not lactating dairy cows (M. Ottman & Mostafa, 2013).

3.13 Seasonal Water Use Efficiency

Alfalfa yields more dry matter per unit of water use during the spring and late fall than the summer, but fall periods do not have the same water use efficiency or quality as the spring. Sunlight and plant physiology are why alfalfa produces the best quality hay in the spring. The amount of sunlight (measured by solar irradiance) is greater in the spring than in the fall. Biomass growth per unit of ET increases with solar irradiance up to a maximum level, after which yields decline. The combination of high light intensity and low temperatures that suit cool season crops only occurs in the spring. This combination results in high levels of photosynthesis and low levels of evaporation. Another factor is that in the spring alfalfa has a reserve of carbohydrates from the previous fall that can used for growth. Finally, in the spring more photosynthetic growth goes to biomass yield than root reserves (T. Bauder et al., 2014).

WUE declines during the season due to changes in solar irradiance and the carbohydrate reserve flux in alfalfa (R. B. Lindenmayer et al., 2011b). In some regions, 40 percent of annual irrigation is applied in July to August, with only 20 percent of the yield being produced during that time. Not irrigating in July and August noticeably increased water-use efficiency for the whole year (Metochis & Orphanos, 1981).

Since yields are typically highest in the spring and the ET rate is less than the summer, the water use efficiency of alfalfa is greater in the spring than mid-summer and fall (Daigger, Axthelm, & Ashburn, 1970; S. Orloff, Putnam, et al., 2014). The water use efficiency decreases with each subsequent harvest later in the growing the season (T. Bauder et al., 2014). Guitjens and Goodrich (1994) found the average water use efficiency to be greater in the early and late season, when temperatures are cooler. They also found that the production capacity for the first harvest was the greatest for a given amount of water.

Decreasing WUE in the hot summer months is driven by the increase of ET of fully irrigated alfalfa. ET for alfalfa is often highest in July and August (Wright, 1988). One study found that ET increased gradually from the start of the season to the first part of July, reaching maximum values of 7.5 mm and 8 mm a day (Hanson et al., 2007). In an alfalfa study in Bushland, Texas, water efficiencies were highest when daily evaporative demand was lowest (spring) (Undersander, 1987). In Nebraska, the average consumptive use of water per day increased for each harvest: 4.1 mm for the first harvest, 5.6 mm for the second, and 5.9 mm for the third. The amount of water use per cutting increased from 9.6
cm/metric ton (first cutting), to 11.2 cm/metric ton to (second cutting), to 15.4 cm/metric ton at the final cutting. The amount of water applied increased to achieve the same yield, resulting in a decline in water use efficiency (Daigger et al., 1970). Similar to difference in yields, there is little evidence to support that alfalfa varieties vary widely in water use efficiency. There may be some differences during parts of the season, but the total-season water use efficiency is not that different (R. B. Lindenmayer et al., 2011b).

3.14 Summer Slump

As discussed above, while springtime is ideal for alfalfa production, quality, yields, and WUE all decline sharply during the hot late summer (July and August), a time known as the “summer slump.” The alfalfa grown during this period is of lower quality and lower yield, but requires the most amount of water applied during the season (Hanson & Putnam, 2000; Metochis & Orphanos, 1981). Orloff et al. (2003a) asserts that summer deficit irrigation has the most potential to conserve water because it allows some forage production in the spring and the established alfalfa cover minimizes the potential for wind erosion and weed encroachment during the summer dry-down period.

Summer slump is associated with higher temperatures (especially during the night), shorter days, and increased humidity (T. Bauder et al., 2014; Cohen et al., 1972; Evans & Peaden, 1984; Husman, 1992; M. Ottman & Mostafa, 2013). Alfalfa is a cool season crop and the higher than normal temperatures are not ideal for optimum growth. The leaves are not able to cool themselves and transpire enough water to the same extent during the spring and fall (M. Ottman & Mostafa, 2013). When this occurs, the structural development of alfalfa is accelerated, shortening the time to maturity when the plants flower (Evans & Peaden, 1984). A lack of height and stem numbers reduce yield. After a cutting, the plant replenishes the root carbohydrates for about two weeks to prepare for the next growth cycle (M. Ottman & Mostafa, 2013). The crown, roots, and reproductive structures of alfalfa receive more growth than leaves and stems (Smeal et al., 1991).

There are strategies to partially mitigate the effects of summer slump. Some research has found more dormant varieties of alfalfa are more resistant to the characteristics of summer slump. However, many semi-dormant alfalfa varieties in the low elevation deserts do not produce yields comparable to non-dormant varieties. Studies have had mixed results with increases and decreases in yields when excess nitrogen is applied. Due to the decrease in alfalfa growth, weeds become more competitive for water. The most effective method to prevent weed encroachment is a healthy and dense stand. Cutting height is also important. A height of 1-inch is recommended on a 4-week harvesting interval, but cutting at 4 inches has some advantages. A small amount of carbohydrates may be stored in the stem, aiding regrowth. Also, since less stem is harvested, the quality also increases (M. Ottman & Mostafa, 2013).
This period of marginal alfalfa production presents a great opportunity to reduce consumptive use, with less harm that full season deficit irrigation or fallowing. In fact, terminating irrigation during the late summer has often been practiced in the past and was referred to as “summer dry-down.” In southern California in the 1950s, it was common for growers to terminate irrigation over the summer. This practice was tried again in the early 1990s. Alfalfa would be cut in July and irrigation withheld until October. There was little loss to alfalfa stands in the 1950s, but many growers’ stands were harmed by this practice in 1991-1992. This was likely due to the different cultivars of alfalfa grown at the time and that the alfalfa was already weakened by a whitefly invasion (Wrona, 1992).

The same practice was common in southern Arizona, where farmers ceased irrigation from July through August and alfalfa went dormant (Schonhorst, Thompson, & Dennis, 1963). Withholding summer irrigation was common in the 1960s and resulted in less stand loss due to scald and fewer problems from encroaching summer grasses. Improved land leveling techniques and effective herbicides significantly reduced these negative effects. (M. J. Ottman, Tickes, & Roth, 1996). Before laser leveling, farmers often resisted irrigating because the increased water necessary to meet ET during the late summer would often pond in the un-level parts of the fields. This would lead to scalding and severe loss
of stand. Laser leveled fields allowed farmers to apply just as much water and not worry stand loss from water ponding (M. Ottman & Mostafa, 2013).

### 3.15 Deficit Irrigation Induced Stand Loss

One of the most important issues with deficit irrigation of alfalfa is stand loss (the loss of some or all of the plants). It is a given that yields will decline when irrigation is withheld, but stand loss would result in future declines in production from the remaining alfalfa. An irrigator is more likely to forego irrigation if there were no long-lasting effects on the plant. Alfalfa survivability depends on the environment, length of growing season, duration of drought period, soil type, depth to water table, salinity, and even alfalfa variety (S. Orloff, Putnam, et al., 2014).

A few studies have shown that terminating irrigation during summer can cause permanent reduction in forage yield due to stand loss, especially in very hot climates with sandy soils (Shewmaker et al., 2015; Matthais Wissuwa & Smith, 1997). However, the bulk of the alfalfa studies show that short periods of deficit irrigation will not cause stand loss when compared to fully irrigated plots. Studies conducted in cooler regions with shorter growing seasons had the best results. In some cases, deficit irrigation could even be implemented on newly planted alfalfa or for two years in a row with few losses. Stand loss was more common when irrigation was terminated for long periods of time, multiple years in a row, or in sandy soils.

In the Intermountain region of California, deficit irrigation studies have found no observed difference in stand density in the year after split season deficit irrigation. This may be because Intermountain regions are cooler and have a shorter growing season. The exception was when the experiments were performed the year alfalfa was seeded. In that case, there was stand loss, indicating that alfalfa needs time to establish itself before it can survive periods of deficit irrigation. Stand loss has also occurred when water was withdrawn for most of the year in areas of shallow soil where the plants were weakened and had lower root reserves (S. Orloff, Putnam, et al., 2014). In Fresno County, California, a study by Frate and Roberts (1988b) concluded that alfalfa planted in early fall can survive irrigation termination in the midsummer in the first and second year. There appeared to be little to no stand loss in trials in the Klamath and Sacramento Basins (S. Orloff et al., 2003a).

On the Front Range of Colorado in Berthoud, the number of crowns that survived was higher in experimental treatments when irrigation was terminated after the 1st or 2nd cutting than a full irrigation control plot or when water was only withheld during the summer (B. Lindenmayer, Hansen, Crookston, Brummer, & Jha, 2008b). At three sites on the western slope of Colorado, stand density was not affected by terminating irrigation after the 1st or 2nd cutting for two years (Jones, 2015). Another study in Fort Collins, Colorado found no decline in stand density in later years of the experiment (T. Bauder et al., 2014).

A study in southern Arizona in the 1960s-withheld irrigation in July and August. There was little difference in stand loss over the three-year study between irrigated and non-irrigated plots. Both plots had significant stand loss during that time, but at this time fields were not laser-leveled and high plant mortality was common in alfalfa due to scalding (Schonhorst et al., 1963).

In Tucson, Arizona, Wissuwa and Smith (1997) terminated irrigation for 84 days, resulting in 24 percent plant mortality. In another test, water was terminated for 42 days one year and 75 days the next. In this
test, there was only 1.5 percent plant mortality, which was comparable to the stand loss in the control plots. They also found that crown mortality was significantly correlated with the concentration of total nonstructural carbohydrates (TNC), the nutrients stored in the crown and the root reserve for future growth. When the amount of TNC drops below a certain level, it is unlikely the plant will survive. Similarly, Takele and Kallenbach (2001a) found that stands declined more rapidly when water is withheld for periods greater than 35 days in the summer.

Significant stand loss sometimes occurred in other very hot low desert regions. A Palo Verde Irrigation District study had stand loss due to the sandy soils (S. Orloff et al., 2003a). A similar case occurred in Yuma, Arizona where stand loss was so severe that alfalfa didn’t recover after the first-year termination. Summer irrigation termination did not have as dramatic an effect in Maricopa, Arizona, which received more rainfall, was slightly less hot, and the soil had a higher water holding capacity (M. J. Ottman et al., 1996). Soil type appears to be the determining factor in many cases where stand loss is an issue (S. Orloff et al., 2003a).

3.16 Post Deficit Irrigation Yields and Recovery

In many cases, alfalfa has shown to be quite resilient to split-season deficit irrigation. Soil, climate, and length of irrigation termination are factors which determine the recovery period. Many studies have found little to no impact on yields once irrigation resumed. Alfalfa appears to be very resilient and quick to recover from induced drought. At the Intermountain sites, there was no observed difference in yield the following year (S. Orloff, Putnam, et al., 2014). In the Berthoud, Colorado study, the first cutting was very similar regardless of whether the previous year’s irrigation treatment was full irrigation, or irrigation termination after the 1st or 2nd cutting (B. Lindenmayer et al., 2008b). In western Colorado, alfalfa that was not irrigated after the 2nd cutting produced similar yields in the 1st and 2nd cutting the following year when compared to fully irrigated alfalfa (Jones, 2015). In Fallon, Nevada, fields fully recovered after three years of deficit irrigation regardless of whether irrigation was withheld after the 2nd or 3rd cutting (Guitjens, 1993).

Alfalfa studies in Cyprus found that when irrigation resumed, alfalfa not irrigated for one or two growth periods produced similar yields to the control (Metochis & Orphanos, 1981). Frate and Roberts (1988b) found that alfalfa planted in early fall can survive induced first and second year midsummer deficit irrigation. After two years of different deficit irrigation regimes, all treatments were irrigated twice per cutting for a third year. These fields produced as well as the standard application of water. Better hay quality was a result for some deficit irrigation treatments in the first harvest after irrigation was reapplied. In Davis, California, after deficit irrigation in July and August, alfalfa yields recovered with the subsequent crop (Hanson et al., 2007).

In some cases, harvests do not fully recover or take time to equal yields on fully-irrigated plots. If irrigation is withheld for a long period, yields can be reduced significantly. In the western Colorado study, alfalfa harvests were significantly reduced the following year when irrigation was terminated after the 1st cutting, as opposed to the 2nd (Jones, 2015). In the Cyprus study, alfalfa not irrigated for three growth periods produced 20 percent less forage than the control the following season (Metochis & Orphanos, 1981). The study in Fort Collins, Colorado found that yields of spring harvests following dry summers of partial season irrigated alfalfa average 85 percent of irrigated alfalfa (T. Bauder et al., 2014). In the Palo Verde Valley, the yield was less than the control at the first harvest after water was withheld for 70 days, but not for 35 days. Yields did recover after one of two normal growth periods with
irrigation (Takele & Kallenbach, 2001b). The case is similar in the Maricopa, Arizona study, where yields recovered the first growth cycle after irrigation resumed in October and during the second growth cycle the following year (M. J. Ottman et al., 1996).

3.17 Soil Factors

The biggest factor with alfalfa survivability after deficit irrigation seems to relate to soil types (K. B. Jensen et al., 2007; S. Orloff et al., 2003a). Consistently, soils with higher water holding capacity and infiltration are better for alfalfa in general, especially when deficit irrigation is being practiced. Sandy loam to clay loam are best because they are the optimum choice for water holding capacity and water infiltration (S. B. Orloff et al., 1997). Sands and loamy sands have a low water capacity (Table 2). Less water in the soil profile means less water the plant can draw upon during drought or DI. Also, the hydraulic conductivity (ability of water to move through the soil profile) is too fast in these soils (S. Orloff, Putnam, et al., 2014). Alternatively, soil with a high water holding capacity, like fine textured clays, are also problematic for alfalfa. In these types of soils, water drainage and conductivity are slow (S. B. Orloff et al., 1997). The right hydraulic conductivity allows water to move upward from the water table to root system at the right rate (S. Orloff, Putnam, et al., 2014). Soils with slow infiltration properties and low hydraulic conductivity are prone to water logging (Guitjens, 1990). In medium textured soils with a shallow water table, alfalfa can survive no matter what hydrologic conductivity exists (S. Orloff, Putnam, et al., 2014).

Table 2: Different soil types and water holding capacity. Source: Jensen et al. (2007).

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Water Holding Capacity mm/m</th>
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<tbody>
<tr>
<td>Coarse sand</td>
<td>42</td>
</tr>
<tr>
<td>Loamy sand</td>
<td>83</td>
</tr>
<tr>
<td>Silt loam</td>
<td>146-167</td>
</tr>
<tr>
<td>Silty clay loam</td>
<td>167</td>
</tr>
<tr>
<td>Clay loam</td>
<td>167</td>
</tr>
<tr>
<td>Clay loam</td>
<td>167</td>
</tr>
<tr>
<td>Heavy clay loam</td>
<td>146-167</td>
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</tbody>
</table>

Even for normal alfalfa growth without deficit irrigation, soil can have a significant impact depending on the water holding capacity. In places with enough winter precipitation, irrigation may not have any significant influence on the first two cuttings of alfalfa due to stored soil moisture. The plant can rely significantly on water stored in the profile (Davis et al., 1963). Sandy soils have the opposite effect. They have too little water-holding capacity to produce a full first cutting without irrigation. Regardless of the amount of winter precipitation, the profile cannot contain a sufficient amount to assist alfalfa in meeting its ET demand in the early spring (Shewmaker et al., 2015).
Soil depth is another issue. A shallow soil profile provides less room for root development and less capacity for water storage (Guitjens, 1990). Ideally, soil depth should be greater than 6 feet deep with a minimum depth of 3 feet (S. B. Orloff et al., 1997). This can be an issue in the Intermountain Region, where shallow soils can hinder root growth (S. B. Orloff et al., 1997).

3.18 Water Table Height, Taproots, and Survivability

Alfalfa has a taproot that commonly extends four to six feet, but can go as deep as 30 feet. However, even though alfalfa roots can extend to great depths compared to other plants, the majority of the root is within two to four feet of the soil surface. Generally, the effective rooting depth for irrigation is the first 4 feet of the soil profile (S. B. Orloff et al., 1997). This area is often critical for irrigation in the spring and throughout the growing season (Berrada & Reich, 2011; Daigger et al., 1970). This is also where most water is absorbed in the soil profile (Figure 6).

![Figure 6: Unit-less schematic showing amount of water extracted compared to root depth. Note: 70% of the water is extracted by the upper half of the root system. Source: Orloff, 1997.](image)

Keeping the upper soil profile properly irrigated is essential. As more water is extracted, soil particles hold stored water more tightly. For alfalfa, the “maximum allowable depletion,” the amount of water loss that can occur before water extraction becomes too difficult, is 50 percent (S. B. Orloff et al., 1997). The deepest roots absorb less water and thus can transport less water to the above ground portions of the plant.

Even though a shallow (but not too shallow) water table is seen as beneficial for alfalfa growth, especially during DI the research provides conflicting results. A study in North Dakota found that ET was affected by the water table depth and irrigation level. Another study in western Colorado found that water from the water table made up 62 and 76 percent of seasonal ET at a depth of 60cm. At 105 cm
water table depth, the water table supplied 27 and 28 percent of seasonal ET. The ET contribution from groundwater declined rapidly as the water table depth increased (R. B. Lindenmayer et al., 2011b). Auckly and Guitjens (1995) in western Nevada studied alfalfa yield response to groundwater after irrigation was terminated. They found that shallow groundwater was not a substitute water source for alfalfa and water-table depth did not have a significant influence on yield even though the water-table was only around 1.5 meters deep. Another study concluded that favorable aspects for growth included a stable and shallow water table, periodic rainfall, and acceptable groundwater quality (Guitjens, 1990).

4 Deficit Irrigation of Other Forage Crops

Even though alfalfa is the most widely grown crop in the Colorado River Basin, other forages and irrigated pastures make up a significant area in the region. According to the 2012 Census of Agriculture, irrigated pasture makes up 14.5 percent of all irrigated land in the eleven western states (Table 7). Cow-calf and beef industries are highly dependent on this pasture (S. Orloff, Putnam, et al., 2014). In the high elevation areas of Colorado and Wyoming, pasture is the dominant water and land use, given the very short growing season that significantly limits what can be grown.

Table 3: Irrigated pasture acreage in western states and U.S. Source: Orloff et al. (2014).

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Arizona</td>
<td>43,769</td>
<td>52,680</td>
<td>26,098</td>
<td>4.9%</td>
<td>6.4%</td>
<td>3.1%</td>
</tr>
<tr>
<td>California</td>
<td>760,302</td>
<td>741,911</td>
<td>490,553</td>
<td>9.6%</td>
<td>10.2%</td>
<td>6.7%</td>
</tr>
<tr>
<td>Colorado</td>
<td>411,906</td>
<td>571,192</td>
<td>406,654</td>
<td>18.9%</td>
<td>24.9%</td>
<td>19.3%</td>
</tr>
<tr>
<td>Idaho</td>
<td>458,432</td>
<td>432,671</td>
<td>320,782</td>
<td>16.2%</td>
<td>15.1%</td>
<td>10.5%</td>
</tr>
<tr>
<td>Montana</td>
<td>419,455</td>
<td>455,045</td>
<td>420,660</td>
<td>26.9%</td>
<td>29.2%</td>
<td>28.4%</td>
</tr>
<tr>
<td>Nevada</td>
<td>212,001</td>
<td>188,052</td>
<td>126,589</td>
<td>39.7%</td>
<td>37.4%</td>
<td>22.6%</td>
</tr>
<tr>
<td>New Mexico</td>
<td>190,627</td>
<td>181,776</td>
<td>90,214</td>
<td>29.1%</td>
<td>28.0%</td>
<td>15.3%</td>
</tr>
<tr>
<td>Oregon</td>
<td>491,801</td>
<td>511,453</td>
<td>363,479</td>
<td>34.7%</td>
<td>38.3%</td>
<td>28.7%</td>
</tr>
<tr>
<td>Utah</td>
<td>310,776</td>
<td>346,939</td>
<td>250,382</td>
<td>39.8%</td>
<td>44.1%</td>
<td>29.3%</td>
</tr>
<tr>
<td>Washington</td>
<td>153,227</td>
<td>146,399</td>
<td>83,433</td>
<td>9.2%</td>
<td>9.2%</td>
<td>5.4%</td>
</tr>
<tr>
<td>Wyoming</td>
<td>581,258</td>
<td>525,541</td>
<td>418,965</td>
<td>60.5%</td>
<td>51.3%</td>
<td>41.2%</td>
</tr>
<tr>
<td>Western States</td>
<td>4,033,554</td>
<td>4,153,659</td>
<td>2,997,809</td>
<td>18.8%</td>
<td>20.1%</td>
<td>14.5%</td>
</tr>
<tr>
<td>USA</td>
<td>4,977,214</td>
<td>5,062,201</td>
<td>3,729,847</td>
<td>9.9%</td>
<td>9.8%</td>
<td>7.2%</td>
</tr>
</tbody>
</table>

Perennial pasture grasses are not as drought tolerant as alfalfa, and do not compare in terms of nutritional quality. Studies have involved tall fescue, orchardgrass, brome, wheatgrass, and festulolium. Under deficit irrigation, there are severe declines in yield and sometimes there was no forage to harvest for many varieties. Alternatively, drought tolerant species like brome and wheatgrass cannot tolerate full-season irrigation (S. Orloff, Putnam, et al., 2014). The shallow root systems of grasses provide fewer reserves to withstand drought. There is a lack of literature on this topic.
5 Deficit Irrigation Case Studies

5.1 Colorado Water Trust

Since 2001, the Colorado Water Trust (CWT) has been working to restore rivers by acquiring water rights for instream flows and facilitating creative water transfers between water right users and the Colorado Water Conservation Board’s (CWCB) instream flow program. CWT uses water right sales, water right donations, long-term leases, short-term leases, conservation easements, and structural and alternative solutions to increase stream flows (CWT, 2015).

Two recent pieces of Colorado legislation have given CWT and agricultural water right holders much more flexibility towards temporarily transferring water from agricultural users to meet environmental needs. A 2003 state statute allowed agricultural water users to loan water to the CWCB for instream flow purposes. These lease agreements allow transfers to occur three out of ten years and often only require the approval of the State Engineer’s Office. Participants do not usually have to go through the water court process to complete such an agreement (Colo. State Stat. § 37-83-105). The statute was modified in 2008 to remove these loan periods from historical consumptive use analyses for a water transfer right case. In addition, the water rights are protected from abandonment. In 2013, Senate Bill 13-019 provided a “safe haven” for agricultural water right holders in the Colorado, Gunnison, and Yampa River Basins to temporarily transfer water without the lower consumptive use affecting their overall historical consumptive use of the water right, as long as they are participating in a state-sponsored program8.

The CWT has brokered some agreements between water right holders and the CWCB, in which an irrigator fallows their land in the late season and transfers a certain amount of water for instream flow purposes. One agreement, which was the first in the state to invoke the 2013 law, allowed a rancher on Willow Creek to divert less water during times of low flows. The rancher was able to transfer water for five out of ten years without lowering the value of his water right (Holm, 2015; Postel & Reeve, 2015). In a project on Deep Creek, water was not diverted in August to increase stream flows. A rancher reduced his irrigated acreage in the summer, and the CWT paid him the value of the foregone hay and alfalfa. A similar lease agreement on the Tomichi Creek stipulates that the landowners can use early season water to irrigate hay meadows and pasture grass but in July or August diversions will cease and the foregone water will be used by the CWCB’s instream flow program (CWT, 2015).

The CWT is in the process of establishing the first permanent water-sharing agreement for agricultural and environmental purposes in Colorado. A 5-mile section of the Cimarron River below the McKinley Ditch is often dried up in late summer. Under the proposed agreement, farmland on the ditch will be irrigated only in the first half of the irrigation season with no irrigation later in year (Buchanan, 2015; CWT, 2015). The ranch that irrigates the land is owned by a conservation organization, Western Rivers Conservancy. The CWT believes that this arrangement can serve as a model for private agricultural water users (Ross, 2015b). The CWT and CWCB have filed in Water Court for a change of use to add an

8 In Colorado, the value of a water right is determined by its actual historic consumptive use, not by the total diversion amount in the water right decree. The determination of historic consumptive use is part of the process of changing the water right in a sale.
instream flow right. Two nearby landowners have filed statements of opposition to make sure that their water rights are not impacted by the transfer (Gardner-Smith, 2015).

5.2 Colorado Compact Water Bank

Under the Colorado River Compact, if the Upper Basin states were to cause the flow at Lee Ferry, Arizona to fall below 75 MAF during any consecutive 10-year period, the Upper Basin states would have to curtail their diversions. Known as “compact curtailment”, these reductions would in theory fall on post-compact diverters, a class that includes most of Colorado’s Front Range cities. The Water Bank Work Group is currently examining the feasibility of a water bank in Colorado to mitigate the negative effects of a compact curtailment. The group is made up of representatives from the Colorado River Water Conservation District, Colorado Water Conservation Board, Front Range Water Council, Southwestern Water Conservation District, and The Nature Conservancy. The bank would compensate agricultural water users to conserve water through deficit irrigation or split-season fallowing. This “saved” water would come from pre-Compact (pre-1922 or possibly pre-1929) water rights than are not subject to curtailment and these diverters would then lease the saved water to users who rely on post-Compact water rights. (Moving Forward, 2015; MWH, 2012).

The study is broken up into three phases: (1) quantifying potential supply and demand, (2) analyzing the feasibility of deficit irrigation on current irrigation systems and how to measure reductions in consumptive use, and (3) examining regional economic and environmental effects. Deficit irrigation would be the best suited method to reduce consumptive use because much of the area in the study involves alfalfa and grass pasture (over 90 percent). After calculating the maximum potential consumptive use available from deficit irrigation and full fallowing, and applying a series of supply-use scenarios, the Water Bank could potentially provide up to 200,000 acre-feet of water per year. The bank could not provide water for all Colorado River depletion curtailments, but it would still be a significant amount. The Water Bank, however, would require a high level of participation among West Slope irrigators to provide such a large amount of water. To produce such savings, the amount of land put under deficit irrigation would be significant: 130,000 to 260,000 acres (MWH, 2012).

Phase 2 of the study examined how participating in the bank would affect irrigation system operations and included an outreach program toward the agricultural community. The study used eight test case irrigation systems that were representative of the systems in Western Colorado and consisted of irrigation organizations that were private, public, federal, tribal, small, large, high elevation, low elevation, and different crops.

One finding is that using deficit irrigation on land used to grow alfalfa and grass hay for cow-calf operations may be difficult. High-elevation grass pastures only have 1-2 cuttings per season and are generally used to feed cattle. There are concerns that reductions in forage yields may affect the size and quality of herds. Ranchers are reluctant to import hay as opposed to using their own. On lower elevation ranches and farms, alfalfa and grass is treated more as a commodity and has much more potential for deficit irrigation and split-season fallowing. The Water Bank would need to be able to quantify the unused consumptive use on farms and ranches on the West Slope, which could be challenging to do if there were broad participation. It is unlikely that any irrigation system has the measurement capabilities or historical data to compute consumptive use savings (MWH, 2014).
Another component of this phase looked at the agronomic effects of deficit irrigation on alfalfa and grass hayfields and found that deficit irrigation may slightly improve quality but will significantly reduce yields. Grass fields will have more difficulty recovering from limited irrigation, but alfalfa fields can recover depending on the length and severity of the deficit irrigation regime. The best scenario in the Upper Basin may be stopping irrigation after the second cutting of alfalfa fields for two consecutive years (Jones, 2015). Lower Basin plants will likely require additional cuttings and water application before ceasing irrigation.

5.3 Colorado River System Conservation Pilot Program

In 2014, the Central Arizona Project, Denver Water, the Metropolitan Water District of Southern California, Southern Nevada Water Authority, and the Bureau of Reclamation provided $11 million to fund water conservation projects in the Colorado River System. This approach attempts to address a possible future water shortage through a basin-wide effort, where projects in the Upper Basin can help reduce the threat of Upper Basin Compact curtailment and projects in the Lower Basin can help alleviate the structural deficit in Lake Mead. The Bureau solicited proposals from agricultural, municipal, and industrial water users to create temporary and voluntary projects to reduce demand for water on the river and restore water levels in Lakes Mead and Powell. The Upper Colorado River Commission administers the program in the Upper Basin, while the Bureau administers program in the Lower Basin (USBR News Release, 2014).

For 2015, five projects were approved in Wyoming and five in Colorado. For the Lower Basin, there were two projects in Arizona and one in Nevada. Nine of the Upper Basin projects were agricultural. Full information on the projects is not yet available, especially Lower Basin projects, but some limited information on the Upper Basin projects has been provided by various participants.

In Colorado, two of the five projects involved split season irrigation. The Carpenter Ranch, operated by The Nature Conservancy, was the first to be awarded funding from the program. The ranch experimented with split season-fallowing and terminated irrigation in fields at the beginning of July to measure the impacts on the river and ranch (Ross, 2015a). A total of 197 acres of hay were involved in the project (Ross, 2016). A two-year project also began in the Lower Uncompahgre and Lower Gunnison Rivers, where alfalfa was only irrigated for half the season on four properties (Henrie, 2016). Also, included in these projects were two fallowing projects (corn) and a municipal transbasin project. For Colorado, a total of 829 AF was conserved at a cost of $379 per acre-foot (Henrie, 2016).

In Wyoming, five split season fallowing projects were implemented along the Green River and its tributaries. Participating irrigators agreed to fallow alfalfa and native grass in the late summer to increase flows in the Green River. In return, they were compensated roughly 200% of what they would have earned from the hay produced. This sum included an amount per acre for weed abatement and a premium for being willing to participate in the program (Toye, 2015). A total of 2,178 acres were fallowed, saving 1644 AF at a cost of $200 per acre-foot (Henrie, 2016).

5.4 Colorado State Engineer Rules on Alfalfa and Grass for Temporary Fallowing

Colorado’s HB13-1248, codified at CRS 37-60-115(8), allows for pilot fallowing-leasing projects within the state. The guidelines say that “All parcels containing alfalfa or pasture grass shall be subject to a reduction in the approved amount of transferrable consumptive use if the field is subirrigated”
(Colorado Water Conservation Board & Colorado Division of Water Resources, 2013). The State Engineer’s calculations, shown below, significantly reduce the transferable consumptive use if groundwater for sub-irrigation is available. At one foot depth, the reduction for alfalfa is 100% and pasture grass is 85%, and at four feet the reduction is 50% for alfalfa and 20% for pasture grass.

Table 4: Colorado state engineer reduction for alfalfa and pasture grass consumptive use credits based on depth to groundwater. Source: Colorado State Engineer (2013).

<table>
<thead>
<tr>
<th>Depth to Groundwater (ft)</th>
<th>Percent Reduction in Consumptive Use Credit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pasture Grass</td>
</tr>
<tr>
<td>1</td>
<td>85%</td>
</tr>
<tr>
<td>2</td>
<td>50%</td>
</tr>
<tr>
<td>3</td>
<td>30%</td>
</tr>
<tr>
<td>4</td>
<td>20%</td>
</tr>
<tr>
<td>5</td>
<td>15%</td>
</tr>
<tr>
<td>6</td>
<td>10%</td>
</tr>
<tr>
<td>7</td>
<td>5%</td>
</tr>
<tr>
<td>8</td>
<td>0%</td>
</tr>
<tr>
<td>9</td>
<td>0%</td>
</tr>
</tbody>
</table>
6 References


MWH. (2012). *Colorado River Water Bank Feasibility Study: Phase 1*.


7 Appendix: Alfalfa Studies Investigated

<table>
<thead>
<tr>
<th>Type of Study</th>
<th>Location</th>
<th>Time Period</th>
<th>Soil</th>
<th>Cultivar</th>
<th>Method</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deficit Irrigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Alfalfa)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Split-Season (Orloff et al., 2014)</td>
<td>Intermountain California</td>
<td>Medium texture</td>
<td></td>
<td>DI after 1st and 2nd cutting</td>
<td>No observed difference on future yield or stand loss</td>
</tr>
<tr>
<td>2</td>
<td>Split-Season (Orloff et al., 2014)</td>
<td>Sacramento Valley, California</td>
<td>Medium texture</td>
<td></td>
<td>DI in early summer (July) and early summer with fall irrigation</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Split-Season (Orloff et al., 2014)</td>
<td>Palo Verde Valley, California</td>
<td>Sandy soil</td>
<td></td>
<td>No summer irrigation and a single irrigation in July</td>
<td>One field recovered and one field had significantly reduced future yields and stand loss</td>
</tr>
<tr>
<td>4</td>
<td>Split-Season (Hanson et al., 2007)</td>
<td>Davis, California</td>
<td>2003-2006</td>
<td>Clay loam</td>
<td>DI in July and August w/o fall irrigation, and deficit irrigation in July and August with fall irrigation</td>
<td>No significant difference in the future spring yields of DI and fully irrigated plots. DI Alfalfa had lower NDF and higher crude protein</td>
</tr>
<tr>
<td>5</td>
<td>Split-Season (Metochis &amp; Orphanos, 1981)</td>
<td>Athalassa, Cyprus</td>
<td>1978-1980</td>
<td>Fine sandy loam</td>
<td>Local (composite of Provence)</td>
<td>Only impact on future yields was when DI was withheld for all 3 growth periods.</td>
</tr>
<tr>
<td>6</td>
<td>Split-Season (Takele &amp; Palo Verde Valley, California)</td>
<td>1997-1998</td>
<td>Silty clay loam</td>
<td>UC Cibola</td>
<td>Water withheld for 35, 70, and 105 days</td>
<td>DI longer than 35 days impacted future yields by at</td>
</tr>
<tr>
<td>Year(s)</td>
<td>Location</td>
<td>Management</td>
<td>Results</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------</td>
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<td>------------</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>Kallenbach, Malin, Oregon</td>
<td>Fine sandy loam</td>
<td>DI after 1st and 2nd cutting</td>
<td>least 20% and increased stand loss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>Split-Season (Orloff et al., Malin, Oregon</td>
<td>Silt loam with a high organic matter content</td>
<td>DI after 1st and 2nd cutting</td>
<td>No observed difference on future yield or stand loss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>Split-Season (Orloff et al., Malin, Oregon</td>
<td>Clay loam</td>
<td>DI midsummer and DI midsummer with fall irrigation</td>
<td>No observed difference on future yield or stand loss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990-1992</td>
<td>Split-Season (Orloff et al., Yuma, Arizona</td>
<td>Supersition sand</td>
<td>CUF 101</td>
<td>DI from July - Oct, and Nov - Feb</td>
<td>Significant stand loss and severe reduction in yields</td>
<td></td>
</tr>
<tr>
<td>1990-1992</td>
<td>Split-Season (Ottman et al., Maricopa, Arizona</td>
<td>Sandy loam</td>
<td>CUF 101</td>
<td>DI from Aug - Mar and Aug - Sept</td>
<td>Yields recovered in the first regrowth. Stand loss similar to normal irrigation</td>
<td></td>
</tr>
<tr>
<td>1981-1984</td>
<td>Split-Season (Guitjens, Fallon, Nevada</td>
<td>Loamy sand to a loamy fine sand</td>
<td>Pacer</td>
<td>Irrigation for only 2, 3, and 4 harvests</td>
<td>All yields recovered when normal irrigation resumed</td>
<td></td>
</tr>
<tr>
<td>2006-2007</td>
<td>Split-Season (Lindenmayer et al., Berthoud, Colorado</td>
<td>Clay loam</td>
<td>Dairyland Magna Graze</td>
<td>DI after 1st and 2nd cutting, and DI during summer</td>
<td></td>
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<td></td>
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<td>---</td>
<td></td>
</tr>
</tbody>
</table>
| 1 | Split-Season (Wissuwa & Smith, 1997) | Tucson, Arizona | 1994-1995 | Clay loam | Arizona 91 Arabian Composite | DI for 84 days, and DI for 42 days year one and 75 days year two  
High plant mortality for 84 days, but normal decline (1.5%) for second treatment. Higher yields after 42 days than control. Crown mortality related to concentration of total nonstructural carbohydrates |
| 2 | Split-Season (Schonhorst et al., 1963) | Southern Arizona | 1959-1962 | Moapa | DI from July - Aug | Not a significant different in yield or stand loss |
| 3 | Split-Season (Jones, 2015) | Western Colorado (Fruita, Eckert, Yellow Jacket) | 2013-2014 | Loam, clay loam, and silty clay | DI after 1st and 2nd cutting | Lower yields in first cutting next spring |
| 4 | Regulated Deficit Irrigation (RDI) (Carter & Sheaffer, 1983) | Becker, Minnesota | 1980-1981 | Loamy sand | Iroquois | Treatments were a percent (0, 33, 66, and 100) of keeping soil water levels at optimal capacity  
66% irrigation had similar yields to 100% |
| 5 |    | Southeastern North Dakota | 1973-1976 | Sandy loam (moderately coarse) | Vernal | No irrigation, and deficient, optimum and excessive of required ET  
Harvest of deficient treatment was slightly lower than optimum and excessive treatments |
<table>
<thead>
<tr>
<th>No.</th>
<th>Study Details</th>
<th>Location</th>
<th>Year(s)</th>
<th>Soil Type</th>
<th>Cultivar</th>
<th>Irrigation Strategy</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RDI (Davis et al., 1963)</td>
<td>Davis, California</td>
<td>1962</td>
<td>Silty clay</td>
<td>Lahontan</td>
<td>A percent (25, 50, 75, 100, 150, and 200) of depth of irrigation to achieve optimum soil moisture, and an additional 75 and 100% with no winter irrigation</td>
<td>A slight decrease in yield with 75%. Treatments without winter irrigation did not have significant decreases in yield. First 2 cuttings, not influenced by irrigation. Protein and carotene were lower as applied water increased</td>
</tr>
<tr>
<td>2</td>
<td>RDI (Jensen et al., 1988)</td>
<td>Wadsworth, Nevada</td>
<td>1984-1985</td>
<td>Sandy loam</td>
<td>Lahontan and L-720</td>
<td>A percent (50, 75, 100, and 125) of FAO Pan Evaporation</td>
<td>Decrease in yields for 125% treatment</td>
</tr>
<tr>
<td>2</td>
<td>RDI (Donovan &amp; Meek, 1983)</td>
<td>Imperial Irrigation District, California</td>
<td>1975-1978</td>
<td>Clayey loam</td>
<td>Mesa Sirsa and Salton</td>
<td>A percent (56, 66, 75, 84) of pan evaporation and 56 and 75% with a winter leaching treatment</td>
<td>The 84% treatment had extensive stand loss and lower yields. 75% had the highest yields. The 75% with winter leaching had lower yields but the 56% with leaching had higher yields than the standard 56%</td>
</tr>
<tr>
<td>2</td>
<td>RDI &amp; Split-Season (Frate &amp; Roberts, 1991)</td>
<td>Fresno County, California</td>
<td>1986-1988</td>
<td>Sandy loam</td>
<td>CUF 101</td>
<td>Irrigation 2 times per cutting and 3 during summer (wet), 2 times per cutting (standard), 1 time per cutting (dry), DI in July and August, and July termination</td>
<td>No treatments had a negative impact on future yields. Standard irrigation produced higher yields than wet</td>
</tr>
<tr>
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</tr>
<tr>
<td>2 3</td>
<td>RDI &amp; Split-Season (Bauder et al. 2014)</td>
<td>Fort Collins, Colorado</td>
<td>2007-2009</td>
<td>Clay loam</td>
<td>RDI was once a week and only 1.5 inches of water and DI termination after 1st cutting</td>
<td>No significant stand loss for both treatments. DI after 1st cutting caused a 15% decline in next spring harvest</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Yield and ET (Alfalfa)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>2 5</td>
<td>ET (Wright, 1988)</td>
<td>Southern Idaho</td>
<td>1969-1975</td>
<td>Sily loam</td>
<td>Ranger</td>
<td>ET was highly variable on a daily basis and seasonal ET was about 50% greater than previously reported for the area. ET was highest in July and Aug</td>
<td></td>
</tr>
<tr>
<td>2 6</td>
<td>Yield (Sammis, 1981)</td>
<td>Las Cruces, New Mexico</td>
<td>1978-1979</td>
<td>Fine sand to clay loam</td>
<td>Mesilla, Moapa, and Hairy Peruvian, and Acala cotton 1517-V</td>
<td>Yield is linear of ET for alfalfa and cotton. Similar water-production function throughout NM</td>
<td></td>
</tr>
<tr>
<td>2 7</td>
<td>Yield related to ET, growth stage, and environment (Smeal et al., 1991)</td>
<td>Farmington, New Mexico</td>
<td>1981-1987</td>
<td>Sandy loam</td>
<td>WL 309</td>
<td>Uniform irrigation</td>
<td>Seasonal yield is a function of ET and year. Yield is maximized during the fifth year and minimized during the first. Yield/ET increases with more solar radiation.</td>
</tr>
<tr>
<td>2</td>
<td>Yield and cultivars (Undersander, 1986)</td>
<td>Bushland, Texas</td>
<td>1983-1985</td>
<td>Clay loam</td>
<td>Vanguard, Cody, Zia, and Dawson</td>
<td>No significant difference between 4 cultivars. CU increased with yield.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Yield and cultivars (Grimes et al., 1992)</td>
<td>San Joaquin Valley, California</td>
<td>1985-1986</td>
<td>Sandy loam</td>
<td>WL 318, CUF 101, and Moapa 69</td>
<td>WL 318 had a greater yield in the spring, but lower in the summer. Total seasonal yields were not different</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Yield and ET of alfalfa and corn (Retta &amp; Hanks. 1980)</td>
<td>Logan, Utah</td>
<td></td>
<td></td>
<td>Alfalfa: Ladak, Washoe, and Masilla, and 5 corn varieties</td>
<td>Cultivars were treated with variable irrigation levels to see response in yield</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Yield and ET (Fransen &amp; Kugler, 2003)</td>
<td>Central Washington</td>
<td>two years</td>
<td>Silt loam</td>
<td>Vernal</td>
<td>A greater growth rate and shorter growth period with increased temperatures contribute to reduced yield</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Seed yield and ET (Cohen et al., 1972)</td>
<td>Coastal Plain Israel</td>
<td>Clay loam</td>
<td>Hairy Peruvian</td>
<td>Irrigation timing at day 10 or 23 or both</td>
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<td>Period</td>
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<td>1973-1978</td>
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<td>Study</td>
<td>Location</td>
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<td>Soil Type</td>
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<td>No loss in hay yield. Increased soil salinity. Less stand loss</td>
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**Adaptive Studies (Alfalfa)**

|   | South Carolina (Piedmont and Coastal Plain) | Sandy loam and loamy sand | Vanguard and cultivars with greatest adaptive potential to region | Normal irrigation | Significant stand loss. Irrigated alfalfa is a marginal practice in the area | No loss in hay yield. Increased soil salinity. Less stand loss | Yield response is more related to salinity of irrigation water than the salinity of the drainage water | Must use irrigation to achieve maximum yields in the region |
| **48** | Split-Season DI on pasture grasses (Orloff et al., 2014) | Tulelake, California | Organic clay loam | 26 perennial grasses | DI after 1st and 2nd cutting | For most crops, dramatic losses of future yields and stand loss. Tall fescue performed the best |
| **49** | Split-Season DI on pasture grasses (Jones, 2015) | Multiple sites in western Colorado | 2013-2014 | Loam and sandy loam | Cool-season grasses and legumes | No irrigation | Grasses did not fully recover, second year produced 49% of control |
| **50** | Moisture use of forage crops (Cohen & Strickling, 1968) | Upper Marlboro, Maryland | 1959 | Sandy loam | Alfalfa, tall fescue, and bermudagrass | Examined CU and yield | Alfalfa and tall fescue require similar amounts of water for the same yield. Crops did not extract much water from deeper in the soil profile |
Agricultural Water Conservation in the Colorado River Basin: Alternatives to Permanent Fallowing Research Synthesis and Outreach Workshops

Part 3 of 5

Rotational Fallowing in the Colorado River Basin: A Literature Review and Case Studies

Brad Udall
Greg Peterson

Colorado Water Institute
Colorado State University

December 2017

CWI Completion Report No.232
Acknowledgements

This report was financed in part by the U.S. Department of the Interior, Geological Survey, through the Colorado Water Institute. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

Additional copies of this report can be obtained from the Colorado Water Institute, E102 Engineering Building, Colorado State University, Fort Collins, CO 80523-1033 970-491-6308 or email: cwi@colostate.edu, or downloaded as a PDF file from http://www.cwi.colostate.edu.

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Project Background

This document is one of four separate reports created under a grant from the Walton Family Foundation to investigate ways to minimize harm to agriculture as water scarcity in the Colorado River Basin forces growing municipal and environmental water users to look at existing uses as potential sources of supply. Agriculture, the largest water user in the basin, is a frequent target in these efforts. The project, “Agricultural Water Conservation in the Colorado River Basin: Alternatives to Permanent Fallowing Research Synthesis and Outreach Workshops” was undertaken to create detailed reports of the four common methods used to temporarily transfer water from agriculture to other purposes. The four reports consider the following methods:

- Deficit Irrigation of Alfalfa and other Forages
- Rotational Fallowing
- Crop Switching
- Irrigation Efficiency and Water Conservation

After the reports were drafted, three workshops were held, one in the Upper Basin in Grand Junction on November 4, 2016, one in the Lower Basin in Tucson on March 29, 2017, and one in Washington, D.C. on May 16, 2017. All of the reports are available from the Colorado Water Institute website.

Acknowledgements

First, Greg Peterson and I thank the Walton Family Foundation for making this project possible. Without their funding and support, the project would not have happened.

Many people assisted with this project by reading and providing comments on drafts. We want to especially thank Perri Benemelis, Mike Bernardo, Perry Cabot, Aaron Citron, Michael Cohen, Bonnie Colby, Terry Fulp, Robert Glennon, Bill Hasencamp, Chuck Howe, Carly Jerla, Dave Kanzer, Doug Kenney, Kelsea MacIlroy, Jan Matusak, Sharon Megdal, Peter Nichols, Wade Noble, Michael Ottman, Ron Raynor, Adam Schempp, Tina Shields, MaryLou Smith, Pete Taylor, Reagan Waskom, John Wiener, and Scott Wilbor. Paul Kehmeier contributed a lovely photograph and important story. The final product was much improved by these insightful comments. It must be noted that any mistakes are solely mine.

Nancy Grice at the Colorado Water Institute provided critical support with financial reporting, travel assistance and working with Colorado State University. MaryLou Smith was instrumental in organizing and chairing the outreach workshops. Reagan Waskom provided much needed intellectual support throughout the project. Beth Lipscomb assisted with overall editing at the end. A very special thanks goes to my co-author, Greg Peterson, who did much of the early, difficult research and writing. Much of the value of this project is in the extensive bibliographies that Greg created by painstakingly acquiring, reading and summarizing hundreds of documents.

We thank Senator Michael Bennet and his staff for acquiring a room at the Capitol Visitor Center for the DC event. Finally, we extend our sincere appreciation to the approximately 100 participants who shared their precious time to join us for our outreach workshops. Thank you, all.

Brad Udall
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<tr>
<td>ALWT</td>
<td>Arizona Land and Water Trust</td>
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<td>CAGRD</td>
<td>Central Arizona Groundwater Replenishment District</td>
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<td>CAP</td>
<td>Central Arizona Project</td>
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<tr>
<td>CBT</td>
<td>Colorado Big Thompson Project</td>
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<td>CEQA</td>
<td>California Environmental Quality Act</td>
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<td>CRA</td>
<td>Colorado River Aqueduct</td>
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<td>CRS</td>
<td>Colorado Revised Statutes</td>
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<td>CVWD</td>
<td>Coachella Valley Water District</td>
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<td>CWCB</td>
<td>Colorado Water Conservation Board</td>
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<td>CWIC</td>
<td>Colorado Water Innovation Cluster</td>
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<td>DWR</td>
<td>Colorado Division of Water Resources</td>
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<td>ICS</td>
<td>Intentionally Created Surplus</td>
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<td>IID</td>
<td>Imperial Irrigation District</td>
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<td>IWSA</td>
<td>Interruptible Water Supply Agreement</td>
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<td>LAVWCD</td>
<td>Lower Arkansas Valley Water Conservancy District</td>
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<td>LCOLP</td>
<td>Larimer County Open Lands Program</td>
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<td>LFT</td>
<td>Lease Fallowing Tool</td>
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<tr>
<td>kaf</td>
<td>Thousand Acre-feet</td>
</tr>
<tr>
<td>maf</td>
<td>Million Acre-feet</td>
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<tr>
<td>MVIC</td>
<td>Montezuma Valley Irrigation Company</td>
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<td>MWD</td>
<td>Metropolitan Water District of Southern California</td>
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<td>NEPA</td>
<td>National Environmental Policy Act</td>
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<td>NSID</td>
<td>North Sterling Irrigation District</td>
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<td>PVID</td>
<td>Palo Verde Irrigation District</td>
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<td>QSA</td>
<td>Quantification Settlement Agreement</td>
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<td>SDCWA</td>
<td>San Diego County Water Authority</td>
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<td>SDS</td>
<td>Southern Delivery System</td>
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<td>SWSP</td>
<td>Substitute Water Supply Plan</td>
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<td>WMIDD</td>
<td>Wellton-Mohawk Irrigation and Drainage District</td>
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<td>YMIDD</td>
<td>Yuma Mesa Irrigation and Drainage District</td>
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1 Summary

Rotational fallowing, also known as lease-fallowing, is the act of temporarily fallowing farm land to save water for other purposes. Rotational fallowing has been used for more than twenty-five years in the Colorado River Basin. Unlike some of the other methods of saving water, such as crop switching and deficit irrigation, temporary land fallowing is a proven, successful strategy for conserving significant amounts of water with a long history of on-the-ground projects in the Colorado River Basin. Although there can be significant issues with quantifying the actual water savings from fallowing, there is little doubt that fallowing does save water.

1.1 Negotiations are Complex

Leasing-fallowing negotiations often take a long time before finding a successful combination of price, land, water amounts, agreement length, and other terms. These agreements are three-party agreements with each party -- the buyer, the sellers, and the irrigation district – having distinct needs. The Metropolitan Water District of Southern California (MWD) – Palo Verde Irrigation District (PVID) agreement in 2004 was preceded by a two-year trial, nearly ten years earlier. Persistence has been key for the Colorado’s Lower Arkansas Valley Super Ditch1 which suffered several false starts but now has on-the-ground projects. Fallowing in the Imperial Irrigation District was part of the larger California Quantification Settlement Agreement in 2003. The agreements are unique to each area and cannot easily be replicated. Efforts generally require complex negotiations, multiple studies on environmental and tax consequences among others, and complicated legal documents to enact.

1.2 Impacts to Nearby Communities

Fallowing agreements need to consider the impact to nearby communities. Agricultural communities and irrigation districts have important economic ties and the impacts of fallowing go beyond the irrigation district and individual farmers. Local agricultural suppliers can suffer from decreased purchases of crop inputs and services, as well as the displacement of jobs associated with the fallowed fields. Other, broad third-party impacts are also in play, including decreased retail sales, sales taxes, and property taxes, which can negatively impact and harm the overall community. In some recent fallowing agreements, relatively large community funds provided by the purchaser have been a part of the arrangement to provide economic support and mitigation for displaced individuals and businesses.

1.3 Agronomic Advantages and Disadvantages of Rotational Fallowing

Rotational fallowing to conserve water should provide many of the benefits of traditional land fallowing for soil health, future yield increases and pest management. These benefits, however, have been much less studied than the water conservation savings, and remain mostly unquantified. Rotational fallowing could be part of a larger, purposeful crop rotation plan to provide these additional benefits, while producing income for a farmer from a fallowed field.

One negative soil impact seems clear. In areas with salty subsurface moisture, which includes most areas

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1 The term “Super Ditch” implies a single physical ditch. The program is, in fact, a joint effort of shareholders on multiple existing ditches in the region.
in the Colorado River Basin, capillary action can move subsurface salt to the soil surface during fallowing and hence a pre-planting leaching irrigation to remove these salts following the fallowing period is often necessary. This leaching water reduces the water savings from fallowing, to the extent that it was not otherwise needed.

1.4 Field Management Issues

All fallowing programs require that bare fields be managed to prevent weeds, avoid topsoil erosion, and control dust. Most agreements require the landowners to sign documents stating that they will perform this work at their cost, or else fallowing payments will be either reduced or withheld. Monitoring efforts need to make sure that the enrolled fields are actually fallowed, and that proper land management activities are undertaken.

1.5 Quantification of Water Savings

Quantifying the water savings of fallowing can be complicated. Several different approaches have been used. A generic, but difficult approach, would be to make assumptions about the exact crop that would have been grown, its expected yield (thus, total crop consumptive water use) reduced by precipitation supplied by nature. In small falling arrangements, a per-acre water savings has often been stipulated. In large irrigation districts with substantial acreage devoted to fallowing such as PVID, the difference in headgate diversions in fallowed years versus non-fallowed years, minus assumed return flows, can be used as an approximation.

In Colorado’s Arkansas River Basin, the State Engineer developed a spreadsheet-based tool to perform calculations on each enrolled tract to determine consumptive use, and the return flows needed to keep downriver users whole.

1.6 Case Studies

Rotational fallowing was originally pursued by the Metropolitan Water District of Southern California in the Palo Verde Irrigation District in the early 1990s. This test case led to a 35-year agreement signed in 2004. Total fallowed acreage has ranged from 6,500 to almost 40,000 acres\(^2\) with water savings ranging from 25,000 to almost 120,000 acre-feet per year. Metropolitan has more recently pursued a small test summer fallowing with the Bard Irrigation District near Yuma. As part of its agreement with the San Diego County Water Authority, since 2003 the Imperial Irrigation District has also been fallowing lands to provide mitigation flows into the Salton Sea with over 700,000 acre-feet generated for the Sea and another 700,000 acre-feet for municipal purposes. This fallowing ends in 2017, with further municipal deliveries to San Diego provided by efficiency improvements. In Colorado, the SuperDitch, a collection of ditches, has been created by farmers in the Arkansas River valley to provide income for farmers and water for cities. In 2004, the city of Aurora, Colorado successfully pursued fallowing in the Arkansas Basin in the midst of a severe drought to provide about 7,500 acre-feet generated for emergency supplies. In 2005, Colorado Springs joined with Aurora to extend the agreement for an additional year. The extension was used to refill depleted reservoirs with about 10,000 acre-feet of water.

\(^2\) The 2004 agreement only allows for a maximum of 26,000 fallowed acres. A later additional emergency fallowing agreement increased this amount by an additional 13,000 acres in one year.
2 Introduction

Since the early 1990s, within the Colorado River Basin and elsewhere in the West, paid temporary rotational fallowing has proven to be an effective strategy for providing drought supplies for municipalities, for increasing environmental flows and for maintaining reservoir levels. For this chapter, rotational fallowing is defined as the process of not planting and not irrigating an annual crop for a season or multiple seasons with the intention of resuming irrigation at some future point. The act of not irrigating perennial crops such as alfalfa and grasses is a similar concept except that these crops can enter dormancy and survive despite the lack of irrigation if done properly. This related, but in practice very different concept, is covered in the chapter on Deficit Irrigation.

Temporary land fallowing as part of a purposeful crop rotation plan has a long agricultural history and was historically used to improve soil health, improve yields, and reduce crop pests and plant diseases. In recent decades in the West, however, rotational fallowing has been used on irrigated lands for a new purpose: to conserve water. Rotational fallowing to conserve water on irrigated land now exists in many places and in a variety of forms across the West.

The original 1992-1994 MWD-PVID test fallowing program began twenty-four years ago, ten years later a thirty-five-year program covering approximately 25 percent of all PVID Valley lands was established. In 2003, IID agreed to a 15-year fallowing program to provide water for San Diego County Water Authority and for the Salton Sea through an exchange with MWD. Other programs in Yuma, Arizona and the Lower Arkansas Valley in Colorado were established more recently, cover less acreage, and will last for a much shorter period. In 2016, MWD and the Bard Water District near Yuma implemented a pilot seasonal fallowing program (MWD, 2016b). In the last decade, some short-term fallowing agreements have been created to handle an immediate crisis. In response to a statewide drought, for example, the Arkansas Valley High Line Canal Company transferred water to Aurora, Colorado in 2004 and 2005 and in 2009 MWD and PVID agreed to a one-year emergency program. The High Line – Aurora agreement led to a longer-term arrangement which put in place an already successful, known mechanism for minimizing a potential municipal future water supply crisis, be it from drought or infrastructure failure.

The focus of this chapter is to investigate how rotational fallowing programs have been implemented, and their benefits and disadvantages. The case studies make up a large portion of the material. Two cases discussed were not successful, but were included because they provide important insights into some of the obstacles that must be overcome.

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3 This practice is also referred to as “lease-fallowing.” The “rotation” in “rotational fallowing” signifies that participating farmers must not fallow the same piece of ground repeatedly. For example, in the PVID-MWD agreement, the same tract is to be fallowed for a minimum of twelve consecutive months and a maximum of five consecutive years. In the case of the Arkansas Valley Super Ditch, however, there has been some interest in fallowing potentially the same, less productive, ground over time.

4 There has also been some recent interest in providing farmers with a limited amount of water to plant a low water use cover crop on the fallowed ground. A cover crop would provide erosion and weed protection, and some soil benefits at the cost of increased water use. While the field would not be completely fallowed, most of the same concepts and issues arise. In the recent Catlin Pilot Project (see below) at least one farm planted a cover crop.

3 Traditional Fallowing vs. Rotational Fallowing

Temporary land fallowing for at least part of the year as part of normal crop rotations is not a new concept. It has a long agricultural history and many agronomic benefits (Karlen et al., 1994). Fallowing is the practice where during a growing season no crop is grown and instead all plant growth is controlled by cultivation or chemicals (Haas, Willis, and Bond, 1974). Fallowing techniques have been practiced for centuries and are still used in semi-arid and arid regions throughout the world (Karlen et al., 1994). Due to varying precipitation in the Great Plains, fallowing has been regularly used in dryland farming Western Canada and the United States (Greb et al., 1974). By forgoing a year of crop production, farmers can somewhat stabilize production instead of producing a variable amount every year. In the Great Plains, fallowing allows maximum water storage by increasing moisture content, trapping snow, and decreasing evaporation (Greb, 1979). Fallowing systems can vary in frequency by fallowing once every two years, every three years, or every four, etc. The frequency of fallowing, tillage, and weed control all have effects on the surface soil residue or crop residue, which are the materials left in a field after harvest (i.e. stalks, stems, leaf, seed, husks, roots). This, in turn, affects the soil structure, moisture storage, nutrients, microorganisms, erosion, and crop production, which have all been noted to be factors in plant growth (Nielsen and Calderon, 2011).

In different regions and with a variety of crops, fallowing can increase the soil water content over continuously cropped systems (Nielsen and Calderon, 2011). Uncontrolled weeds in fallowed fields can, however, deplete soil moisture. Depending on the soil management practices, the water use efficiency of crops can increase by 25 to 40 percent after fallowing (Hatfield, Sauer, and Prueger, 2001). Fallowing also maintains and can even increase the level of nitrogen in the soil through mineralization of organic matter (Smika, 1983; Campbell et al., 1990; Nielsen and Calderon, 2011). The amount of added nitrogen can be significant, sometimes allowing farmers to forego application of fertilizer (Cabot, 2014a). Unfortunately, fallowing is sometimes consistent with increases in soil salinity, although this can often be easily handled by leaching soil salts with pre-planting irrigation (Cusimano, 2013a; Cabot, 2014a). Some fallowing systems can also result in erosion risk because bare soil is exposed to both wind and water (Nielsen and Calderon, 2011) but residue management, clod plowing, and other techniques can minimize this risk. Organized fallowing programs call for farmers to control for weeds, erosion, and dust.

4 Land, Economic and Social Considerations

Fallowing has multiple land, economic, and social impacts, some of which can be detrimental. If fallowing is done at large scale these impacts need to be understood and mitigated to the best extent possible. The PVID – MWD 1992-1994 fallowing test case resulted in a post-event analysis of these impacts (Great Western Research, 1995) and before the 2004 agreement was signed, a California Environmental Quality Act (CEQA) analysis was performed (PVID 2002). Both documents provide interesting analyses of the multiple impacts of fallowing, and the ways in which such impacts can be reduced. In the case of Colorado’s Super Ditch a number of studies were also performed prior to the creation of the program (Nichols, 2011). This section briefly summarizes these issues, and they are also discussed under the Case Studies below.

4.1 Land Management Issues

Converting productive agricultural land into bare ground, even temporarily, creates several land management issues. Bare ground is subject to colonization by weeds, and those weeds can utilize
beneficial soil moisture and shallow groundwater, as well as spread to nearby cultivated fields. The weeds can also cause future weed control issues when the field is replanted. Bare ground is also subject to wind and water erosion of valuable topsoil. Fallowing programs generally require that the landowner control weeds and prevent erosion at the expense of the landowner. MWD, in falling agreements executed with PVID landowners, has the right to withhold payments if such control is not performed, or even perform the necessary actions and subtract the costs from the falling payments. Generally, landowner agreements spell out in detail the duties required to be performed by the farmer.

4.2 Effects on Land Productivity

There have been only two studies on the agronomic effects of rotational fallowing to conserve water on future crop yields and soil health.

A University of Arizona Master’s thesis in 2013 on the Palo Verde Fallowing Program found that fallowing has actually increased the quantity of nitrogen and carbon within soil, which helps plant growth (Cusimano, 2013b). The study noted that increased concentrations of surface salt from capillary action would require an application of leaching water prior to planting. Soils from fallowed and non-fallowed fields were tested throughout the valley, and then the plots were planted with broccoli in the fall to determine the effect on yield. The fields that were previously fallowed produced broccoli with a significantly higher marketable yield and total plant biomass than the fields that were continuously planted with crops. On average, the fallowed field produced more broccoli per acre (14,757 lbs./acre) than the fields that were not fallowed (13,803 lbs./acre), an increase of 7 percent (Cusimano, 2013a).

From 2009 to 2012 a falling study using irrigated corn as a control crop was performed to investigate changes in yield, nutrient availability, and profitability in Colorado’s Lower Arkansas Valley (Cabot, 2014b). The study was conducted as part of the Colorado Water Conservation Board’s (CWCB) Alternative Agricultural Water Transfer Methods Grant Program. Over the course of four years, a continuous corn plot was compared to 3 other fields with differing numbers of corn/fallow periods. Weeds dominated some of the fallowed sites despite significant expenditures on herbicides. The experimental program stipulated that no additional nitrogen would be applied to the fields after the first year, complicating yield comparisons with the nearby irrigated and fertilized corn control plot. Furthermore, droughts in 2011 and 2012 make yield comparisons difficult. Yields on fallowed plots were comparable to the control plot. Organic matter showed modest increases on fallowed fields compared to continuous corn. Nitrogen was retained on the fallowed fields, suggesting that nitrogen can carry over the winter months. Soil salinity increased modestly on most of the fallowed fields.

4.3 Community Socioeconomic Aspects of Rotational Fallowing

Community socioeconomic concerns need to be understood and potentially addressed for rotational falling to be a viable option. Often in specialized agricultural regions with little other economic activity, water transfers can have severe social and economic impacts with these regions incurring higher direct and indirect losses of income, tax receipts and jobs. In these communities, the losses will be greater on a per capita basis and will tend to persist over a longer period of time (Howe and Goemans, 2003). In some cases, however, more diverse local economies can be more severely impacted by water transfers because they may rely on local agricultural inputs for added-value production. Thus local agricultural service industries can be affected from large amounts of land falling (Thorvaldson and Pritchett, 2006).
The 1992 MWD-PVID test fallowing program did not plan for or attempt to compensate for community socio-economic impacts. Overall, an analysis of the regional economic impacts of the test fallowing program indicated that the program contributed to a modest decrease in regional employment—approximately 1.3 percent of average employment for 1991-92—but did not result in measurable changes in other regional economic performance indicators such as taxable sales, property tax revenues, and construction activity (M.Cubed, 1994). Approximately 61 percent of program payments were reportedly spent locally. MWD, in conjunction with its approval of the MWD-PVID 2004 agreement, provided $6 million for an economic development community improvement fund in the Palo Verde Valley. The SDCWA-IID agreement in 2003 provided for several actions including a large $50m fund, and the creation of a board to monitor and model these impacts. It should be noted that PVID is about 1/5 the size of IID in terms of acreage, and the Imperial Valley has several towns compared to the single town in PVID.

4.4 Measurements of Water Savings

Although it may seem simple to calculate the water saved by fallowing land, several complications arise which confound the quantification of water savings. First, in some cases there is the desire to quantify the actual consumptive use if farming had occurred. This requires knowing what would have been grown, what the weather was, and what the yield would have been. One could alternatively compare water diversions between years in which fallowing occurred and years in which it did not. However, weather, crop changes, changes in application efficiency and resulting return flows, and system operations can easily overwhelm numerical year-to-year differences, especially if the fallowed amount of land is a relatively small portion of the total ditch diversions. This method also must rely on knowing the return flows to net the consumptive use from diversions less return flows.

Different areas have derived different methods to calculate these savings. For PVID, Reclamation, PVID, and MWD generate an annual report using three different methods to calculate the savings (PVID, MWD, and Reclamation, 2014). For the Super Ditch, the Colorado State Engineer uses the Lease Fallowing Tool to calculate the savings (DWR, 2015a). In the case of the relatively minor fallowing in the Yuma area, a stipulated amount based on historical consumptive use per acre measured on a district-wide basis was part of the agreement (Reclamation and YMIDD, 2008).

4.5 Tax Considerations of Fallowing Payments

Fallowing payments to farmers can generate unusual tax consequences. Prior to the 2004 MWD-PVID fallowing program, lawyers issued guidelines to farmers about how to handle these payments (Downey Brand LLP, 2015). The memo indicated that the one-time sign-up payments could be subject to a lower capital gains tax rate rather than be considered ordinary income. The memo also indicated that annual rental payments would be considered ordinary income, but that the income could be offset by any management expenses associated with the fallowed land including weed control and dust measures. Tax issues also arose during the investigations into the Super Ditch in Colorado but these dealt with the tax implications of the corporate structure of the Super Ditch entity (Nichols, 2011).
5 Case Studies

5.1 California Cases

5.1.1 Palo Verde Irrigation District – MWD Land Management, Crop Rotation, and Water Supply Program

The original, best known, and most studied case of rotational fallowing in the Colorado River Basin involves an agreement between the Palo Verde Irrigation District (PVID) and The Metropolitan Water District of Southern California (MWD). The PVID is located in southeastern California along the Colorado River near Blythe, California, a city of approximately 20,000 residents, although 8,000 of these are prison inmates at two nearby state prisons. The district covers 189 square miles of land (~94,000 irrigated acres) in a valley approximately 30 miles long and 9 miles wide, and consists of 80 farmers farming an average of 1,250 acres (PVID, 2016). A long growing season, reliable and plentiful water supplies, and high temperatures have allowed the region to become a hub of agricultural production throughout the year. In recent years, crop values have ranged from $60m to nearly $160m (“PVID History”, 2016). While some high-value crops — such as lettuce, melons and citrus — are grown in the valley, two-thirds of irrigated acreage grows forage crops like alfalfa (“PVID 2014 Crop Report”, 2014). PVID diverts approximately 900 kaf/year from a single structure at the head of the valley and consumes about 450 kaf/year, with the remainder returning to the river through a large network of surface drains and subsurface return flows.

The PVID has the most senior California Colorado River water right and is unique in that it is quantified as the amount of water needed to irrigate 104,500 acres of land rather than a fixed volumetric amount. In order of decreasing seniority, this right is senior to the Yuma Project Reservation Division, the Imperial Irrigation District (IID), the Coachella Valley Water District (CVWD), and the Metropolitan Water District of Southern California. First appropriations in the area began in 1877, over thirty years before IID was established. The Palo Verde Valley forms a narrow, flat, fertile floodplain of the Colorado River and hence the irrigation infrastructure was relatively easy and inexpensive to construct. The Imperial Valley, by contrast, is a wide valley necessitating sub-canals, and many laterals, all of which are fed by a lengthy canal. The PVID Board is controlled by the farmers, with votes allocated on an acreage basis. This is unlike IID where all citizens can vote for the IID Board of Directors. This difference in governance has led to very different outcomes with respect to fallowing and relationships with MWD (Glennon, 2009b; Zetland, 2015).

MWD is the largest public utility in the United States and includes 26 cities, districts, and a county water authority in the Southern California region that supply 18.7 million people with water. MWD obtains its water from Northern California via the State Water Project and from the Colorado River via their Colorado River Aqueduct (CRA), and provides financial incentives to develop additional local supplies in

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6 Thomas Blythe filed the first California water right on the Colorado River in 1877 in the Palo Verde Valley. Although some early attempts were made to farm in the valley in the 1870s, farming at scale did not commence until much later in the early 20th century, contemporaneous with development in the Imperial Valley (“PVID History” 2016; Reclamation 1921). But because of Blythe’s early filing and a provision in PVID’s 1933 contract for delivery of water with the U.S. Bureau of Reclamation, it has the senior Colorado River right in California.
Southern California. The aqueduct was built from 1933 to 1939 and transports up to 1.2 maf/year 242 miles from Lake Havasu on the Colorado River into Lake Mathews in Riverside County (MWD, 2017).

MWD’s Colorado River water rights and use of the CRA are complicated by several factors. In 1929, California agreed to limit its water use from the Colorado River to 4.4 maf of the waters apportioned to the Lower Basin states by paragraph (a) of Article 3 of the Colorado River Compact annually, plus not more than one-half of any excess or surplus waters unapportioned by the Compact. But Compact paragraph (e) of Article 3 provides that the States of the Upper Division (Colorado, New Mexico, Utah, and Wyoming) shall not withhold water, and the States of the Lower Division (Arizona, California, and Nevada) shall not require the delivery of water, which cannot reasonably be applied to domestic and agricultural uses. MWD has (1) a 550 kaf/year Colorado River entitlement under a fourth priority within California’s 4.4 maf/year normal apportionment; (2) an additional 662 kaf/year entitlement under a fifth priority; and (3) a 180 kaf/year surplus entitlement. Prior to 2004, approximately half of the capacity in the CRA was subject to the 4.4 maf/year limitation. Between 1994 and 2002, the state’s average annual consumptive use was over 5.1 maf/year using water apportioned to, but unused by neighboring Arizona7 and Nevada and surplus water, which was made available by the Bureau of Reclamation in accordance with the U.S. Supreme Court Decree in Arizona v. California — with MWD being one of the beneficiaries of the available supply. In the 2003 Quantification Settlement Agreement, the California water contractors agreed to live within 4.4 maf/year except in ‘surplus’ years, with the burden of this limitation falling on MWD. MWD is assisted in meeting its obligations by nearly 300,000 af/year of ag-to-urban water transfers from IID to SDCWA, an MWD member agency.

Retail water demand in MWD’s service area varies from year to year, as does the availability of other water supplies. For example, total retail demand in MWD’s service area increased from 3.33 maf in 1995 to 3.94 maf in 2000, and declined to 3.80 maf in 2005, 3.35 maf in 2010, and 3.14 maf in 2015 as population increased from 15.7 million in 1995 to an estimated 18.7 million in 2015. Between 1994 and 2002, local supplies (surface water, groundwater, and recycled water) varied from 1.53 maf to 1.89 maf, Los Angeles Aqueduct supplies varied from 133,000 to 467,000 af, and State Water Project supplies varied from 0.45 maf to 1.80 maf.

Due to the variability in both retail demand and other water supplies available to MWD’s service area, MWD needed to use between 0.93 and 1.26 maf of Colorado River water in its service area between 1994 and 2002, a portion of which was water apportioned to, but unused by Arizona or Nevada, or surplus water. Thus, MWD has sought ways to keep the CRA full despite their water right limitations in non-surplus years.

5.1.1.1 1992-1994 Two-Year Fallowing Test Agreement8

In the late 1980s, MWD and PVID began to discuss a program to implement a rotational fallowing program in the Palo Verde Valley. The original negotiations stalled on price and other terms. A severe drought in California, along with depressed agricultural prices, brought the two parties to agreement in

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7 When Arizona’s Central Arizona Project Canal was completed in 1994, Arizona was able to utilize 1.9 maf of its 2.8 maf annual apportionment. Between 1994 and 2002 California’s average consumptive use was over 5.1 maf/year. This water use, along with other factors, prompted the 2003 Quantification Settlement Agreement.
8 A complete chapter in Rivers of Gold (Chapter 6, Haddad, 2000) is devoted to the details of this transaction, including the history before and after the program.
1992. A two-year test fallowing program began in 1992. Over sixty farmers participated and 22 percent of the total irrigated acreage in the PVID was fallowed. A post-event environmental analysis was conducted and it determined that there were no significant negative impacts from fallowing, mainly because the district implemented approved mitigation measures to preserve fallowed land (Great Western Research, 1995). The district, landowners, and the MWD were all satisfied with the results of the test program, which generated about 186 kaf at a cost of $25m in program payments to participating farmers or $135/acre-foot (MWD, 1995).

Farmers were paid $1240 per acre over the two-year period, or $620 per acre each year. The program ran from August 1, 1992 to July 31, 1994. Sixty-three contracts were executed, covering 20,215 acres out of the 80,336 “base” acres owned by the participating farmers. Fallowed acreage was thus 25 percent of the total base acreage, and 22 percent of the total cropped acreage of 93,000 acres. Over 73 percent of the fallowed acreage would have been planted in forages including alfalfa, Sudan grass and Bermuda grass. Of the remaining fallowed acreage, 16 percent would have been planted with cotton and small grains, and 11 percent would have been planted with melons and vegetables. The program was estimated to have generated 4.6 af/acre/year over the two years. This resulted in annual savings of 92,989 acre-feet and a two-year total of 185,978 acre-feet. Three different methods were used to calculate the actual water savings but at the outset the parties agreed to credit a fixed amount, 4.6 af per acre per year.

A post-fallowing analysis completed in 1995 indicated that there were few economic impacts in Blythe during the test period (Great Western Research, 1995). This was in part due to the city’s successful attempts to obtain state funding for two state prisons nearby beginning in the late 1980s. The principal findings of the study conducted to evaluate the economic impacts to program non-participants as well as the program’s overall impact on the regional economy were:

- The program was not found to have affected overall regional economic performance to any significant degree.
- The program was not found to have caused non-farm-related businesses in the region to reduce employment or lose revenue,
- Negative economic impacts of the program were concentrated within farm-related businesses providing services or supplies to the region’s farmers.
- The program was found to be only one of several causes for a reduced regional demand for farm-related labor, services, and manufactured inputs.
- A high proportion of program payments were injected into the local economy.

The saved water was protected by an agreement among PVID, IID, MWD and CVWD and the Bureau of Reclamation which allowed the water saved to be stored in Lake Mead for use by MWD (Haddad, 1999). At the time, the Secretary of the Interior had not issued conditions as to the accumulation, retention, release, and withdrawal of water in Lake Mead by Metropolitan, to which Metropolitan had the exclusive right in California by its 1931 Reclamation water delivery contract. In 1997, during a very large El Nino event, the water was spilled from Lake Mead when the Lake was drawn down for flood control (Haddad, 1999).

The issue of storage of water by a contractor in Lake Mead is now less problematic. First, the Department of the Interior’s 2007 Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead allow for “intentionally created surplus” (ICS)
water which can now be legally stored (Department of Interior, 2007). In addition, the existing supply and demand imbalance in the Colorado River Basin will grow in the future if the potential effects of climate change are realized and demands continue to increase. Lake Mead levels may not ever rise to the point where flood control becomes a problem. A different kind of problem, however, now exists with stored water. The ICS guidelines prevent the delivery of stored ICS water when the Secretary of the Interior has declared a shortage condition and could limit the amount of stored ICS water delivered when the Lake nears declared shortage levels. In 2015, for example, based on the May runoff forecast, the end of December projection of the elevation of Lake Mead was only 0.9 feet above the elevation at which a shortage condition would be declared for 2016, then a wet May in Colorado increased the June runoff forecast, resulting in the end of December projection of the elevation of Lake Mead being 6.6 feet above the shortage condition elevation. This allowed MWD to access water in 2015 that it had previously stored as ICS. From 2013 to 2015, MWD diverted water saved by the PVID-MWD falling program in the year it was saved. However, the inability to take delivery of ICS water during a shortage condition serves as a disincentive for future creation of ICS and storage of that water in Lake Mead.

5.1.1.2 2004 Long-Term Agreement

In August of 2004, PVID came to an agreement with MWD for a 35-year fallowing and forbearance program beginning January 1, 2005 and running until July 31, 2040 (PVID and IID, 2004). Participating farmers would fallow between 7 and 35 percent of their land on a rotating basis. From 6,493 to 25,947 acres can be fallowed in a given year depending on the amount of water required by the MWD. Landowners were paid an initial one time payment of $3,170 per water toll acre of the Landowner’s Maximum Fallowing Commitment (total $73.5 m) and an annual escalating payment of $602 ($789.89 in 2016) for each fallowed acre. In return, landowners must implement agreed upon land management practices on fallowed land, provide program related data, and pay PVID’s water toll and taxes. PVID is compensated annually by MWD to administer the program, a total of $225,000 in 2016. MWD estimates that the program will provide from 25,000 to 118,000 acre-feet/year (MWD, 2015) (MWD Brochure, Agreement). Nearly 90 percent of PVID landowners elected to participate in the program (Perry, 2015).

There were potentially significant tax implications of the agreement to local farmers. PVID commissioned a study to assist farmers with tax planning to handle these issues (Downey Brand LLP, 2015). To mitigate third party effects of rotational fallowing, the MWD provided $6 million to offset any local economic losses. The Community Improvement Fund, a nine-voting-member ad-hoc committee, developed a local and regional business plan to adapt to the decrease in agricultural activity. The money provided by the MWD has been used to provide loans to local business and grants to various nonprofit entities that serve the local community. As of July 2015, the fund has made available $5.4 million in loans to 23 local businesses and has provided more than $0.9 million in grants to various nonprofit

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9 The August 2004 agreement provided for landowners to make Landowner Participation Offers to Metropolitan and PVID in two tiers within 75 days of the Solicitation Notice. The first tier of a Landowner Participation Offer was to specify a Maximum Fallowing Commitment the landowner proposed to make, which was to not exceed an amount equal to 29 percent of the total Program Qualified Land then owned by the landowner. If the first tier of the Landowner Participation Offer specified the maximum acreage permitted, the Landowner Participation Offer could contain a second tier specifying an additional Maximum Fallowing Commitment the landowner proposed to make, the acreage of which, when added to the acreage in the first tier, was to not exceed an amount equal to 35 percent of the total Program Qualified Land then owned by the landowner.
entities serving the Blythe community. Through August 2016, the MWD has made $141.3 million in annual fallowing payments to landowners and $3.9 million to PVID for administrative costs.

Prior to the program agreement in 2004, PVID issued an Environmental Impact Report under the California Environmental Quality Act in 2002 (PVID, 2002). The study investigated impacts to agricultural resources, geology and soils, air quality, hydrology and water quality, biological resources, growth inducement, and cumulative impacts. The report found no significant impacts to any of the studied areas.

Although it might seem simple to calculate the water savings associated with this fallowing – clearly a field that could be irrigated is not being irrigated – there are many ways to calculate the savings, but no clear best way. In theory, the savings should be based on the consumptive use of the crops that would have been grown, which, in turn, is a function of weather and water deliveries. With a large fallowing program, further complexities arise because there would have been multiple crops on multiple fields with different savings associated with each crop. Every year Reclamation, PVID and MWD address these quantification issues by jointly issuing a report (PVID, MWD, and Reclamation, 2015). The 2015 version of this report calculated saved water using 3 different averaging periods (12-year 1988-2002, 5-year 1998-2002, and 3-year 2000-2002), and an actual use method for 2015. These numbers varied from 77,143 af to 94,477 af. The report indicates that actual use in 2015 (94,477 af) was the best estimate based on agronomic, weather, and market conditions. This represented 5.29 acre-feet of saved water per acre of fallowed land.

5.1.1.3 2009 Emergency Fallowing Agreement

On March 24, 2009 MWD and PVID issued a joint call for emergency fallowing above and beyond the fallowing under the 2004 agreement (MWD and PVID 2009; MWD 2009b, 2009a). This call, in response to the 2009 California drought, allowed farmers one month (from April 1 to 30) to allocate up to 15% of their land toward a one-year continuous fallowing, to commence between April 15 and August 1. Landowners were to control weeds and prevent wind erosion per the 2004 agreement. For each fallowed acre, MWD paid $1,665 and additional $35 to PVID to reduce future increases in water tolls that would otherwise be required. Under the program, MWD paid a total of $22m for 13,222 acres. At the time, 25,947 acres were already enrolled under the 2004 agreement (Hasencamp, 2016b). The payments under this agreement to the famers were more than twice the amount paid per acre under the 2004 agreement, although there was no sign-up fee. PVID received approximately the same amount per acre as under the 2004 agreement to manage the transactions.

5.1.1.4 Analysis

For farmers in the PVID, this has been considered a successful program (Perry, 2015). There has been no change in their water rights, and landowners control their destiny after the 35-year term. Farmers have made considerable financial gains, especially since the initial upfront payment of $3,170 was the average market value of the land in 2004. (A recent 2016 purchase of almost 2,000 acres by a Saudi dairy company planning to export forage was for $18,000 per acre, with an estimated water use of 4.5 acre-feet/acre. Given that in 2014, approximately two-thirds of the valley was planted in forages which provide relatively low dollar returns, the fallowing payments seem to provide a reasonable return compared to current crops. Were higher-valued crops more commonly planted, the payments might not cover the opportunity cost of forgone production).
MWD receives a reliable source and significant quantity of water from the agreement (Glennon, 2009b). A 2014 study commissioned by MWD determined that the water leases have been a net economic positive for the valley, and that there has not been an overall job loss (Perry, 2015). However, there has been criticism that $6m was not enough money to offset third-party economic losses, and a lot of the initial bonuses for fallowed land went to out-of-state, absentee owners. (SDCWA is providing IID with a total of $40m through 2017 to be used for socioeconomic mitigation under their 2007 settlement agreement, although it should be noted that the IID is five times the acreage. IID is contributing another $10m to the fund). Since the Board of the PVID is controlled by property owners and votes were based on property values, there is concern that a board dominated by farmers will make choices that solely benefit landowners, but may harm the larger community (Glennon, 2009b). In 2013, the Governor approved Assembly Bill No. 1156, amending the Palo Verde Irrigation District Act to entitle each property owner to one vote for every one acre of land owned, rather than one vote for every $100 of assessed valuation.

In terms of agronomic effects of rotational fallowing, there has only been a single study. A University of Arizona Master’s thesis on PVID fallowing found that fallowing has increased the quantity of essential nutrients like nitrogen, and has improved soil carbon, which helps plant growth. The study noted increased concentrations of salt that require a post-fallowing and pre-planting application of “leaching” water. The soil from fallowed and non-fallowed fields was tested throughout the valley, and then plots were planted with broccoli in the fall to determine the effect on yield. The fields that were previously fallowed produced broccoli with a significantly higher marketable yield and total plant biomass than the fields that were continuously planted with crops. On average, the fallowed field produced more broccoli per acre (14,757 lbs./acre) than the fields that were not fallowed (13,803 lbs./acre), an increase of 7% (Cusimano, 2013a). The study concluded that land fallowing enhanced soil quality including nutrients and microbial communities, and such enhanced soil quality led to increased crop growth. These benefits are likely short-lived, however, and could be masked by producer decisions.

Recently, irrigators in the valley have become concerned about a large land purchase by MWD. In late 2015, MWD purchased 12,000 acres for $256m, ($21,300/acre), adding to the 8,000 acres acquired in 2001 (MWD). MWD now owns about 25 percent of the land in the valley. A late 2015 article in the Palo Verde Valley Times described how farmers in the area were concerned about MWD’s actions and were worried that it may lead to drying up the valley (Steele, 2015). In April 2016, Metropolitan’s Board of Directors authorized Metropolitan’s staff to negotiate new leases with HayDay Farms and River Valley Ranches, with lease terms to meet the objectives stated in the General Manager and Manager, Water Resource Management’s letter to the Board with respect to consumptive water use and positive revenue, and pursue leasing the remaining Metropolitan-owned lands through a generalized request for proposals process. All leases will be brought back to the Board for final approval.

In recent years, despite the success of the program, MWD has expressed concerns about the time lags and inflexibility in the agreement. Every year on August 1, MWD issues a fallowing call good for the next two years. Within this two-year call is (1) a possible adjustment upward to last year’s 2nd year call (which is now the call for the coming year), and (2) an estimated call for the 2nd year which could be revised upward, but not downward, the following year as in item (1).

In this way, farmers know what the call will be for the current year, and a minimum call for the 2nd year which might be increased. MWD is limited to a 100% call for 10 years of the thirty-five-year program. The maximum call otherwise is 90%. Due to the severe California drought of 2012-2015 (and ongoing)
and MWD’s subsequent limited supply of State Water Project Water (a record low 5 percent of the contractual amount in 2014 and 20 percent of the contractual amount in 2015) MWD has been forced to rely heavily on their Colorado River supplies including the PVID agreement. MWD would like more flexibility in this agreement in order to handle fast changing drought water supply issues (Hasencamp, 2016a).

Table 1: MWD Fallowing in PVID by Year. Source: Hasencamp, MWD. Note: See Section 5.1.1.3 for payment rate for 2009 Emergency Fallowing Agreement.

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5.1.2 1998 Imperial Irrigation District – SDCWA Transfer Fallowing

From 1992-94, California endured a severe drought, and during that time, MWD imposed substantial water cutbacks on its member agencies. After these impacts, the San Diego Country Water Authority (SDCWA) decided to pursue more secure Colorado River supplies to avoid future cutbacks, and thus began negotiations with IID about possible water transfers. In 1998, after several years of negotiations, IID and SDCWA signed an agreement to transfer conserved water from IID to SDWCA (“Water Authority–Imperial Irrigation District Water Transfer San Diego County Water Authority”, 2015; IID and SDWCA, 1998). The agreement anticipated a transfer of between 130 kaf and 200 kaf /year to SDCWA to be delivered via MWD’s Colorado River Aqueduct, which is the only way to move Colorado River water into San Diego County. The agreement was for a 45-year term with a potential 30-year renewal. There is a 10-year early exit option for SDCWA if it can’t come to agreement with MWD about water wheeling terms for the final 30 years). The agreement anticipated the need for both CEQA and NEPA studies.

Multiple issues arose after the signing of the lengthy 1998 agreement, leading to a complicated process involving several of California’s Colorado River diverters now known as the Quantification Settlement Agreement (QSA). The QSA, which was signed in 2003, was supplemented by more than 40 documents dealing with the various rights of California’s Colorado River diverters (“Imperial Irrigation District: History of the QSA & Related Agreements”, 2015).

In the revised fourth amendment to the IID-SDCWA agreement for transfer of conserved water, SDWCA obtained a commitment from IID based on its earlier 1998 agreement to provide up to 200 kaf/year to SDWCA, ramping up from 10 kaf in the first year to the full amount in year 19 (Revised 4th Amendment, 2003). In separate agreements, SDWCA also obtained the right to 67.7 kaf/year from the All-American Canal and Coachella Canal lining projects for a total potential amount of 277,700 af/year. These canal lining projects are covered in the Efficiency Chapter). From 2003 to 2012, the water savings for SDWCA were from fallowing and from 2013 through 2016 were and are from a combination of on-farm efficiency measures and fallowing. The water saved from fallowing for SDWCA ramped up from 3 kaf in 2003 to 107 kaf in 2012 and then ramps down to 0 in 2017. Starting in 2017, SDWCA will receive the entire 200 kaf/year from on-farm efficiency measures paid for by SDWCA through a program administered by IID (IID, 2015).
In additional to the fallowing water savings transferred to SDWCA, the environmental impact analysis for the QSA required 15 years of environmental flows to the Salton Sea to be obtained by fallowing in the IID. These fallowing flows varied from 14 kaf in 2004 to 153 kaf in 2015. IID reported a remaining obligation of over 236 kaf for the period from 2016 to 2017, after which there is no obligation. A total of 800 kaf for the Salton Sea will ultimately be provided from fallowing (Exhibit 1, IID and SDCWA, 2003). For both the SDWCA and Salton Sea, in 2015-2016 IID fallowed approximately 16,700 acres at a cost of $175/acre (IID 2015-2016 Fallowing Report). In 2010, IID delivered 46,546 af of Colorado River water to the Salton Sea with a stated intention to store the water for use for Salton Sea mitigation requirements in 2011 and half of 2012. IID did not conserve an equivalent amount of water in 2011 and 2012 for delivery to the Salton Sea resulting in a Colorado River system storage depletion of 46,546 af. This matter is the subject of a series of letters between Reclamation and IID, and currently remains under discussion between Reclamation and IID. For both the SDWCA and Salton Sea, in its one-year 2015-2016 fallowing program approximately 16,700 acres lie idle at a cost of $175/acre (IID 2015-2016 Fallowing Report).

IID and SDCWA had a fundamental disagreement concerning the likely socioeconomic impacts to be caused by land fallowing. Under the revised fourth amendment to the IID-SDCWA agreement for transfer of conserved water, in addition to the socioeconomic impact payments to be made by SDCWA and IID, the amendment created a panel of 3 professional economists to establish a Socioeconomic Methodology to estimate and measure the annual and cumulative socioeconomic impacts of land fallowing based on procedures to be developed for combining evidence from different approaches specified in the amendment. A regional economic model was to be built based on credible available information and annual reports were to be issued ( Exhibit 2, IID and SDCWA, 2003). At the request of IID, Dr. Rodney T. Smith prepared a December 2005 report on the socioeconomic impacts of land fallowing by the IID for 2003 and 2004 as a model for the correct implementation of the methodology agreed upon by IID and SDCWA in their executed agreement. IID and SDCWA disagreed about how socioeconomic impacts are to be determined under the provisions of the IID/SDCWA Transfer Agreement, as amended.

Pursuant to the provisions of their transfer agreement, IID and SDCWA arbitrated the dispute before a private arbitration panel comprised of three retired judges in the Spring of 2007. Resolution by compromise was reached after the completion of the arbitration, but before the arbitration decision was released. SDWCA agreed to provide a total of $40m through 2017 to be used for socioeconomic mitigation under a 2007 settlement agreement with IID. This fund is administered by a local entity, which was reconstituted in 2009 to be made up of the IID Board of Directors.

The original 1998 agreement was amended three times before 2003, in 2003 for the QSA and then again in 2007 and 2009. The original 1998 agreement set forth a complicated per acre-foot water cost to be paid by SDWCA. In the 2003 and 2009 amendments, the parties changed this computation to an escalating figure. In 2015, the payment was $624 per acre-foot (IID and SDWCA, 2009).
5.1.3 2016-2017 Bard Irrigation District – MWD Fallowing

In 2016, MWD announced a new agreement for a summer fallowing pilot project in the 6,400-acre Bard Water District for 2016 and 2017 (MWD, 2016a). The Bard Unit and the “Quechan” Indian Unit together constitute the Reservation Division of the Yuma Project, a federal Reclamation project located in southeastern California. Over 6,100 acres are irrigable in the Indian Unit. This land is on the California side of the Colorado River a few miles northeast of Yuma. MWD would like to fallow no more than 2,000 acres of land and will pay farmers and Bard Water District a total of $400 per acre to conserve approximately 2 acre-feet per acre during the portion of the spring and summer growing season from April 1 to July 31. Bard area farmers typically grow lower value and higher water using crops during this hot period. About 550 acres of land enrolled in the program for 2016. After the 2016 fallowing program is complete, Metropolitan will again solicit participants to participate in 2017, the final year of the two-year pilot program. MWD believes it can obtain water supplies at lower cost and at little to no harm to farmers with the program given the typical water use during this period.

5.2 Arizona Cases

5.2.1 Yuma Mesa Irrigation and Drainage District – Mead Elevation Support

Yuma, Arizona has one of the longest growing seasons in the country and a nearby, reliable source of year-round water in the Colorado River. Unlike the Imperial Valley or the Palo Verde Valley which are
each served by a single irrigation district, the Yuma agricultural area is serviced by 7 different districts operating under two different federal Reclamation projects. The original project, the 1904 Yuma Project, services lower lying gravity-fed areas near Yuma, and in 1978 covered approximately 68,000 acres. This includes Yuma County Water Users Association, Unit B10, the Bard Water District, and a portion of the Fort Yuma Indian Reservation, the latter two located in California.

The second project, the Gila Project, was authorized in 1937 for about 100,000 acres and generally involves areas upstream of the Yuma Project and areas that require pumping to deliver water, technology that was not possible in 1904. Gila Project lands generally lie north of the Gila River upstream of its confluence with the Colorado River and include the North Gila Valley and South Gila Valley Irrigation and Drainage Districts and the Wellton-Mohawk District. In addition, lands on the Yuma Mesa are served by the projects. These mesa lands are approximately 50 feet above the Colorado River, thus the need for pumping from the main Gila Project Canal (Bureau of Reclamation Project Data, 1981; Sauder, 2009).

Since the early 1900s, the Yuma area has slowly adapted to market demands to become the center of winter vegetable production in the United States — providing up to 90 percent of the leafy vegetables consumed from November to March in the United States11 (Radonic, 2014). Such crops now make up 80 percent of the acreage in the area (Noble, 2015a). Since 1975, the agricultural industry in the area has become quite efficient with their water resources and now use about 20% less water per year than before, a savings of approximately 225 kaf/year (Moving Forward, 2015; Noble, 2015b).

Although Yuma growers have different water rights based on the dates of the two Reclamation projects (1904, 1937, and later), these water rights are senior to the 1968 Central Arizona Project. Were a Lower Basin shortage to occur, fourth priority Colorado River water uses like the CAP would be the first to be shorted and thus CAP has recently looked to Yuma water rights as a way of potentially managing their risk.

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10 Unit B is a small 3000-acre tract of land located on the Yuma Mesa. It was part of the Yuma Auxiliary Project authorized in 1920. It was originally served by a small pumping plant located on a main canal in the valley lands along the river south of Yuma. After the Gila Project was completed the Unit B lands could be better served by the Gila Project pumping and canal system and thus this pumping plant was inactivated. Unit B, thus, has a more senior water right than the later Gila Project even though it uses the Gila Project’s facilities.

11 Some of this 90 percent is produced in the Imperial Irrigation District. A workers’ strike in the 1990s in IID encouraged growers there to send produce to Arizona for processing before shipment. This arrangement continues to this day, and thus the 90 percent figure includes all produce from the area, not just Yuma.
Established in 1954, the Yuma Mesa Irrigation and Drainage District (YMIDD) is one of the seven irrigation districts in Yuma. The YMIDD, the Yuma Irrigation District, and the North Gila Valley Irrigation and Drainage District share a single consumptive right that is assigned to the Yuma Mesa Division\textsuperscript{12} of the 1937 Gila Reclamation Project. Each district has a contract for a share of the total amount (250,000 acre-feet) assigned to the Yuma Mesa Division (Noble, 2015a). YMIDD is entitled to just over 140,000 acre feet (ADWR, 2015). YMIDD is supplied by the Gila Gravity Main Canal, which diverts water from the Colorado River at Imperial Dam. The Yuma Mesa Pumping Plant lifts water 52 feet from the canal near I-10 into the YMIDD system to irrigate approximately 15,500 acres, comprised of citrus, alfalfa, peanuts, cotton, and grains (Noble, 2015a; Morgan, 2015). Their distribution system includes canals (23 miles), laterals (41 miles), and ditches (96 miles) that are entirely lined (Noble, 2015a). Yuma, IID and PVID all use nearby Mexican labor to harvest crops. This cost-effective and highly talented labor is a unique feature of the area, and provides local growers with a significant competitive advantage, at least compared to other U.S. growers.

\textsuperscript{12} The other Division of the 1937 act is the Wellton Mohawk Division, located far upstream on the Gila River.
5.2.1.1 2008 Pilot Fallowing Project

In 2008, the YMIDD began a fallowing pilot project with the Bureau of Reclamation (Reclamation and YMIDD, 2008). The Bureau paid $120 per acre-foot conserved through falling. The dollar amount was based on Reclamation’s farm budget analysis for current crop returns on irrigated alfalfa in the YMIDD. It was estimated that for every acre fallowed, seven acre-feet of consumptive water use was conserved. Under the agreement, the district fallowed 500 acres (out of approximately 15,500) for a total planned water savings of 3500 acre-feet. The total cost of the program was $420,000, paid for by Reclamation. The YMIDD agreed to reduce water diversions at the Imperial Dam by the planned savings. Essentially, the YMIDD would fallow land to reduce water bypassed around the Mexican delivery point (Agreement, 2008). This program was instigated by Reclamation to fulfill the goals of a 2006 policy for “System Conservation of Colorado River Water” to replace water not being desalted by the shuttered Yuma Desalting Plant (Agreement, 2008). In effect, the program assisted the Central Arizona Project delivery reliability through higher Lake Mead levels. The program was too small to verify how much water was saved due to falling (Walton, 2013).

5.2.1.2 2009-2010 Fallowing Project

The following year, Reclamation signed another agreement with YMIDD using nearly identical terms to fallow another 529 acres, this time at the slightly reduced price of $90 per acre-foot with seven acre-feet of water savings stipulated per acre of fallowed land. The total payment from Reclamation totaled $330,000 (Reclamation and YMIDD, 2009).

5.2.1.3 2014-2017 Fallowing Project

Four years later, the YMIDD and the Central Arizona Water Conservation District (the owner of the Central Arizona Project) on behalf of its Central Arizona Groundwater Replenishment District (CAGRD) launched a pilot program in 2014 consisting of up to six years comprised of two, three-year cycles commencing in 2014. The purpose of the pilot program was to develop a methodology to quantify the forgone consumptive crop water use. The CAGRD worked with the Bureau of Reclamation and the Arizona Department of Water Resources to develop an acceptable quantification methodology for the pilot program.

CAGRD exists to ensure the sustainability of various groundwater-dependent entities in Arizona under Arizona’s Assured Water Supply rules by replenishing groundwater for its members. It relies on a number of water sources to fulfill its replenishment function, including Colorado River water supplied by the Central Arizona Project and other renewable water supplies (CAGRD, 2014). CAGRD’s Water Supply Program was created to acquire diverse water supplies to meet current and projected demands under all operating conditions including Colorado River shortage. CAGRD’s recently approved Plan of Operation identifies the need to acquire an additional 50,000 acre-feet of supplies by 2034 to meet its projected replenishment obligations.

Under the agreement, land cannot be taken out of production for more than three years and must be maintained while fallowed. The CAGRD agreed to pay the District $21.36 per acre for lost district revenue from the sale of excess water and $10,000 annually to administer the program. Through the program, YMIDD landowners could fallow a maximum of 1,500 acres of land per year, less than 10 percent of the district’s total irrigated acreage. CAGRD paid farmers $750 per acre of fallowed land and increased the payment a minimum of 2% and maximum of 6% each subsequent year based on the
change in the consumer price index for All Urban Consumers (SPI-U). Qualified land must have produced irrigated crops in four of the last five years, and no landowner can put more than 18 percent of their land in the program (Agreement, 2013; Radonic, 2014).

For 2014, the YMIDD conserved 6,827 acre-feet, fallowing 1,420 acres of citrus and alfalfa (Colorado River Accounting, 2014). In 2015, 1,410 acres were fallowed conserving 7,180 acre-feet of water. The YMIDD has found willing participants from at least two types of farmers/landowners. Farmers with citrus crops near the end of their useful life have removed trees and fallowed the land without incurring any economic losses. Landowners who rent land at $150 to $200 an acre can fallow that same land and receive $750 an acre.

![Figure 3: Crop types in Yuma Mesa Irrigation and Drainage Division. Source: Central Arizona Groundwater Replenishment District.](image)

5.2.1.4 Analysis

The pilot program was successful in developing a defensible quantification methodology; CAGRD did not need to renew the program for an additional three-year period. The district is unsure of the value of their water in three to five years, and will wait until they are more certain of the value (Morgan, 2015) before considering another future program. The YMIDD has been able to use the current program to fallow fields and replant crops while earning more money than they would have if they continued to farm. There is a definite economic benefit for members of the YMIDD to participate in this program as they transition to other crops. The program has been relatively small, however, and it is difficult to see how it might be enlarged significantly.
5.2.2  Wellton-Mohawk Permanent Fallowing – Local Urban Transfer

Just before 2008, the Wellton-Mohawk District of the Gila Project near Yuma permanently retired 3000 acres of “mesa” land with lower quality soils to provide a future source of water for municipal and industrial growth in the district. Prior to the 2008 world-wide financial crisis, the district was experiencing significant urban growth and the need to supply water for local growth seemed obvious. Thus, the District decided to retire land to save water for future urban use. This land retirement was estimated to save 12,000 acre-feet of water per year. After 2008, growth in area slowed significantly, and now WMIDD currently does not need the water. The District is currently leaving the water in Lake Mead to raise the lake elevation. To make this water available for M&I uses, WMIDD amended its Reclamation contract to reduce the total allowable acreage for agricultural purposes and to allow M&I use of the saved water. The original WMIDD contract, which called for 75,000 irrigated acres, has now been amended several times. The 1974 Salinity Control Act cut the number back to 65,000 acres, the Pima-Maricopa Indian settlement in 1990 retired another 2200 acres, and this action removed another 3000 acres. Thus, the current allowable irrigated acreage in the District is approximately 60,000 acres.

Unlike other cases in this document, this example involves permanent, not temporary, fallowing. Permanent fallowing has historically been controversial because the water saved was typically moved out of the area and the land was no longer farmable. This is a different case where the water supplies are to be used for local in-basin non-agricultural economic growth and hence the action was less controversial.

5.2.3  Arizona Land and Water Trust – Environmental Water

The Arizona Land and Water Trust (ALWT) has worked to conserve land in the Sonoran Desert in southern Arizona in 1978 using traditional conservation easements and other techniques. Recently they have begun to use water agreements to address both land and water conservation, launching their Desert Rivers Initiative in 2007. The initiative sought to sustain the riparian habitat while maintaining rural livelihoods in the Southern Arizona area including the Gila, San Pedro, and Santa Cruz Rivers. This program is accumulating actual data of water consumption and how fallowing affects the river and riparian habitat.

5.2.3.1  2012 Gila River Project

In 2012, the trust crafted a three-year deal with a local landowner on the Gila River. The ALWT paid the farmer to fallow a 100-acre alfalfa field and not pump 600 acre-feet of groundwater per year. The ALWT hoped that the decrease in groundwater pumping would boost the flow of the Upper Gila River. The ALWT monitored whether reduced pumping increased the river’s flow with the assistance of university scientists and consultants (Bates et al., 2014).

In Arizona, a water right can be lost under the abandonment statutes if it is not used for five years. Even though the abandonment statutes have not been enforced in the state of Arizona, the parties agreed on a lease time frame that did not exceed the abandonment standard (Torrens, 2015). Fortunately, this transaction did not need state approval because the temporary agreement did not cause a change in use of the underlying water right (Bates et al., 2014).
5.2.3.2 Additional Projects

Since that original project, the ALWT has pursued and signed several different agreements along the upper Gila and San Pedro Rivers. They have reached four water lease agreements on the upper Gila that compensate farmers to completely fallow alfalfa. Another two agreements on the San Pedro River involve water reductions with transitions from alfalfa to native grass. The ALWT believes that paying farmers to fallow while they transition to alternative and native crops will become the majority of their future work and provide the most opportunities (Torrens, 2015).

5.2.3.3 Analysis

The ALWT program highlights the potential for water transfers to meet the needs of agricultural and environmental interests. Participating landowners are benefitting economically from the program and some are using these fallowing payments to transition to alternative crops that use less water. Although the program is too small to generate large increases in river flow, it is clear that less water is being used for agriculture, and the savings should be apparent in higher tributary groundwater and/or river flows even if these are difficult to measure. If this program continues to increase in participation, the ALWT will be closer to its goal of maintaining and preserving the riparian habitat and rural culture of Southern Arizona.

5.3 Colorado Cases

5.3.1 Rocky Ford High Line Canal – Aurora Municipal Transfer

Aurora, Colorado is located just east of and contiguous with Denver. It is the third largest city in Colorado with a population of over 350,000 residents. From 2004-2005, Aurora Water took part in the largest temporary water transfer in Colorado state history. The Rocky Ford High Line Canal Company13 leased water to the municipality in what is seen as a successful transfer for both the agricultural community and the municipality. This short-term project then led to a long-term agreement to provide Aurora with more reliable supplies during potential future droughts.

In 2002, Colorado was experiencing a severe drought, prompting Colorado Governor Bill Owens to call it “perhaps the worst drought in 350 years” (Henz et al., 2004; Owens, 2003). The May snowpack in the South Platte Basin and Upper Colorado Basin were 23 and 28 percent of normal, respectively (Kenny, Klein, and Clark, 2004). Aurora relies heavily upon the winter snowpack for their raw water supply as do most of Colorado’s cities. That July, the city’s storage dipped to a level that caused serious concerns (McLane and Dingess, 2014).

5.3.1.1 2004-2005 Drought Agreement

As the drought continued into 2003, Aurora investigated leasing water from the Rocky Ford High Line Canal Company in the Arkansas River Basin. Aurora’s reservoirs declined to record low storage of 26% in

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13 This is the full name of the canal but it is typically referred to as just the “Highline Canal” or alternatively “High Line”. There are countless ‘Highline Canals’ throughout the West with the term referring to a gravity-determined canal layout as high as possible above the source water supply in order to be able to provide water service to as much land as possible.
March 2003 (Aurora Water). Aurora’s excess capacity in existing transbasin infrastructure made transfers out of the Arkansas River possible (McLane and Dingess, 2014). After reaching agreement with the canal company, a uniform lease was offered to all High Line Canal shareholders in 2003. Aurora agreed to pay $5,280 every year per share (a share is water for approximately ten acres, thought to yield about 10 acre-feet each year), plus an annual fee of $1,000 per share when land was out of production to offset the agricultural yields from the temporary non-irrigated land. Aurora withheld $500 of the payment to be paid when shareholders controlled weeds and implemented land stabilization measures per the landowner agreement (Agreement Application, 2003). Aurora agreed to develop the required engineering analysis and defray any potential costs the High Line Canal incurred during the leasing process (Aurora-High Line Canal Agreement, 2003).

The State Engineer of Colorado granted approval of the temporary change for up to 840 shares of the High Line Canal under Colorado’s Substitute Water Supply Program (CRS 37-92-308)14. If Aurora leased all 840 shares, then the High Line Canal would be required to fallow 8,241 acres (McLane and Dingess, 2014). In 2004, Aurora leased 833.3 shares, 36 percent of the High Line Canal Company. Aurora paid nearly $5.3m to the High Line Canal Company and its shareholders, and additional money to use Pueblo Reservoir to transfer the water (Woodka, 2005).

Among the shareholders of the High Line Canal, the transfer was seen as a success. Due to the low water year, Aurora only received about 7,600 acre-feet from the lease, about 10 percent less than the expected 8300 acre-feet (Woodka, 2005). To refill reservoirs diminished by the drought, in 2005, Colorado Springs Utilities joined Aurora with each receiving 50 percent of the transferable yield under the same payment terms. Runoff in 2005 was approximately normal, the first time since 1999, and the jointly leased 833 shares yielded over 10,000 acre-feet (McLane and Dingess, 2014).

5.3.1.2 2008-2018 Long-Term Agreement

The 2004-2005 High Line Canal water transfer was a success for Aurora and the High Line Canal Company. The municipality avoided a potential water crisis, and established a positive relationship with the High Line Canal Company. Three years later, in 2008, the entities signed a new ten-year lease agreement. This renewable agreement called for Aurora to pay in leasing and non-leasing years, and the canal company will support future leasing to Aurora (CWCB, 2011). While the use of Interruptible Water Supply Agreements is good for drought protection and recovery, it less useful tool for municipalities to rely on as a long-term water supply and even less so to supply new demand15. The lack of infrastructure in some regions may even make such a transfer technically impossible. For agricultural producers, there is also widespread uncertainty about how temporary leasing water will affect the value of their water right, specifically when calculating the historical consumptive use of the right (McLane and Dingess, 2014).

14 Shortly thereafter the Colorado Legislature passed and the Governor signed a bill allowing such transfers under a new program, Interruptible Water Supply Agreements, designed specifically for these kinds of temporary fallowing arrangements, CRS 37-92-309. The Substitute Water Supply Program is one of several ways in which out of priority diversions can be authorized. Diversions approved under this program are designed to be temporary and only need approval of the State Engineer, not water court.

15 The City of Fountain, however, believes it can use these agreements to provide a dependable source of water by using multiple agreements with fallowing on different cycles.
### 5.3.2 Arkansas Valley Super Ditch – Municipal Transfers

The Lower Arkansas Valley in southeastern Colorado below Pueblo has lost a quarter of its irrigated lands since the 1950s through the process known as “buy-and-dry” (WGA, 2012). The first major water sale occurred in 1955 to Pueblo. Between 1971 and 1986, there were eight major sales mostly to Aurora, Colorado Springs and Pueblo that totaled over 128,000 acre-feet in a basin with a native supply of approximately 500 kaf/year. Even though there were calls to oppose water transfers, farmers resisted attempts to impose restrictions on their right to sell water. The story of dry up in Crowley County and the resulting economic has been well told (MacDonnell, 1999) and is Colorado’s version of California’s Owen’s Valley buy and dry.

These water sales went to Pueblo, Colorado Springs, and Aurora. Pueblo sits on the Arkansas River and thus can easily take water upstream with existing infrastructure. Colorado Springs and Aurora established infrastructure to move water from the Colorado River Basin into the Arkansas and South Platte basins when they built their joint Homestake Project in 1963-1967. The Homestake project moves water via tunnel from Homestake Reservoir in the Upper Colorado River Basin into upper Arkansas Basin reservoirs, and then via the Otero Pump station on the Arkansas River into the South Platte Basin where it can be delivered to Aurora’s South Platte Reservoir on the South Fork of the South Platte, Spinney Mountain, and onto Colorado Springs via a continuation of the pipeline\(^{16}\).

This infrastructure is the key to possible Super Ditch transfers to Aurora – without it, there would be no way to physically move Arkansas Basin water to Aurora which exists outside the basin. Colorado Springs, which is far upstream from the river on a small, mostly dry tributary, can obtain water using the same infrastructure or potentially by the newly constructed Southern Delivery System. The $800m Southern Delivery System is a 75-cubic-feet-per-second (cfs) conduit from Pueblo Reservoir on the Arkansas River to Colorado Springs designed to carry approximately 42,000 acre-feet per year. The 50-mile pipeline has a vertical lift of 1500 feet. The SDS is not allowed currently by Pueblo County’s 1041 permit or by the Environmental Impact Statement to move leased water, however.

During the 2000-2002 drought, interest in purchasing shares of the Arkansas Valley’s largest ditch, the Fort Lyon Canal, pushed citizens in five counties to establish the Lower Arkansas Valley Water Conservancy District in 2002 (LAVWCD) (McMahon and Smith, 2013). Unlike almost all other conservancy districts, LAVWCD’s mission is to prevent further buy-and-dry transfers and “acquire, retain, and conserve” water. The district intends to use water for the socio-economic benefit of the citizens of the district and establish methods of meeting municipal water demand both in and out of the basin without the negative effects of buy and dry on rural communities (LAVWCD, 2016).

In 2007, LAVWCD facilitated the creation of the Super Ditch, a Colorado Corporation consisting of shareholders on 7 of the principal ditches in the Lower Arkansas. The District contracted with HDR Engineering to conduct a preliminary proof of concept study on a fallowing-leasing model (Nichols, 2011). The Super Ditch is pursuing a leasing program modeled after the Palo Verde Irrigation District – MWD fallowing program in California. However, instead of one irrigation district, the Super Ditch is a collaboration of shareholders on seven ditch companies located between two reservoirs along the pipeline.

\(^{16}\) The continuation of the pipeline takes water out of the South Fork of the South Platte into a small tributary of the Arkansas River.
Lower Arkansas River, Pueblo, and John Martin. Irrigators from different ditches with different characteristics can pool their resources into a larger temporary-fallowing plan (WGA, 2012). The leasing program hopes to generate new sources of income and opportunities in a place where 32 percent of the farms reliant on agriculture operate at a net loss (McMahon and Smith, 2013).

Before incorporation of the Super Ditch, the LAVWCD completed many studies on the potential fallowing. Technical studies included tax considerations, the correct form of entity (taxable, non-profit), how to move the water upstream by exchange and by pipeline, water quality impacts and considerations, the financial aspects of lease-fallowing to both farmers and municipal partners, and the availability of storage to retain the water before its actual transfer (Nichols, 2011).

The first Super Ditch pilot project in 2012 (to supply the City of Fountain and Security Water District) failed due to difficult-to-meet conditions imposed by the State Engineer in his approval of the substitute water supply plan (SWSP). Tri-State Generation and Transmission et al., also filed a lawsuit challenging the State Engineer’s authority to approve the SWSP, although insulated from injury by a reservoir located between the project and their water rights. Another time, boards of the Super Ditch and Highline Ditch rejected an offer for water from the City of Aurora because they believed the price to be too low (Woodka, 2014). Negotiations over a higher price ended during the winter when significant snow occurred and Aurora no longer needed the water.

### 5.3.2.1 2014 Fowler Pilot Project

The first H.B. 13-1248 (discussed below) project, proposed by two shareholders on the Highline Canal, was meant to supply Fowler: a small town on the Arkansas River downstream of Pueblo under water restrictions that needed an outside supply of water to augment their existing wells. Before the pilot project could be launched, however, the irrigators on the Highline Canal backed out of the deal after being threatened by other shareholders. Ironically, most Highline shareholders live in Fowler. However, in 2015 the Super Ditch received approval for the first pilot project. The Super Ditch anticipates several future leasing agreements, and is working on submitting two proposals in 2017 to go into operation in 2018, one involving the U.S. Forest Service’s Lake Isabel, and the other involving Colorado Springs.

### 5.3.2.2 2015 Catlin Canal – Fowler, Security, Fountain Pilot Project

In early 2015, the Colorado Water Conservation Board (CWCB) approved a plan to lease water from the Catlin Canal of the Super Ditch to the municipalities of Fowler, Security Water District, and Fountain. Fowler is on the mainstem of the Arkansas downstream of Pueblo. Security and Fountain are located south of Colorado Springs on Fountain Creek, the Arkansas tributary that leads from Colorado Springs to the Arkansas. The Catlin Pilot Project was the first to go completely through the process established in the CWCB’s Lease-Fallowing Criteria and Guidelines (Colorado Water Conservation Board and Colorado Division of Water Resources, 2013) and the first to use the Lease-Fallowing Tool developed by the Division of Water Resources to determine historical consumptive use, assess injury to other water rights, and return flow obligations (DWR, 2015a).

The CWCB’s approval, consistent with H.B. 13-1248, stipulates that water can be only transferred three out of ten years and only 30 percent of a farm can be temporarily dried up (Woodka, 2015a). The CWCB adopted all the State Engineer’s 59 conditions on the project, and added one requested by Colorado Parks and Wildlife. The pilot project received the full support of the Catlin Canal shareholders (The
During 2015 and 2016 water was exchanged or traded from the Catlin Canal headgate into Pueblo Reservoir for Fountain and Security for $500 per acre-foot. It was then delivered up Fountain Valley Authority Pipeline. Since the infrastructure was already in place, the transport of the water from Pueblo Reservoir to Fountain and Security was relatively easy and only required a little more planning for the municipalities (Fink, 2015).

Water for Fowler was traded with the Colorado Water Protection and Development Association to replace the Town’s out-of-priority well depletions. Water for Fountain and Security was similarly traded with so-called Rule 10 Plans, which replace water consumed by increased irrigation efficiency to comply with the Arkansas River Compact with Kansas.

Approximately 1,100 acres of land were fallowed, making up 311 shares of the Catlin Canal. Representatives from Kansas observed every property with fallowed land to ensure compliance with the Arkansas River Compact. (Kansas follows Colorado’s Arkansas River water use closely because of the potential for harmful downstream impacts).

In an economy with depressed commodity prices, it was a successful year for farmers, who could install improvements on fallowed fields like drip irrigation and laser-leveling (Woodka, 2015c). A post-year water accounting report was released in January of 2016 (LAVWCD, Berg Hill Greenleaf Ruscitti LLP, and Martin and Wood Water Consultants, 2016).

Colorado Springs Utilities has formally offered a partnership with the Super Ditch, hoping that leasing can help top off their water supplies in drought recovery years. Such a deal would not be likely until 2017, going into effect in 2018 (Woodka, 2015b). One preliminary analysis of the Super Ditch projected a loss of $192 in net income per acre for the local economy due to fallowing without considering the benefits of the lease payments. However, these payments could exceed these losses and possible benefits from an increase in dry land farming could mitigate some of the negative impacts (McMahon and Smith 2013).

5.3.2.3 Lease-Fallowing Water Accounting Tool

Anticipating temporary water transfers from the Super Ditch, the state developed the Lease-Fallowing Water Accounting Tool (LFT) to “streamline and standardize the evaluation of the historic use of irrigation water and return flows to streams associated with land parcels in Colorado that may alter irrigation practices as part of a lease-fallow project” (DWR, 2015b). The LFT has been used successfully to evaluate the water transfer between the Catlin Canal and the cities of Fowler, Security, and Fountain in 2015 and 2016. The Excel-based program was developed within the criteria and guidelines of HB13-1248 and can be used to model similar projects in other basins. Data for every land parcel is input into the program, which completes an analysis that simulates the historical water balance and then computes return flows to the stream for historic and altered conditions. The program’s analytics take minutes compared to the typical, much longer historical water court process (Thompson, 2015).
5.3.2.4 Analysis

The creation of the LAVWCD and the Super Ditch represent an unusual collaborative effort by local entities historically known for fighting to prevent future impacts to farming and rural lifestyles from out of basin water transfers. The Super Ditch has not yet transferred larger amounts of water on an annual basis, and at times has struggled to form partnerships with municipalities, largely due to the inability to agree on a price for transfers. The successful Catlin Pilot Project, however, appears to have paved a way forward for larger transfers in the future. Aurora and Colorado Springs – both parties to permanent ag transfers in the Lower Arkansas basin since the 1950s – approached the Super Ditch in 2016 to discuss long term leasing-fallowing agreements as part of their future water supply portfolios.

5.3.3 The Lake Canal Transfer – Environmental Transfer (Failed)

The Colorado Water Innovation Cluster (CWIC), a group of public, academic, and private entities, was formed in 2010 to produce innovative solutions to water issues. CWIC set out to temporarily transfer water from agriculture to meet environmental needs. Specifically, they proposed that shareholders of the Lake Canal would fallow, deficit irrigate, or use other methods to conserve water for instream flows on the Cache la Poudre downstream of Fort Collins. As originally envisioned in 2010, this transfer would rely upon an Interruptible Water Supply Agreement (IWSA) under Colorado Water Law (CRS 37-92-309) to transfer water for three years during a ten year term, with use commencing during the 2011 irrigation season (CWIC, 2013). The proposed transfer amount, 60 acre-feet, was to demonstrate the possibility of using such a mechanism (Smith, 2015).

After postponing negotiations due to a low water year in 2012, the project was terminated without ever reaching a transfer agreement. The parties could not agree on a price or amount of water to transfer. The 2012 drought caused the price of leased water and the value of crops such as corn and alfalfa to increase to record highs. Water demand by oil and gas producers was also increasing water prices. Farmers could not economically justify the transfer if they could obtain higher returns by putting that water to agricultural or other use. Agricultural water users were also openly skeptical of the intentions of environmental groups wanting to purchase the water (CWIC, 2013; Smith, 2015).

5.3.3.1 Analysis

The Lake Canal case provides some valuable insight into the difficulties of these agreements. Due to 2012 drought, commodity prices increased along with the value of water, and thus it was not in the interests for landowners to lease water. Droughts may provide both opportunities and problems. If a user does not have enough water to grow a crop, he may be interested in selling the water at a scarcity premium. On the other hand, high commodity prices might encourage the farmer to keep the water, in order to maximize crop and economic returns.

5.3.4 Larimer County Open Lands Program – Land Preservation and Municipal Transfer

The Larimer County Open Lands Program (LCOLP) was created in 1998 to preserve land in Larimer County. LCOLP currently owns 25,000 acres in fee and 8000 acres in conservation easements. Less than 1000 acres of these lands have water rights due to the high cost of water. LCOLP is funded by a ¼ cent sales tax that has been approved by voters twice, most recently in 2014. The county is losing farmland at the rate of 4500 acres per year with the loss of 8.4% of total country farmland in the ten-year period.
from 1997 to 2007. County citizens recently identified the acquisition of working irrigated farms as a high priority.

In 2015, LCOLP received a $186,000 grant from the Colorado Water Conservation Board to create a test program which combines land conservation with a permanent dry year interruptible water supply agreement for a municipality (Larimer County Open Lands, 2015). The CWCB grant funds legal, engineering, economic, and program management for the acquisition of the two properties. It does not cover the actual land and water cost. LCOLP hopes to establish a model that can be replicated.

LCOLP will offset the high cost of water acquisition by making dry year water available on a permanent basis to a municipal user. LCOLP is looking to acquire the rights for two irrigated farms with the purpose of creating a water sharing agreement(s) with M&I partner(s). One property would have primarily water from the Colorado Big Thompson Project (C-BT) water rights and another with primarily native water rights. Native water rights can be purchased for less, but have higher transaction costs to move the water to a municipal user. CBT rights are more easily moved, but in recent years have been expensive.

In early 2016, LCOLP signed a contract for one 211-acre farm near Berthoud Colorado on the Little Thompson River. The property has 188 irrigated acres, and its water portfolio is made up primarily of C-BT water rights and some local ditch shares ("Larimer Approves Farm, Water Purchase - Loveland Reporter-Herald", 2016) LCOLP has informally discussed this project with several potential M&I water providers in Northern Colorado, and some have confirmed that they would participate in a pilot project (Larimer County, 2015).

5.3.4.1 Analysis

This is still a work in progress. The addition of an experienced but predominantly dry land conservation organization to this effort brings much needed expertise. This water will provide permanent, reliable dry year supplies to a municipality but not base demand water.

5.3.5 Montezuma Valley Irrigation Company – NGO Environmental Transfer (Failed)

The Montezuma Valley Irrigation Company (MVIC) supplies water out of the Delores River in southwestern Colorado, near Cortez, using water from the Delores Project stored in McPhee Dam. In 2011, the board of directors proposed a leasing program for environmental purposes to its shareholders. The plan involved leasing water during the summer months to improve the fish habitat on the Lower Dolores River below McPhee. The farmers would have leased up to 6,000 acre feet of water in three of the next five years to the Colorado Water Conservation Board’s instream flow program. The Nature Conservancy, Trout Unlimited, and the San Juan Citizen’s Alliance would have put up $1.5m toward the water purchase, and the funds would have been used to improve the MVIC irrigation system. This funding would have helped modernize a system that loses 25 percent of water before it reaches end users (Hartzke, 2011; Smith, 2011).

After initially requesting the board to investigate the possibility of leasing water, the shareholders chose to not participate. The vote failed with 68 percent opposed to the lease agreement and 31 percent in favor (Wright, 2011). There was concern among the irrigators that once they leased water, they may have been forced to continue leasing, especially if Delores River fish were listed under the Environmental Species Act. Also, some farmers were already not getting enough water due to problems with the current irrigation system, and leasing water would have further limited the available water in
the system (Smith, 2011). The impact of the 2002 drought was also a strong reminder of low water supply challenges (Benedict, 2011). After the vote, there was substantial turnover in the MVIC management due to ill feelings about the agreement and the overall process.

Even though there was a willing buyer and a need to repair infrastructure within MVIC, shareholders were unwilling to lease water. Irrigators brought up typical concerns that have been issues with other similar fallowing projects. Most fallowing negotiations take multiple years to reach agreement, especially with such a large amount of water. The Arkansas Valley Super Ditch and the Palo Verde Irrigation District final agreements took many years of discussions. For the Imperial Irrigation District, pressure from the federal government was necessary to create a final comprehensive agreement. A pilot project or small-scale lease may have smoothed the way for a larger project.

5.3.6 North Sterling Irrigation District – Xcel Energy Industrial Water (Energy)

Xcel Energy owns and operates the Pawnee Power Plant, a water-cooled 550 MW coal-fired power plant east of Fort Morgan near Brush, Colorado on the South Platte River. Prior to the 2002 Colorado drought, the State Engineer did not administer South Platte winter water rights. Hence, Xcel had no need for a reliable senior winter water right. After the extreme low flow year of 2002, however, it became apparent that the power plant would need to acquire a senior right for future low flow years. Seeking reliable winter water, Xcel approached the North Sterling Irrigation District (NSID), which owned 74,000 acre-feet of storage in the downstream North Sterling Reservoir. NSID and its shareholders were provided with an opportunity to increase economic returns from their water rights from an unusual source. In contemplating a water sharing deal, NSID management believed that they needed a strong vote of support from its members to pursue the agreement. An agreement would require the district to pursue a change of its water rights, a new concept for the district that would set a precedent and possibly lead to more leases in the future.

The district board voted to pursue the agreement and a strong majority (113/140) of the members agreed in district-wide vote. A new company, Point of Rocks Water Company, was formed among the 113 participating members to contract with Xcel. Under the agreement, from November to March 3,000 acre-feet could be transferred to the power plant if requested. NSID would receive a guarantee $50 per acre-foot per year and additional $425 per acre-foot per year on delivery. The agreement was finalized in 2005 for a 25-year term. NSID paid their own legal and engineering fees to adjudicate a portion of their water rights, but they could not change their entire water rights portfolio due to Colorado’s anti-speculation doctrine. The agreement states that Xcel will divert the transferred water at their wells upstream of the district and NSID will forego an equal amount of diversions while maintaining historical seepage and return flows. To date, no water has actually been delivered to the Xcel power plant, but the district has received $632,000 and its members have made over $1m since 2005 (Yahn, 2015).

5.3.6.1 Analysis

The NSID case is unique. The district has significant storage and a valuable senior water rights portfolio. Many other irrigation districts are not as fortunate. To date, they have received significant economic gains for very little cost in dollars to set up the agreement and no cost in water delivered. The NSID-Xcel agreement presents a viable formula of how agriculture and industry can lease water in a way that benefits both parties. In this case, Xcel has managed a significant water risk using money, and the farmers have been compensated for acquiring that risk without, at least so far, having to make water
sacrifices. In the case of actual water deliveries, is not clear how the farmers would reduce water use. Fallowing would be one option, as would acquiring other water, planting other types of crops, or deficit irrigating alfalfa or other crops.

5.3.7 House Bill 13-1248 Fallowing-Leasing Pilot Projects

In 2013, the Colorado Legislature enacted HB13-1248, which was signed into law by Governor Hickenlooper on May 13, 2013. The law (C.R.S. 37-60-115(8)) allows for the Colorado Water Conservation Board to administer a pilot program to test the efficacy of lease-fallowing as an alternative to permanent agricultural dry-up. Ten separate pilot projects, each up to ten years in duration, can be selected. On November 19, 2013, the CWCB board approved “Criteria and Guidelines” for the Pilot projects (Colorado Water Conservation Board and Colorado Division of Water Resources, 2013). The guidelines set forth the process and rules by which applications for these pilot projects will be considered.
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Agricultural Water Conservation in the Colorado River Basin: Alternatives to Permanent Fallowing Research Synthesis and Outreach Workshops

Part 4 of 5

Crop Switching in the Colorado River Basin: A Literature Review and Case Studies

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December 2017

CWI Completion Report No.232
Acknowledgements

This report was financed in part by the U.S. Department of the Interior, Geological Survey, through the Colorado Water Institute. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

Additional copies of this report can be obtained from the Colorado Water Institute, E102 Engineering Building, Colorado State University, Fort Collins, CO 80523-1033 970-491-6308 or email: cwi@colostate.edu, or downloaded as a PDF file from http://www.cwi.colostate.edu.

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Project Background

This document is one of four separate reports created under a grant from the Walton Family Foundation to investigate ways to minimize harm to agriculture as water scarcity in the Colorado River Basin forces growing municipal and environmental water users to look at existing uses as potential sources of supply. Agriculture, the largest water user in the basin, is a frequent target in these efforts. The project, “Agricultural Water Conservation in the Colorado River Basin: Alternatives to Permanent Fallowing Research Synthesis and Outreach Workshops” was undertaken to create detailed reports of the four common methods used to temporarily transfer water from agriculture to other purposes. The four reports consider the following methods:

- Deficit Irrigation of Alfalfa and other Forages
- Rotational Fallowing
- Crop Switching
- Irrigation Efficiency and Water Conservation

After the reports were drafted, three workshops were held, one in the Upper Basin in Grand Junction on November 4, 2016, one in the Lower Basin in Tucson on March 29, 2017, and one in Washington, D.C. on May 16, 2017. All of the reports are available from the Colorado Water Institute website.

Acknowledgements

First, Greg Peterson and I thank the Walton Family Foundation for making this project possible. Without their funding and support, the project would not have happened.

Many people assisted with this project by reading and providing comments on drafts. We want to especially thank Perri Benemelis, Mike Bernardo, Perry Cabot, Aaron Citron, Michael Cohen, Bonnie Colby, Terry Fulp, Robert Glennon, Bill Hasencamp, Chuck Howe, Carly Jerla, Dave Kanzer, Doug Kenney, Kelsea MacIlroy, Jan Matusak, Sharon Megdal, Peter Nichols, Wade Noble, Michael Ottman, Ron Raynor, Adam Schempp, Tina Shields, MaryLou Smith, Pete Taylor, Reagan Waskom, John Wiener, and Scott Wilbor. Paul Kehmeier contributed a lovely photograph and important story. The work product was much improved by these insightful comments. It must be noted that any mistakes are solely mine.

Nancy Grice at the Colorado Water Institute provided critical support with financial reporting, travel assistance, and working with Colorado State University. MaryLou Smith was instrumental in organizing and chairing the outreach workshops. Reagan Waskom provided much needed intellectual support throughout the project. Beth Lipscomb assisted with overall editing at the end. Finally, a very special thanks goes to my co-author, Greg Peterson, who did much of the early, difficult research and writing. Much of the value of this project is in the extensive bibliographies that Greg created by painstakingly acquiring, reading, and summarizing hundreds of documents.

We thank Senator Michael Bennet and his staff for acquiring a room at the Capitol Visitor Center for the D.C. event. Finally, we extend our sincere appreciation to the approximately 100 participants who shared their precious time to join us for our outreach workshops. Thank you, all.

Brad Udall
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Abbreviations

AF  Acre-feet       
ET  Evapotranspiration  
FRIS  Farm and Ranch Irrigation Survey 
IID  Imperial Irrigation District  
MAF  Million Acre-feet  
NASS  National Agricultural Statistical Service  
PVID  Palo Verde Irrigation District  
SARE  USDA Western Region Sustainable Agriculture Research and Education Program  
USDA  US. Department of Agriculture  
WMIDD  Wellton-Mohawk Irrigation and Drainage District
1 Summary

Crop switching has been proposed as a way to save large amounts of water in the West, including the Colorado River Basin. While in theory this technique is appealing as a way to save water, numerous studies and publications have shown that crop switching is difficult to implement because there are many complicated and potentially expensive issues to resolve. For a farmer, crop switching implies modifying much of what they depend upon to generate income.

1.1 Calls for Crop Switching Often Ignore Larger Economic and Market Forces

Large economic and market forces encourage farmers to produce many traditional, water-intensive crops. These crops have an entire production and risk management system built around them.

1.2 The Lower Basin has More Crop Switching Opportunities

For crop switching to work, the new crop must offer lower water usage, relative to the old crop. Unfortunately, the consumptive-use difference between crops in the Upper Colorado River Basin is often relatively small, because the Upper Basin has lower evapotranspiration due to cooler temperatures and a shorter growing season. This decreases the crop-switching advantages in the Upper Basin. A few locations in the Upper Basin, such as the Uncompahgre and Grand Valleys, do have climates that allow for many different crops. There are more crop-switching options in the Lower Basin because the climate there allows for greater crop selection, and because the longer growing season increases the water-use difference between high- and low-consumptive-use crops.

1.3 Farm Level Concerns

Soils, irrigation systems, farm equipment, labor, and risk management instruments are all farm-level issues that must be surmounted in order to switch crops. These are discussed below.

a. Climate and Soils Constrain Crop Selection

In the West, alternative crops must be able to survive, and even thrive in extreme conditions, including aridity, wind, hail, maximum and minimum temperatures, and other unusual weather. Compared to alfalfa and other forage crops, vegetables and fruits are only suitable for certain soils, and are generally less resilient to weather extremes. The risks from insect pests, crop diseases, and weeds are often tied to soils and climate, and with new crops these risks are not well understood.

b. Vegetables Generally Require Higher Water Quality Than Forage Crops

With a switch to vegetables, either a new source of water may be necessary, or investments may be needed to improve the quality of the water being used.

c. Water-Delivery Methods May need to change

To shift crops to orchards and vineyards, a farmer may need to invest in micro-irrigation. Micro-irrigation and sprinklers require clean water and a pressurized delivery system.
d. **Crop Switching Can Reduce Drought Resiliency**

Perennial tree and vine crops, unfortunately, require consistent irrigation and cannot be fallowed or reduced in acreage in times of drought like forages. Switching to these crops can thus reduce resiliency when a drought occurs. This can impact the individual farmer as well as entire basins if large transitions to these crops occur. This has been the case in California with the large-scale switch to highly profitable nut trees.

e. **Farming is Very Specialized and New Knowledge May Be Necessary**

In many headwater streams, ranching is the predominant activity, with irrigation used to grow grass forages. Even if the climate allowed it, asking ranchers to transition to growing crops is extremely unlikely and would represent a dramatic shift in their agronomic knowledge. Acquiring the knowledge and skills to grow a new crop requires a significant investment. There needs to be an effective network, including extension services, to disperse and share knowledge on any new crop.

f. **Significant On-Farm Investment May Be Needed for New Equipment and Inputs**

Ideally, with crop switching farm investments would be minimal. Especially compared to alfalfa and other forages, the most common crops in the Colorado River Basin, most crops require more fertilizers, herbicides, pesticides, and/or other inputs, thus raising farm operating costs.

g. **Labor Needs May Change, Impacting Costs**

Most high-value crops like lettuce require intensive labor, unlike forage crops. Production of labor-intensive crops in some parts of the basin may not be competitive due to the lower cost of labor in countries like Mexico. On the other hand, transitioning from an existing, labor-intensive crop can reduce rural labor demand, depress rural wages, and threaten agricultural households and communities.

h. **Financial Risk Management Mechanisms, Such as Insurance, May Not Be Available**

The supporting bank will want to know that the farmer has the necessary knowledge to plant, harvest and market a crop. The ability to store the crop before shipment, if needed, may be important. Knowledge of how markets might affect the final price is necessary, as are hedging mechanisms for that price.

i. **Alfalfa, Often the Crop to Replace, Has Significant Benefits**

Alfalfa consistently has the highest consumptive use of any crop in the basin. For this reason, it is often a target for replacement. By switching out of alfalfa, however, farmers forego significant benefits. Alfalfa is planted once and lasts for several years, thereby reducing annual input costs. Pesticides and herbicides are often not used. As a nitrogen-fixing legume, it can be an important crop in a rotation, and it does not require nitrogen fertilization. It is relatively easy to grow, and is robust to varying weather and climate conditions. It is drought-tolerant.

Because humans do not consume it, alfalfa is less susceptible to quality concerns, although these can certainly affect its market price. It can be readily stored and sold later when prices are high. It has a widely available and growing market, thanks in part to the emergence of a strong dairy sector in the
West. Until recently, prices have been high. In short, farmers know how to grow this crop, it is relatively low risk, and it provides decent, reliable returns. Any other crop can look risky by comparison.

It seems unlikely that unknown non-forage niche crops will replace alfalfa, at least in the short term. A better strategy might be to replace one forage (alfalfa) with another, less water intensive forage, such as forage sorghum. This approach would affect the overall forage market less by providing a substitute crop. If large declines were to occur in alfalfa production, surely alfalfa prices would rise, thus encouraging more alfalfa production.

1.4 Broad Scale, Off-Farm Issues

There are also significantly larger economic, political, and business factors that can limit a farmer’s options of what to grow. Even though switching to low-water-use crops may conserve water, such a change may be economically unviable due to these off-farm issues.

a. Large Shifts in Output May Impact Prices, Farmers’ Incomes and Other Agricultural Sectors

One proposal to shift a significant amount of acreage from alfalfa to fresh tomatoes in California would likely have a dramatic effect on prices. Processing facilities and a market for the new crop need to exist. The market for vegetables and high-value crops can also be much more volatile, with more market fluctuations in price than traditional crops.

b. Politics and International Competition are Significant Factors in Crop Selection

There is also a competitive disadvantage for U.S. growers for produce that can be grown less expensively in other countries. Many areas in the Colorado River Basin are well-suited economically for alfalfa and forage production, but cannot compete with the low-cost production of certain crops in other countries, thus encouraging continuation of current cropping patterns.

c. Subsidies May Constrain Changes in Crop Production.

Cotton, a crop with high consumptive water use, has been supported by federal subsidies. These subsidies encourage production and discourage switches to alternative crops.

d. An Entire Supporting Infrastructure Often Must Be Built Around New Alternative Crops

This new business infrastructure includes seed and fertilizer supplies, marketing and distribution networks, and even processing and storage facilities. Plus, processing a crop often requires a certain amount of the crop to justify the investment in processing and storage facilities.

e. Water Law Disincentives

In most Western states, there are strong water law disincentives against switching crops to save water. The key disincentive is the loss of historical crop consumptive use when switching to a crop that uses less water. When selling a water right, an historical consumptive-use analysis, based on the actual crops grown, determines how much water can be transferred. Only this historical consumptive use can be sold, not the far larger decreed headgate diversion amount. This, unfortunately, provides a strong incentive for growing crops with large consumptive water use.
Colorado farmers know that alfalfa uses lots of water, and they believe that growing it will preserve their water rights and maximize their return in a future sale. If a farmer wanted to monetize the water savings from crop switching, the savings would need to legally quantified and transferred at the time of the switch, not later when lower consumptive use numbers would apply. Finally, a farmer’s water rights are his or her most valuable asset, and selling these assets are often the only retirement plan the farmer has; this fact further encourages maximum use.

1.5 Case Studies

There are very few documented cases of switching crops to save water. The Walker River Basin in Wyoming is one case, although this example was funded by the federal government in an unusual experiment. There are many cases of crop switching encouraged by market forces. Avocados took decades to become a mainstream crop. Nuts, on the other hand, became a very large and valuable crop in California in about two decades. Both of these crops provide interesting lessons. Since the mid-1970s, growers in the Yuma area have switched from citrus, cotton, and other crops into more sophisticated multi-cropping oriented around very profitable winter vegetables. As a result, this has saved about 250,000 acre-feet of water per year. Some of the Yuma savings also arise from irrigation efficiency improvements.

2 Introduction

Switching from traditional low-value, high water consuming crops (i.e. alfalfa, cotton, corn) to high-value crops that use less water — like lettuce, grapes, or tomatoes — or even switching from one kind of forage (alfalfa) to other kinds of forage (Sudan grass, sorghum, teff) have all been proposed methods for conserving water in the Colorado River Basin, and elsewhere in the West. These proposals typically compare the water use of alfalfa to the water use of other crops, concluding that the significant difference in consumptive use could then be transferred to municipalities or environmental purposes. In addition, these studies state that switching to high-value, low water use corps would be economically beneficial for farmers. In theory, the increased profits from the new crop should provide enough incentive for farmers to make such a switch. Crop switching, unfortunately, involves substantial disincentives that outweigh a simple increased profits analysis.

This chapter discusses some of the proposals for crops switching and the knowledge needed to successfully pursue such a strategy. It first provides some historical background on how and why crop shifts have occurred. Two interesting cases, one involving avocados and one nuts, are presented as lessons in how slowly – and how quickly – transitions to new crops can occur, and how obstacles can be overcome. A brief discussion on how climate change might affect crop selection is next. This is included because climate change has the potential to upset many long-standing assumptions about crops and markets regionally, nationally, and internationally. The chapter then discusses published western Extension Service farmer adaptation strategies when water is short. Next, several crop-switching proposals for unusual and lesser known crops are discussed. An overview of the existing crop mix in the Colorado River Basin follows. This information is critical to understanding what and where crop switching opportunities exist. A number of Colorado River Basin-specific proposals to switch crops with the express purpose to save water have been made in recent years. These are discussed, as are the some of the published objections to these studies. Finally, the chapter ends with several case studies on crop switching.
3 Selected History and Insights from Past Crop Shifts

U.S. farmers have changed crops for many reasons through the years. Most often, changing climates and changing markets have forced shifts. In the American West, periodic drought in the Southern Great Plains, including Oklahoma, and portions of Kansas, Texas, Colorado, and New Mexico, induced farmers to shift crops from corn to wheat after a drought from 1889 to 1892. Farmers also adopted a series of agronomic practices that became known as “dry farming.” Eastern Colorado farmers early in the twentieth century learned to grow winter wheat and fallow in the summer and following winter to maximize soil moisture accumulation. The region continued to see periodic drought and dust storms, and each time farmers experimented with new crops and new forms of soil management. One of the largest changes in Great Plains agricultural practices was after a series of droughts and dust storms in the 1950s. The federal government sponsored the Great Plains Conservation Program, which offered 10-year contracts to farmers with assured sales and subsidized credit if they agreed to adopt conservation measures and shift from agriculture to grazing. The program also supported the transition to irrigated alfalfa for livestock (Orlove, 2005).

In more recent times, changing consumer tastes in the United States and around the world have driven shifts to crops that now seem normal but not so long ago seemed exotic or minor. Avocados and nuts in California provide two good case studies of how production and demand can change over time. In the case of tree nuts, the shift reduces flexibility in water supplies because water must always be supplied, no matter the cost, in order to protect the large investments. Indeed, during California’s recent drought, nut farmers were able to outcompete even municipal interests in markets to acquire water (Howitt & MacEwan, 2015) and in another case a large water wholesaler decided against competing against these high valued, perennials (Hasencamp, 2016). Cotton has seen a very large decline in the Colorado River Basin in recent years due to economics but federal crop subsidies may be preventing an even greater shift.

Irrigators often change the crops they grow for economic and agronomic reasons, but water savings appear to be almost never a driving force. Market forces seem to be the primary reason for these changes. In recent years, there is evidence in some locations that a changing climate is allowing farmers to plant different crops. Crop shifting to save water is certainly possible, but it will take significant investments if it is to be successful on a large scale. Expecting individual farmers to shift crops to save water without substantial incentives seems highly unlikely, especially given that Western water law promotes as much use as possible1 and that there is no easy way to monetize saved water currently.

3.1 Growing Avocados in California

Crop shifting can involve foods unknown to consumers and in such cases consumers need time to literally acquire a taste for the food. The rise in popularity of avocados, for example, took decades. Even though it is a water-intensive-crop, avocados are now produced in large quantities almost exclusively in California to meet the sharp increase in consumer demand in recent years.

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1 In Colorado, for example, there are two legal forces pushing farmers to maximize their water use. The first is the idea that if they do not use their entire decree, they may be forced to abandon the portion that is not used. The second force is that in a water rights change case the amount that can be changed is the historical consumptive use amount. This encourages farmers to grow the most water consumptive crops. One legal scholar has suggested that converting decrees to set consumptive use amounts rather than headgate diversions would encourage conservation and trading (Squillace, 2013).
Avocados have been cultivated in California since the late nineteenth century, but growth in the industry did not begin until approximately 1970. Several problems initially hindered consumer acceptance and, in turn, limited demand. The original name was unfamiliar and hard to pronounce. The first association of California avocado growers was called the California Ahuacate Association, the word commonly used in Mexico. The word avocado was not in dictionaries and often people used the term “alligator pear.” There was a basic lack of knowledge about color and even how to tell if the fruit was ripe. Changing the type of avocado to dark-skinned varieties like Hass from green skin avocados also took time for consumers to understand (Arpaia, 2012). From 1970 to 2000 consumption of avocados doubled (Brunke, 2003). Since then the increase has been even more dramatic. In 2014, 1.9 billion pounds of Hass avocados were sold. That is double the amount in 2005 and four times the amount in 2000 (Ferdman, 2015). Now, California produces 95 percent of the nation’s crop and avocados are grown year-round in southern California. San Diego County produces 40 percent of all avocados in the state (Brunke, 2003).

The rise in demand occurred for three reasons. In 1914, a U.S. ban on Mexican avocados was enacted to prevent invasive pests. This ban allowed the California industry to mature and grow without competition (Arpaia, 2012; Brunke, 2003). Second, the Hass avocado has a longer shelf life and is easier to ship. This allowed farmers in California to export the crop throughout the rest of the country. Third, the country’s growing Hispanic population and the expansion of Mexican cuisine created a much larger market. There are almost 40 million Hispanics of Mexican origin in the U.S. and guacamole is now a mainstream food (Ferdman, 2015). All of these changes took time, especially the shifting demographics and palate of the U.S. population. Several different factors had to align for the demand of avocados to increase to where it is today.

Interestingly, U.S. avocado production has recently suffered. In light of the recent drought in California and competition from cheap imports, more farmers have been fallowing acres of avocados. Irrigating has not been cost-effective for some farmers, and some have shifted to growing grapes which consume far less water (McClurg, 2015; Nagappan, 2014; Sofia Knauf, 2015).

3.2 California Nut Production

Three nut crops are in the top five agricultural products by value in California from 2012 to 2014. Almonds were first in value, followed by dairy products, walnuts, wine, and pistachios (CDA, 2015). Total tree nut production in the U.S. was over $10 billion, with almonds, walnuts, and pistachios making up over 93 percent of sales. California is the nation’s major producer of these three crops, and is the main global producer. California is the number one global producer of almonds and pistachios, making up 80 and 40 percent, respectively, of the global production. It is also the second largest walnut producer in the world after Iran (CDA, 2015).

Almonds were a niche crop in California for about 150 years before vaulting to prominence. European varieties of almonds were first planted in California in 1853 but early production was poor. Almond varieties did not consistently bear nuts and the cultivars were not well adapted to the environment. In the 1880s, local varieties were introduced and cross pollination of almond trees became more common in the early 1900s. These improvements boosted production, but it was not until the 1930s that farmers even began irrigating the crop. Production and acreage continued to grow, especially from the 1960s to 1980s when new product development and marketing increased the demand for almonds. Also, irrigated acreage expanded significantly in the San Joaquin Valley, where the soil and climate are ideal
for almond trees. In decades since, acreage has not increased as much, but farmers have made considerable strides in producing more yield per acre (Geisseler & Horwath, 2014).

Almond acreage, yields, and value began making significant gains from 1960 to 2000. However, since 2000, increases dwarfed the prior decades (Figures 1 & 2). Almond cultivation has increased from 510,000 to 870,000 acres. In 2000, 703 million pounds of almonds were produced. In 2014, production was over 1.8 billion pounds, almost 260 percent more. The total value of California almonds was $666 million in 2000. Fourteen years later it was 900 percent more, almost $6 billion.

The same story holds true for pistachios and walnuts, where significant growth occurred from 2000 to 2014. In 2000, there were 74,600 acres of pistachios producing 243 million pounds with a total value of $245 million. By 2014, acreage nearly tripled to 221,000, production more than doubled to 514 million pounds, and the total value was almost $1.6 billion, a 6.5 fold increase (CDA, 2015). For walnuts, acreage steadily increased 102,900 in 1920 to 200,000 in 2000. It took nearly 80 years for an increase of almost 100,000 acres. From 2000 to 2014, the acreage increased by another 90,000. Production more than doubled from 478 million pounds to 1,140 million pounds. During the same time period, the increase in total value has been dramatic: $286 million to $1.8 billion, a 630 percent increase (CDA, 2015).

Rising global and national demand for nut crops spurred this production increase (Figure 3). For 2013-2014, 642 million pounds of almonds were shipped in the U.S., but twice this amount, 1,296 million pounds, was exported to other countries like Spain, China, Germany, India, the United Arab Emirates, and Japan (Almond Almanac, 2014). Since 2000 almond and walnut exports have about tripled, and pistachios exports have increased by six times (USDA, 2014).

In 2014, during the height of the recent California drought, the water use of almonds was widely discussed. Headlines from prominent news sources read It Takes How Much Water to Grown an Almond?!, The Dark Side of Almond Use, Stop Water Abuse by the Almond and Pistachio Empire, and Here’s the Real Problem with Almonds (Hamblin, 2014; Hauter, 2015; Park & Lurie, 2014; Philpott & Lurie, 2015). It became common knowledge that a single almond requires more than a gallon of water (which is actually similar to most nut and fruit crops) and that almond farmers in California use more water than all California families use indoors. During the drought, significant quantities of water continued to be used for these crops because nut farmers, unlike many other farmers, could afford the high price of water in spot markets and had to water their plants. When residential mandates on water conservation began, many argued that farmers of water-intensive crops like almonds should also conserve. Articles from The New York Times and New Republic argued that exporting almonds was exporting water (Bittman, 2015; Hamblin, 2014; Park & Lurie, 2014; Philpott & Lurie, 2015). One lesson from this massive California crop switch is clear: crop switching to high value perennials that cannot be fallowed clearly reduces water flexibility during times of drought.
Figure 1. California nut acreage 1920-2014. Source: NASS.

Figure 2. California nut value, 1920-2014. Source: NASS.
4 Changing Crops in Response to Climate Change

Researchers have extensively studied the impact to agriculture by climate change with a focus on future yields and if enough food will be grown to feed expanding populations. Many of these projections show varied future outcomes in terms of crop yields (Easterling, 1995; Fischer et al., 2005; Gustafson et al., 2016; Howden et al., 2007; Parry, Rosenzweig, Iglesias, Livermore, & Fischer, 2004). Most assert that rising temperatures, changing rainfall patterns, and extreme weather will harm crop yields worldwide if greenhouse gas emissions remain unabated (Gustafson et al., 2016). Large temperature changes at the end of the century are expected to lower crop yields, while shifting patterns of precipitation may either increase or decrease yields (Malcolm et al., 2012). Smaller temperature changes may increase yields in the short term by expanding the growing season, provided that precipitation patterns do not change too much and extreme events do not hamper production.

Some studies show that food production will increase in developed countries and decrease in developing nations. Overall, in the short term the negative impact on total world crop yields may be minimal but will increase the disparity between developed and developing countries (Fischer et al., 2005; Parry et al., 2004). Cold-limited climates like mountainous regions may benefit significantly from climate change (Easterling 1995). Some cropping systems, like wheat-growing regions, may also benefit from climate change (Howden et al., 2007). Acreages of corn, wheat, and soybeans may shift from the eastern United States to the Central Plains or mountain states. Carter and Culp (2010), state that there will be an increase in locally produced crops in response to overall decreases in crop yields, which will raise prices and transportation costs.

Many parts of the country are already undergoing climate-induced crop switching. Planting of hard red winter wheat in the Great Plains and southern Canada has moved northward. Warming of the region will most likely expand the wheat growing area, especially with the development of hybrids that can deal
with arid climates, cold temperatures, and shorter length of day (Easterling, 1995). Conversely, the changing climate in North Dakota has allowed farmers to shift from durum wheat to growing corn and soybeans. In the area known as the “durum triangle,” rainfall has been 2 to 3 inches greater in the past 20 years and the growing season has increased by 2 weeks over the past century. The increased moisture and humidity contribute to disease like scab in wheat, while at the same time it has led to better yields and hence more profit in corn. Corn and soybeans now make up 15 percent of North Dakota’s cropland, a region that was used to be almost exclusively wheat (Ydstie, 2014). In recent years, copious spring precipitation has delayed planting in the Northern Great Plains. Growing zones have shifted significantly over the past 50 years and will continue to shift as the planet warms.

It is clear that farmers change crops in response to changes in climate. Crop shifting plans to conserve water should consider how a warming climate and water supply changes will affect the viability of all crops in a given area. In addition, many markets will respond to global production changes, thus impacting farmers’ profits and ultimately crop selection at the local level. In the short term, climate change may increase yields due to longer growing seasons and CO₂ fertilization. Extreme events of all kinds, however, may offset these potential gains. In the longer term, significant warming appears to be harmful to agriculture. Climate change, therefore, has the potential to change agriculture significantly as the 21st century unfolds, especially if substantial warming occurs.

5 Extension Investigations of Irrigating with Less Water

State Extension services in the West sometimes investigate the water savings associated with growing different crops (Amosson et al., 2005b; Bauder et al., Hansen, Lindenmeyer, Bauder, & Brummer, n.d.; MSU & CSU, 2006; Schneekloth & Andales, 2009). These studies have been driven by the need to inform farmers about what to grow when water supplies are short, typically during drought, not necessarily how to conserve water for other purposes. Nonetheless, this information is also useful for considering crop switching to produce water savings.

The guides make similar recommendations including choosing “short season” cultivars that likely reduce yields somewhat, but take less time to mature (which helps to decrease total water consumption). This practice can include using dwarf species that consume less water than full size crops, switching to altogether different crops that use less water, using conservation tillage to conserve moisture, scheduling irrigation based on known evapotranspiration to minimize soil evaporation loss, and even converting irrigated crops to rain fed crops. They note that annuals generally use less water than perennials because they need water for a shorter period of time. The studies also touch on deficit irrigation of different crops if needed due to short water supplies. For example, they note that “indeterminate” crops² such as grains are less sensitive to water shortages when small, and more sensitive during their grain-producing phase. “Determinate” crops such as potatoes, are very sensitive during their early life stages, and less so later. Perennials such as grasses and alfalfa are quite drought tolerant and many go dormant if dried significantly.

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² Indeterminate crops grow until killed by frost or some other factor. Determinate crops stop growing once a genetically predetermined structure is created.
6 Switching to Unusual or Lesser Known Crops

Extension services occasionally investigate the suitability of unusual and unknown crops for several reasons including lower water use. Teff, a gluten-free grain consumed by humans in Africa but used in the U.S. as a high-quality horse forage; jojoba, an oil producing desert shrub; guayule, a rubber substitute; and forage sorghum are four examples of unusual or lesser-known crops that use less water than alfalfa. These crops could be grown in the Colorado River Basin and each has been studied as an alternative crop. With the exception of forage sorghum, these are very unusual crops, however.

The primary water savings available with teff is due to its shorter growing season compared to alfalfa (Davison, Laca, & Creech, 2011a). Multiple studies have demonstrated the crop’s viability in the West. Teff is a warm season grass that needs high temperatures to maximize yield. It can produce 5 to 6 tons of hay per acre over a relatively short growing season and has a consumptive use of approximate 2.5 af/acre in Nevada. Since 2005 its price has closely tracked alfalfa hay. It was even recently been promoted as a new ‘super grain’ for humans (O’Connor, 2016).

Foster and Wright (1980) examined the potential to grow jojoba near Tucson, a shrub native to the Sonoran Desert, which contains an oil that can be extracted from its seeds. Jojoba’s low consumptive use, 1.5 AF per acre, would represent a significant savings compared to the 4.0 AF per acre for most crops grown in the area. The 2.5 AF / acre water savings could be exported from farms to meet municipal demand, with 1.5 AF / acre left to irrigate the jojoba. The authors proposed a variety of financial schemes for cities like Tucson to subsidize the crop, which could be cheaper than purchasing the water outright.

Guayule has recently been promoted as a rubber substitute (“Native Crops,” 2012). It is a low bush that grows wild throughout the Chihuahuan Desert. The bark is harvested from a perennial plant to create a low allergy rubber product. It was commercially produced during World War II when other rubber supplies were not available.

McCorkle et al. (2007) presented a more thorough study on potential and actual crop switching to sorghum silage as an alternative forage for beef and dairy industries in the Texas Panhandle, an area dependent on groundwater. Water demand projections show that water demand will surpass supply by 2020, and there will be a significant water deficit in the Texas Panhandle, hence the interest in alternative crops. Sorghum silage uses one-third to one-half less water than corn silage. Acreage planted to sorghum silage has increased by 30,000 acres, a 40 percent rise, from 2003 to 2007 in the Texas study area. Field tests have shown that sorghum silage: (1) has roughly the same yield as corn; (2) uses far less water — up to 50 percent less — which reduces fuel costs for pumping; and (3) has nutritional quality equal to corn. Feed quality trials show that sorghum silage did not lower the rate of gain or the feed efficiency of cattle. Prices for sorghum silage are becoming more competitive, but corn silage has a long history with growers, feedlots, and dairies. Sorghum is a warm season crop, is very drought tolerant, provides a useful rotation with corn, and has seen a spike in interest from growers in recent years, in places like Oklahoma and eastern Colorado, in addition to Texas.

7 Colorado River Basin Crop Mix

The current mix of crops in the basin and each basin state are an important starting point to understand the overall crop-switching potential in the basin. Most of the recent data comes from the 2013 Farm and Ranch Irrigation Survey (FRIS) by the USDA. The survey is a supplement to the 2012 Census on
agriculture that focuses on irrigation activities in the nation. Figures are extrapolated from 35,000 participants across the country to detail acreage, crop types, irrigation methods, and crop yields. The irrigation survey shows just how much of the irrigated acreage in the basin is used for livestock forage (i.e. alfalfa, hay, silage, etc.). Forage is a significant irrigated crop in both the Upper (~90 percent of irrigated acreage) and Lower basins (~40 percent of irrigated acreage). The Upper Basin’s high elevation, short growing season, and harsh climate limits the types of crops that can be grown to mostly pasture, grasses, and alfalfa. In the lowest and warmest parts of the Upper Basin, (areas like Colorado’s Grand and Uncompahgre Valleys), corn, onions, orchards, grapes, and other row crops can be grown. By contrast, the Lower Basin provides the climate and long growing season for a much wider array of crops.

Figure 4. Irrigated acreage in the Upper Basin by crop type. Source: 2013 Farm and Ranch Irrigation Survey.

7.1 Upper Basin

As mentioned by American Rivers (2014), Moving Forward (2015), and Cohen et al. (2013), the crops grown in the Upper Basin are fairly consistent and not as diverse as in the Lower Basin. The climate, lack of access to markets, and short growing season limit the options for widespread cultivation of many
crops. The Upper Basin is therefore mainly devoted to livestock feed (Figure 4). Alfalfa and alfalfa mixtures are the single most dominant crop types, making up 26 percent of the Upper Basin acreage. All other hay and pastureland each make up 32 percent of irrigated acreage. Ninety percent of the irrigated acreage in the Upper Basin is therefore devoted to some sort of forage crop or pasture. That leaves only 10 percent of irrigated acreage devoted to all other crops; this acreage is typically in the lowest and warmest parts of the basin.

The crop mix in each of the Upper Basin states (including the lands outside of the basin irrigated with Colorado River water) is similar and is predominantly livestock feed and irrigated pasture (Table 1). The production of these crops is closely linked to the livestock and dairy industry in each state. In many locations of Wyoming, western Colorado, and eastern Utah, hay grown for forage is mainly consumed by the grower’s herds, but some is sold locally or exported (Cohen et al., 2013). Alfalfa, hay and pasturelands make up the majority of irrigated acreage in Colorado (56 percent), New Mexico (53 percent), Utah (82 percent) and Wyoming (81 percent). The next highest group of crops in terms of acreage is corn for grain or livestock feed, ranging from 7 percent in Wyoming to 29 percent in Colorado. There is significant acreage devoted to other crops, like wheat and orchards in New Mexico, and vegetables in Colorado, but they are still a small fraction compared to irrigated forage (FRIS, 2013).

Table 1: Irrigated acreage and percent of total irrigated acreage of crops in the Upper Basin states. Source: 2013 Farm and Ranch Irrigation Survey.

<table>
<thead>
<tr>
<th>Crop</th>
<th>1,000s of Irrigated Acreage by Crop / % of Total Irrigated Acreage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Colorado</td>
</tr>
<tr>
<td>Alfalfa and alfalfa mixtures</td>
<td>558</td>
</tr>
<tr>
<td></td>
<td>24</td>
</tr>
<tr>
<td>All other hay</td>
<td>428</td>
</tr>
<tr>
<td></td>
<td>19</td>
</tr>
<tr>
<td>Pasturelands</td>
<td>296</td>
</tr>
<tr>
<td></td>
<td>13</td>
</tr>
<tr>
<td>Other small grains</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Corn for grain or seed</td>
<td>583</td>
</tr>
<tr>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Corn for silage or greenchop</td>
<td>104</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Wheat for grain or seed</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Land in orchards, vineyards and nut trees</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>&lt;1</td>
</tr>
<tr>
<td>All other crops</td>
<td>177</td>
</tr>
<tr>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>

7.2 Lower Basin

The crop mix is much different in the Lower Basin, where the climate allows more options for farmers and some crop switching has already occurred (Noble, 2015a). Even though the climate supports a greater variety of crops, irrigated livestock forage is still about 40 percent of the total acreage (Figure 2).
Alfalfa (32 percent) is the single most widely cultivated crop in the Lower Basin, and other hay adds another 6 percent. Cotton (19 percent), vegetables (11 percent), and wheat (8 percent) are next. Even though the climate in southern California and Arizona allow the growth of a wide array of crops, high value crops like lettuce and other vegetables (11 percent) only make up a small fraction of the total area (FRIS, 2013).

The irrigated agriculture in all of Arizona, California, and Nevada is more diverse, but that is mainly due to central and north California, where significant acreage is devoted to vegetables, tomatoes, and orchards (Table 2). For Nevada (which, like California, lies mostly outside of the Colorado River Basin), the crop mix is very similar to the Upper Basin states. Alfalfa, pastureland, and other hay make up over 92 percent of the limited irrigated acreage in the state. The crops grown in Arizona are more diverse. The major irrigated crops are alfalfa (28 percent), cotton (18 percent), vegetables (11 percent), wheat (7 percent), small grains (6 percent), and other hay (5 percent). Crops like lettuce and citrus orchards that are widely grown in areas like Yuma, Arizona, are only 5 and 3 percent of total irrigated acreage, respectively (FRIS, 2013).
Figure 5. Irrigated acreage in the Lower Basin by crop type. Source: 2013 Farm and Ranch Irrigation Survey.
Table 2: Irrigated acreage and percent of total irrigated acreage of crops in the Lower Basin states. Source: Data from 2013 Farm and Ranch Irrigation Survey.

<table>
<thead>
<tr>
<th>Crop</th>
<th>1000s of Irrigated Acreage by Crop / % of Total Irrigated Acreage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nevada</td>
</tr>
<tr>
<td>Wheat for grain or seed</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Alfalfa and alfalfa mixtures</td>
<td>322</td>
</tr>
<tr>
<td></td>
<td>47</td>
</tr>
<tr>
<td>All other hay</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Pastureland</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>28</td>
</tr>
<tr>
<td>Cotton</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Land in vegetables</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Other small grains</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Lettuce and romaine</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>&lt;1</td>
</tr>
<tr>
<td>Land in orchards, vineyards, and nut trees</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>&lt;1</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Rice</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Corn for silage or greenchop</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>All other crops</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Over the past ten years, there has been an increase in field crop acreage, and a decline in vegetables and citrus in all of Arizona. Acreage for vegetables declined by about 25 percent while alfalfa and hay acreage has increased by more than 30 percent. The increase in forage crops has paralleled an increase in the number of cattle and sheep in the state over the same period. In California, alfalfa acreage fell during the time period shown, and acreage of field crops and vegetables increased. The acreage planted in fruits and vegetables is much greater in terms of total acreage and percentage than any other states in the basin with the exception of Arizona. Still, alfalfa and field crops are a significant portion of the crop mix (Cohen et al., 2013).

7.3 Evapotranspiration of Crops in the Basin

Crop evapotranspiration (ET) or water use is a function of the climate and the type of plant. Plants use water for a variety of purposes. It is as medium and substrate for biological reactions. Water provides structural support for plants; wilting is the absence of water. The act of transpiration from the leaves pulls water and water-soluble nutrients from the soil. Finally, transpiration allows the plant to absorb carbon in the form of CO₂ from the atmosphere. Leaf openings, called stomata, release water vapor while they absorb CO₂. This exchange cools the plant while providing carbon for growth. Higher
temperatures and lower humidity drive higher evaporation; therefore, plants use more water in hot, arid areas. The consumptive use of different crops throughout the basin shows the large variation of ET in the region (Table 3) and the possible water savings from crop switching (Table 4). ET in the Lower Basin is significantly higher than the Upper Basin, an expected finding given the hotter temperatures and longer growing season. This difference in ET between the basins provides dissimilar opportunities for water savings.

In the Lower Basin, there is a significant water use difference between a high-ET crop like alfalfa (~60 inches) and a low-ET crop like lettuce (~10 inches) or dry beans. Throughout all of the Lower Basin, alfalfa has the highest ET, requiring more water than any other crop including corn (~25+ inches), other forages (~40 inches), and even citrus (~40 inches). In Yuma, Arizona, comparing the ET of other forages like Sudan grass (~43 in.) and Bermuda grass (~40+ inches) to alfalfa (~64 in.) shows the substantial consumptive use savings (~20 inches) by switching from alfalfa. The consumptive use savings are even greater when compared to potatoes, onions, and small grains like barley (~20 inches). In general, in the Lower Basin, crop switching from alfalfa to any other crop will save significant amounts of water.

In the Upper Basin, however, switching from alfalfa to other crops will result in significantly less consumptive-use savings. The ET of the alfalfa ranges from ~29 to ~43 inches in the Upper Basin states. This is half to two-thirds of the ET of alfalfa in the Lower Basin. Alfalfa’s consumptive use in the Upper Basin is not that much greater than other crops like corn (~25 inches), potatoes (~25 inches), onions (~30 inches), or sugar beets (~25 inches). In Utah, the ET of alfalfa can even be lower than orchard ET. The lower alfalfa ET in the Upper Basin is a combination of lower temperatures and the much shorter growing season.

Far fewer alfalfa cuttings are possible compared to the year-round growing season in the Lower Basin. For a given acre in production, the water savings by switching out of alfalfa in the Upper Basin is therefore less than in the Lower Basin. Importantly, however, much more of the Upper Basin is planted in alfalfa and other forages than in the Lower Basin, thus providing more theoretical potential crop switching acres even if the water savings per acre are less. Unfortunately, much of this acreage is at high elevations, where alternative crops are not possible.
Table 3: Consumptive use of crops in the Lower and Upper Colorado River Basins (inches/growing season). Data for Arizona and California is from the 2010 Bureau of Reclamation report “Estimates of Evapotranspiration and Evaporation Along the Lower Colorado River”. Data for Colorado is from the CoAgMet by Colorado State University and the USDA. Data is from 2015 and can be found at [http://ccc.atmos.colostate.edu/~coagmet/index.php](http://ccc.atmos.colostate.edu/~coagmet/index.php). Data for Utah is from the Utah State University's 2011 report “Crop and Wetland Consumptive Use and Open Water Surface Evaporation for Utah” by Robert W. Hill, J. Burdette Barker, and Clayton S. Lewis. Data for New Mexico is from the National Resources Conservation Service. Data is from 2005 and can be found at [http://www.nrcs.usda.gov/wps/portal/nrcs/detail/nm/technical/?cid=nrcs144p2_068704](http://www.nrcs.usda.gov/wps/portal/nrcs/detail/nm/technical/?cid=nrcs144p2_068704).

<table>
<thead>
<tr>
<th></th>
<th>Lower Basin</th>
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<tr>
<td></td>
<td>Fort Mohave, AZ</td>
<td>Wellton-Mohawk, AZ</td>
<td>Yuma, AZ</td>
<td>Parker Dam, CA</td>
<td>HD and Coachella, CA</td>
<td>Cortez, CO</td>
<td>Hayden, CO</td>
<td>Montrose, CO</td>
<td>Bloomfield, NM</td>
<td>Eastland, UT</td>
<td>Maeser, UT</td>
<td>Green River, UT</td>
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<td>58.45</td>
<td>64.75</td>
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<td>61.21</td>
<td>39.83</td>
<td>36.54</td>
<td>42.62</td>
<td>36.68</td>
<td>34.55</td>
<td>28.91</td>
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<td>Corn</td>
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<td>27.54</td>
<td>28.26</td>
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<td>24.75</td>
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<td>33.76</td>
<td>23.51</td>
<td>19.94</td>
<td>21.11</td>
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<td>13.34</td>
<td>15.08</td>
<td>20.47</td>
<td>12.89</td>
<td>30.1</td>
<td>23.95</td>
<td>21.62</td>
<td>28.8</td>
<td>41.65</td>
<td>21.17</td>
<td>17.72</td>
<td>18.15</td>
</tr>
<tr>
<td>Oranges</td>
<td>1/3.34</td>
<td>1/4.54</td>
<td>2/1.17</td>
<td>1/4.34</td>
<td>2/8.04</td>
<td>2/8.7</td>
<td>2/6.74</td>
<td>3/3.25</td>
<td>-</td>
<td>3/0.71</td>
<td>2/6.75</td>
<td>2/9.56</td>
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<td>Sugar beets</td>
<td>24.47</td>
<td>21.74</td>
<td>24.47</td>
<td>22.22</td>
<td>27.75</td>
<td>30.95</td>
<td>28.01</td>
<td>32.93</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Dry beans</td>
<td>13.34</td>
<td>15.08</td>
<td>20.47</td>
<td>12.89</td>
<td>30.1</td>
<td>23.95</td>
<td>21.62</td>
<td>28.8</td>
<td>41.65</td>
<td>21.17</td>
<td>17.72</td>
<td>18.15</td>
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<td>Small grains</td>
<td>22.02</td>
<td>19.4</td>
<td>20.97</td>
<td>21.95</td>
<td>24.75</td>
<td>22.59</td>
<td>21.57</td>
<td>23.85</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wheat (spring &amp; fall)</td>
<td>22.02</td>
<td>19.4</td>
<td>20.97</td>
<td>21.95</td>
<td>24.75</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Winter wheat</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>29.18</td>
<td>24.4</td>
<td>32.77</td>
<td>32.4</td>
<td>-</td>
<td>-</td>
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<td>-</td>
</tr>
<tr>
<td>Citrus (mature)</td>
<td>31.68</td>
<td>39.9</td>
<td>43.05</td>
<td>42.05</td>
<td>43.17</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Orchard</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
</tr>
<tr>
<td>Cotton</td>
<td>32.64</td>
<td>37.41</td>
<td>41.54</td>
<td>34.48</td>
<td>38.84</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Bermuda grass</td>
<td>35.57</td>
<td>36.6</td>
<td>40.01</td>
<td>38.48</td>
<td>53.23</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Grapes</td>
<td>35.19</td>
<td>33.99</td>
<td>36.95</td>
<td>35.72</td>
<td>36.51</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lettuce (spring, late)</td>
<td>6.88</td>
<td>8.08</td>
<td>8.92</td>
<td>6.95</td>
<td>12.41</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sudan grass</td>
<td>40.74</td>
<td>39.37</td>
<td>43.05</td>
<td>40.83</td>
<td>36.93</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>27.08</td>
<td>25.75</td>
<td>26.75</td>
<td>26.61</td>
<td>26.33</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

a – grown only in the spring and fall  
b – grown only in the summer
8 Proposals for Crop Switching in the Basin

Several sources have advocated crop switching in the Colorado River Basin and the West (Aylward, 2013; Cohen et al., 2013; Cooley et al., 2008; Hardest Working River, 2014; Moving Forward, 2015). One recent effort has proposed crop conversion as a way for “impact investors” to make a difference in Colorado River Basin water use (Squire Patton Boggs & Encourage Capital, 2015). Alfalfa is usually the recommended crop to switch out because its high-water usage provides the most water savings, and because it is a very common crop in the Basin and throughout the West. Water savings from switching from alfalfa to other crops have been discussed in a number of studies (Davison, Laca, & Creech, 2011b; Foster & Wright, 1980; Santhi, Muttiah, Arnold, & Srinivasan, 2005; SARE, 2005, 2007, 2009).

These studies discuss some of the factors that determine what can be grown in a given area. American Rivers (2014) mentions that soil conditions, climate, water availability, and market conditions can all limit options for what producers can grow. Most of the studies state that crop switching would be more difficult in the Upper Basin because higher elevations, colder temperatures, and shorter growing season limit the selection of possible new crops. They agree that the Lower Basin presents more opportunities for crop switching due to its long growing season and more hospitable winter climate. High-consumptive-use forage crops like alfalfa make up a significant irrigated acreage in the Lower Basin and provide significant opportunity. It should be noted, however, that both the beef and dairy industry provide significant and growing demand for these forage crops. (Cohen et al., 2013; Hardest Working River, 2014; Moving Forward, 2015). The dairy industry in California, for example, is a $5B/year enterprise (either the 2nd or 3rd highest value agricultural industry in the state, depending on the year) and has experienced significant growth in the last 30 years. Were crop switching out of alfalfa effective on a large scale, alfalfa prices would surely increase — ultimately providing economic pressure to grow more alfalfa. Finally, no study mentions the value of alfalfa, a nitrogen fixing legume, as part of a crop rotation, and what might replace it.

There is very little information in these studies on exactly how to go about switching crops, and there are few examples of successful crop-switching. The Bureau of Reclamation’s Moving Forward Report (2015) does briefly mention one example in the Wellton-Mohawk Irrigation and Drainage District of switching to a lower-water use alfalfa cultivar that produces less in the summer when yields are already low, and water use is high. (This is known as “summer slump.” See the Deficit Irrigation Chapter for details). There is generally no analysis of the costs of switching farming operations, the need for different planting and harvesting equipment, changes in labor, the distance to processing facilities, insurance, water quality, marketing assistance, soils, etc. There is also usually just a cursory analysis on the economic component of crop switching, often only comparing the gross receipts of different crops to calculate net returns from the change.

One of the more detailed proposals comes from the Pacific Institute. “Water to Supply the Land: Irrigated Agriculture in the Colorado River Basin” (Cohen et al., 2013) discusses current crops in the Colorado River Basin and the potential water savings from crop switching. The study presents a series of crop shifting scenarios: shifting from cotton to wheat, from alfalfa to sorghum, and from alfalfa to wheat and cotton (Table 4). The economic analyses did not consider hard to quantify third party impacts. They assume that other interests would compensate irrigators for making the conversion. Mean crop water use was used to determine the consumptive use savings between crops. Net returns above operating
costs were determined by subtracting the total annual operating costs by the total annual revenue (gross receipts) per acre. This was used to determine the cost per acre-foot of water saved.

Table 4: Water savings from crop switching scenarios. Source: Cohen et al. (2013).

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Consumptive Use Savings (Acre-feet/Year)</th>
<th>Base Cost (per AF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70,000 acres from cotton to wheat</td>
<td>&gt;90,000</td>
<td>$112</td>
</tr>
<tr>
<td>74,000 acres from alfalfa to sorghum</td>
<td>&gt;140,000</td>
<td>$96</td>
</tr>
<tr>
<td>74,000 acres from alfalfa to cotton and wheat equally</td>
<td>&gt;250,000</td>
<td>$36</td>
</tr>
</tbody>
</table>

Another report by The Pacific Institute, “More with Less: Agricultural Water Conservation and Efficiency in California: A special Focus on the Delta” (Cooley et al., 2008) presented crop shifting scenarios of a small percentage of lower-value, water-intensive crops to higher-value, water-efficient crops in California. They indicated this could free up nearly 1.2 MAF per year if 25 percent of irrigated field crop acreage were shifted to irrigated vegetable crop acreage. Cooley et al. assessed the economic impact of crop switching by evaluating changes in the gross production value. They do identify market value, local weather, crop subsidy programs, the need to rotate crops, and other factors, and state that future assessments should evaluate how shifting crop types affects the net production value.

Burt et al. (2008) of the Irrigation Training & Research Center at Cal Poly responded to Cooley et al. (2008) in “Agricultural Water Conservation and Efficiency in California – A Commentary.” They argued that Cooley et al. neglected the impact of crop shifts on the overall market. Prices for the new crops would decline due to increased production and thus the farmer’s profits would be significantly less. They noted that the vegetable market is stable with no significant shortages at the current acreage level yet the proposal recommended nearly doubling the acreage. They also indicated that no economic analysis was done on what this would do to prices or where the additional demand would come from. Current production matches demand and long-term contracts between tomato growers and processors have stabilized the acreage. Finally, vegetables are a high-risk endeavor and irrigators are likely to apply more water and/or use double cropping to minimize risk. (In Yuma, double cropping with lettuce, for example, is common). Burt et al. (2008) concluded that the predicted large water savings are unlikely.

The Cohen et al. (2013) study has some of the same issues. Two of the scenarios (cotton to wheat and alfalfa to sorghum) require irrigators to switch from high-value to equal- or lower-value crops. There is no analysis on demand or price. Switching from alfalfa to cotton may be problematic given that U.S. produced cotton has plummeted in recent years and it is much more labor intensive than alfalfa (See Decline of Cotton Section below).

9 Crop Switching Cases

There are very few examples of crop switching specifically to conserve water for other uses, although there are a number cases of switching due to drought or declining groundwater supplies. Crop switching for economic reasons is relatively common as discussed above. Future projects that want to utilize crop switching to save water must take into account the larger political, economic, agronomic, and climatic forces that support the production of the existing crop mix. The cases below occurred either in the Colorado River Basin or near the Basin.
9.1 Wellton-Mohawk Alfalfa Cultivar Switch

The Wellton-Mohawk Irrigation and Drainage District (WMIDD) is one published case where crop switching has taken place to specifically reduce consumptive use. In 1980, improved varieties of alfalfa were planted in the WMIDD. Approximately 25,000 acres were converted and the annual water savings are approximately 15,000 AF (Moving Forward, 2015). This appears to be a very simple way to save water, but details are lacking on the costs and other aspects of the transition. The biggest cost would be a likely decline in yield, and hence, economic returns associated with a lower water using crop.

9.2 Yuma, Arizona Switch to Winter Vegetables

Over the past 40 years, Yuma growers have changed much of their acreage from perennial citrus and full season crops to multi-crop systems that include high-value, and shallow-rooted vegetables. They now focus on high profit, low water use winter vegetables rather than on lower profit, high water use summer crops (Table 6). The main driver for this crop shifting was higher profits but significant water savings also accrued from these changes.

In 1970, the dominant winter crop was wheat, which was the transition crop from cotton to alfalfa. Less than 17 percent of acreage was in vegetables and only 10 percent was multi-cropped. Today, acreage devoted to vegetables has increased 6-fold while the acreage of traditional crops has decreased by 43 percent. Acreage of citrus, cotton, and sorghum have declined 70, 50, and 85 percent, respectively. The acreage of irrigated alfalfa has remained relatively the same (15-20 percent of the area) but it fluctuates due to dairy-driven market demand. Now, nearly 70 percent of irrigated acreage has been converted to a multi-crop system (Noble, 2015b).

![Figure 6. Change in irrigated acreage by crop in Yuma 1970-2010. Note: 2010 numbers include double cropping. Source: Noble, 2015.](image)

During this period of transition, water diversions decreased (Figure 7). The amount of water diverted for irrigation has decreased 15 percent since 1990 (0.8 AF/acre) and 18 percent since 1975 (1 AF/acre)
(Figure 4). Even though multi-crop production now dominates the area, the total water requirement is less than the perennial and full season production systems of the past. Relative to 1970, the only months with increased water deliveries are October through December, when water is used to establish winter vegetables. Compared to the traditional cropping systems, less water is now applied during the hot summer months of July, August, and September, when more water would evaporate due to high temperatures, and when crops have higher ET requirements.

Figure 7. Water delivered to Yuma farms 1970 - 2010. Source: Noble, 2015.

Compared to the traditional cropping systems of the 1970s, the consumptive use of leafy green vegetables, broccoli and cauliflower combined with a second crop of durum wheat, Sudan grass, spring melons, or short season cotton is less (Figure 7). From about 1975 to the mid-1980s high salinity drove declines in water use and led to an international agreement to limit salinity\(^3\). In the late 1980’s as water quality improved, water delivery to farms increased as acreage dedicated to vegetables climbed. At the time, it was standard practice to uniformly germinate newly planted vegetable fields and promote early crop growth using “subbing”, which consisted of filling the furrows with water for seven to ten days to induce sub-irrigation\(^4\). This technique greatly increased the demand for water from September through November. The practice led to excess water lost though deep percolation below the root zone and high groundwater tables.

Several water-saving infrastructure changes accompanied this crop shifting. Rather than sub-irrigating vegetables, growers now use sprinklers to start the crop which saves 8 to 30 inches of water each year.

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\(^3\) Minute 242 of the U.S. – Mexico water treaty.

\(^4\) Sub-irrigation is the practice of overfilling the root zone with water from surface irrigation.
Laser leveling of fields occurs frequently, in some cases annually, and many canals were lined. When laser leveling is combined with high flow turnouts and pressed furrows using bola wheels, the on-field water application efficiency rates are very high. Because of these techniques, water deliveries to farms have declined substantially since 1990 and are at their lowest since 1970 (Noble, 2015b).

![Figure 8. Crop water use of different crop mixes. Note. Solid bars above the hatching represent the water use of the 2nd crop in the annual rotation. Source: Noble, 2015.](image)

The crop transition in Yuma was not a response to save water, but to meet growing demand for high-value winter produce. Shifting crops on this scale took years, on-farm investment, significant knowledge, and a ready supply of labor. District-wide infrastructure efficiency measures also helped with the water savings. Most importantly, the unique climate of Yuma allows irrigators to grow high-value, low-water-use produce in the winter, a situation that exists only in southernmost portions of the basin, and almost nowhere else in the United States.

### 9.3 Farmers Investment Company Switch to Pecans

Fifteen miles south of Tucson, the Green Valley Pecan Company, a subsidiary of the Farmers Investment Company, switched from cotton into pecans around 1965. The founder of the company was concerned that synthetic fabrics would replace cotton, so he began methodical experiments growing other crops. Stone fruits, grapes, and tree nuts were all planted. Grapes and pecans both did well, but pecans were ultimately selected because they have a longer harvest window and can be harvested by machine. Pecan trees, carefully managed, can produce for centuries, although they take five years to mature. By 1970, the first trees were producing and now over 100,000 trees exist on 5900 acres, the largest pecan orchard in the world. The company has a vertically integrated operation with a 120,000 square-foot

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5 In the absence of laser or GPS leveling during flood and furrow irrigation, water either flows too fast, or too slow, for optimal root zone application. In the summer, standing water from unleveled fields can become too hot for the plant and can damage roots. This is known as “scalding”.

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processing facility on site. In 2000, they began converting some of the acreage to organic, and now have 1200 acres certified (Buchanan, 2011).

9.4 The Decline of Cotton Production in the Basin

In the last few decades, the global cotton market has changed significantly with impacts rippling into United States including the Colorado River Basin. The U.S. is still a leading producer and exporter of cotton but developing countries have ramped up production during this period while U.S. production has declined significantly (Figure 9). Since 2000, China has become a dominant consumer and importer of cotton while India and Pakistan have increased production to meet national and international demand. These competing countries can take advantage of exceedingly low labor costs in both cotton farming and in cotton mills (Seock, Giraudo, Gauteaux, & McLaughlin, 2013). Subsidized prices in other countries have also put pressure on U.S. producers.

In the U.S., the predominant type of cotton is American Upland, which makes up 97 percent of the annual U.S. cotton crop and is mainly grown in the Southern Cotton Belt. The other type, American Pima, is produced mainly in California and other arid regions of southwest Texas, New Mexico and Arizona. The market for Pima, or extra-long staple (ELS), is mainly for high-value products. Consumption of cotton by U.S. textile mills peaked in 1997, then dropped by 50 percent by 2005 and 70 percent by 2009 reflecting lower production costs overseas (Meyer, Kiawu, & McDonald, 2015).

![Figure 9. U.S. cotton harvested acreage over time. Source: National Cotton Council of America](http://www.cotton.org/)

In the major cotton producing states in the basin (Arizona, California, and New Mexico), cotton acreage has significantly decreased in all three states for almost every type of cotton since 1995 (Figure 10). In Arizona, cotton acreage of both Pima and Upland amounted to 466,000 in 1991. Acreage declined by nearly two-thirds to 165,000 in 2014. In New Mexico, 88,600 acres were planted in 1991, but only 48,400 in 2014. In California, acreage of Upland Cotton decreased from around 1 million acres in the
early 1990’s to 57,000 in 2014. The California climate and soils can support crops that are much higher-value, thus aiding the shift. In the Palo Verde Irrigation District (PVID), cotton has been replaced with alfalfa, which brings in reliable prices with little effort (Barlow, 2016). Currently, there is no cotton production in the IID service area based on latest crop reports and there has been little production in the past 10 years (Bali, 2016).

The one relatively small exception to this trend is Pima, a luxury cotton. Production of luxury cotton began in the San Joaquin Valley of California in the 1990s, and seen as a rival to premium Egyptian cotton, sought after by high-end retailers. In 1994, only 64,000 acres were planted. In 2006, it reached as high as 260,000 acres, but it has leveled-off with only 155,000 acres in 2014 (NCC, 2014). The demand for Pima cotton by manufacturers was so high that cotton farmers could afford high water prices. This trend peaked in 2011, when manufacturers started to shift to synthetic fibers because they were weary of high prices, and China began increasing cotton production after several years of decline. Cotton demand and prices then fell (Tabuchi, 2015).

A recent series of articles by Lustgarten and Sadasivam (2015) looked at cotton production in the Colorado River Basin. According to this series, cotton requires six times as much water as lettuce, and 60 percent more than wheat. In the past, the federal government has subsidized cotton and offered price protection. Over the last 20 years, Arizona and California farmers have collected more than $1.1 billion and $3 billion respectively in cotton subsidies. The authors claim that without government subsidies, even less cotton would be grown in the basin.

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6 This comparison is not entirely fair as lettuce is generally multi-cropped in a year. Cotton, by contrast, takes much longer to mature. Wheat, too, can be multi-cropped. See Figure 8 for examples of total water use by different multi-cropping systems.
The story of cotton in the West highlights how the global market can affect farmers. Even federal subsidies cannot completely remove the impact of global prices on demand for American cotton. Unlike some other common crops, cotton is much more of an international crop. In part, this is because it is a fiber that is easily stored and shipped. About 30 percent of the world’s cotton consumption crosses international borders before processing. A significant amount of U.S. produced cotton is shipped to India, Pakistan, and China for processing, and shipped back in the form of material goods. This is larger than other traditional crops like wheat, corn, soybeans, rice, and alfalfa (NCC, 2014; Seock et al., 2013).

This case study highlights how government subsidies and the global market including labor costs can influence the production decisions of U.S. farmers. In this case, U.S. subsidies likely provide incentives against switching crops. Despite this market intervention, however, cotton acreage has decreased dramatically throughout the country (Figure 9). Cheap labor in developing countries for both cotton production and in mills, and transportation costs to and from these counties can influence the price U.S. cotton farmers receive. Proposals to shift crops should consider the interplay of all of these factors.

Table 5: Change in irrigated acreage in California. Source: CIT (2011).

<table>
<thead>
<tr>
<th>TYPE OF ACREAGE</th>
<th>1978</th>
<th>1987</th>
<th>1997</th>
<th>2007</th>
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<td>Total Irrigated Land (acres)</td>
<td>8,505,824</td>
<td>7,596,091</td>
<td>8,712,893</td>
<td>8,016,159</td>
<td>- 5.8%</td>
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<tr>
<td>Rice Acreage</td>
<td>484,822</td>
<td>399,193</td>
<td>574,081</td>
<td>531,075</td>
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<tr>
<td>Cotton Acreage</td>
<td>1,517,980</td>
<td>1,083,811</td>
<td>1,036,316</td>
<td>471,378</td>
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<tr>
<td>Total Bales</td>
<td>1,911,050</td>
<td>2,619,934</td>
<td>2,543,194</td>
<td>1,418,751</td>
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<td>Bales/Ac</td>
<td>1.26</td>
<td>2.42</td>
<td>2.45</td>
<td>3.01</td>
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<tr>
<td>Hay Acreage</td>
<td>1,501,143</td>
<td>1,532,777</td>
<td>1,698,773</td>
<td>2,183,761*</td>
<td>45.5%</td>
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<td>Vegetable Acreage</td>
<td>900,401</td>
<td>882,741</td>
<td>1,209,259</td>
<td>1,169,786</td>
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<tr>
<td>Orchard Acreage</td>
<td>1,892,077</td>
<td>2,152,664</td>
<td>2,582,084</td>
<td>2,826,291</td>
<td>49%</td>
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<tr>
<td>Dairy Cows</td>
<td>836,675</td>
<td>1,070,366</td>
<td>1,403,217</td>
<td>1,840,730</td>
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9.5 California Crop Switching Thru Time

Since 1978, there have been major shifts in crops grown in California (Table 5: Change in irrigate acreage in California). Most of these shifts over the last nearly 40 years appear to have been the result of market forces. As discussed earlier, cotton acreage in California has declined significantly (-69%), and avocado and nut production has increased substantially. Acreage of hay (+45%), vegetables (+30%) and orchards
(+49%) has increased to meet rising demand for these products. Also, forage pasture acreage for dairy cows has increased significantly to support the expanding dairy industry (CIT, 2011).

In the Imperial Irrigation District (IID), the crop mix has been fairly consistent over the past ten years with forage crops (alfalfa, Bermuda grass and Sudan grass) at approximately 50 percent of the total land area. There have been some year-to-year changes in acreage of major crops in the district, but overall the six most common crops (alfalfa, Bermuda grass, Sudan grass, wheat, sugar beets, and lettuce) have been mostly consistent (Figure 11). When changes have occurred, they were likely due to changing markets. This is certainly the case with cotton, which has decreased significantly to the point where it isn’t even cultivated in the district anymore. The case is similar for asparagus. The acreage of the crop has declined due to competition from countries like Mexico and Peru, where labor costs are very low (IID Crop Report, 2004; Karp, 2010).

![Acreage of Major Crops in IID](chart.png)

Figure 11. Changes in major crops in the Imperial Irrigation District. Source: Imperial Irrigation District Crop Reports.

9.6 The Walker Basin in Nevada – Water for the Environment

In the Great Basin of Nevada and Utah, the USDA supported Western Region Sustainable Agriculture Research and Education Program (SARE) has created a comprehensive educational program with five modules to inform farmers about the opportunities and obstacles when switching to lower-water-use crops (SARE, 2012a). The educational program derives in part from a peer-reviewed study that modeled a number of relevant issues when crop switching (Bishop, Curtis, & Kim, 2010b). The peer-reviewed study modeled yields of alternative crop production using different amounts of water, while considering costs, returns and numerous other factors. The study also conducted producer interviews, and field trials in the Walker Basin where the main crop is alfalfa. The researchers found that alternative crops do exist that could reduce water consumption by one-half.

One of the motivations behind the study was to increase environmental flows in the Walker River. To achieve this aim, producers would have to grow a crop that would use less water, withstand the harsh climate, and match or exceed the current farm returns. Fruits, cereals, legumes, and industrial crops
were investigated as potential new crops. Of all the crops examined, and considering issues of climate, water use, market demand, prices, and infrastructure, they found that onions showed the most potential.

The accompanying SARE educational program has been used in the Great Basin to assist farmers switch crops with some success. The program consists of five modules: (1) introduction and water issues, (2) agronomics of alternative crops, (3) market opportunities for alternative crops, (4) selecting alternative crops, and (5) sources of assistance when moving to alternative crops. The section on evaluating alternative crops includes assessing the dominant soil types and what already grows. SARE also provide numerous information sources and a guide where producers can find information on potential markets, distribution networks, and how to evaluate the profit potential. Farmers using the modules create an enterprise budget and determine what agronomic practices are associated with the alternative crop. The section on assistance includes information on federal funding sources, USDA Conservation Programs, Farm Bill details, and how to obtain information from local university extension (Bishop, Curtis, & Emm, 2010).

There have not been wide scale crop changes in the Walker Basin despite the program, but farmers who have participated in the program have helped other producers plant lower-water-use crops on their farms (SARE, 2012b). Even though conserved water is not protected from use by other diverters, there are some recent efforts to provide a legal foundation for such protection. This SARE program provides a useful framework for how to navigate crop switching, including the realities and difficulties behind actual crop changes to conserve water.

9.7 The Rise of Organic Agriculture

Organic agriculture is growing rapidly, in large part because of increasing consumer demand. In the Four Corners States, the majority of organic producers are planning to either maintain or expand acreage. Some organic crops use less water than the crops they replace. There is potential to save water in this evolving sector, but there are also significant barriers. More organized marketing and distribution networks need to be established to assist producers with finding markets. Most importantly, there needs to be a significant effort to establish regional production facilities (SARE, 2008).

Transitioning to organic crops is the purpose behind one project in western Colorado being funded by the Colorado River System Conservation Pilot Projects. According to USDA regulations, conventional fields must be transitioned to organic fields over a three-year period when no pesticides or herbicides are used. In this pilot project, a low-water-use cover crop is being planted on conventional fields that will be converted to organic production. Specifically, corn is being replaced, and the difference in the consumptive-use of the cover crop will be counted as water savings. It is likely that the cover crop is contributing to soil health, another benefit. This project is the first year of the required three-year transition.
10 References


Agricultural Water Conservation in the Colorado River Basin: Alternatives to Permanent Fallowing Research Synthesis and Outreach Workshops

Part 5 of 5

Irrigation Efficiency and Water Conservation in the Colorado River Basin: A Literature Review and Case Studies

Brad Udall
Greg Peterson

Colorado Water Institute
Colorado State University

December 2017

CWI Completion Report No.232
Acknowledgements

This report was financed in part by the U.S. Department of the Interior, Geological Survey, through the Colorado Water Institute. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

Additional copies of this report can be obtained from the Colorado Water Institute, E102 Engineering Building, Colorado State University, Fort Collins, CO 80523-1033 970-491-6308 or email: cwi@colostate.edu, or downloaded as a PDF file from http://www.cwi.colostate.edu.

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Project Background

This document is one of four separate reports created under a grant from the Walton Family Foundation to investigate ways to minimize harm to agriculture as water scarcity in the Colorado River Basin forces growing municipal and environmental water users to look at existing uses as potential sources of supply. Agriculture, the largest water user in the basin, is a frequent target in these efforts. The project, “Agricultural Water Conservation in the Colorado River Basin: Alternatives to Permanent Fallowing Research Synthesis and Outreach Workshops” was undertaken to create detailed reports of the four common methods used to temporarily transfer water from agriculture to other purposes. The four reports consider the following methods:

- Deficit Irrigation of Alfalfa and other Forages
- Rotational Fallowing
- Crop Switching
- Irrigation Efficiency and Water Conservation

After the reports were drafted, three workshops were held, one in the Upper Basin in Grand Junction on November 4, 2016, one in the Lower Basin in Tucson on March 29, 2017, and one in Washington, DC on May 16, 2017. All of the reports are available from the Colorado Water Institute website.

Acknowledgements

First, Greg Peterson and I thank the Walton Family Foundation for making this project possible. Without their funding and support, the project would not have happened.

Many people assisted with this project by reading and providing comments on drafts. We want to especially thank Perri Benemelis, Mike Bernardo, Perry Cabot, Aaron Citron, Michael Cohen, Bonnie Colby, Terry Fulp, Robert Glennon, Bill Hasencamp, Chuck Howe, Carly Jerla, Dave Kanzer, Doug Kenney, Kelsea MacIlroy, Jan Matusak, Sharon Megdal, Peter Nichols, Wade Noble, Michael Ottman, Ron Raynor, Adam Schempp, Tina Shields, MaryLou Smith, Pete Taylor, Reagan Waskom, John Wiener, and Scott Wilbor. Paul Kehmeier contributed a lovely photograph and important story. The work product was much improved by these insightful comments. It must be noted that any mistakes are solely mine.

Nancy Grice at the Colorado Water Institute provided critical support with financial reporting, travel assistance and working with Colorado State University. MaryLou Smith was instrumental in organizing and chairing the outreach workshops. Reagan Waskom provided much needed intellectual support throughout the project. Beth Lipscomb assisted with overall editing at the end. Finally, a very special thanks goes to my co-author, Greg Peterson, who did much of the early, difficult research and writing. Much of the value of this project is in the extensive bibliographies that Greg created by painstakingly acquiring, reading and summarizing hundreds of documents.

We thank Senator Michael Bennet and his staff for acquiring a room at the Capitol Visitor Center for the DC event. Finally, we extend our sincere appreciation to the approximately 100 participants who shared their precious time to join us for our outreach workshops. Thank you, all.

Brad Udall
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### Abbreviations

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<td>af</td>
<td>Acre-feet</td>
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<td>BMP</td>
<td>Arizona Best Management Practices</td>
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<td>CAWA</td>
<td>Colorado Agricultural Water Alliance</td>
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<td>CRBSCP</td>
<td>Colorado River Basin Salinity Control Program</td>
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<td>Polyacrylamide</td>
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<td>Quantification Settlement Agreement</td>
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<td>Supervisory Control and Data Acquisition</td>
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1 Summary

Two related ideas, irrigation efficiency and water conservation, can be used to obtain water from agriculture for other purposes. These concepts are related, because improving irrigation efficiency and improving water conservation can both lead to reductions in water use. The two terms as defined herein, however, deal with distinctly different kinds of reductions in water use. Each concept has different physical and legal ramifications, especially in terms of how they affect other uses and users. Both concepts can potentially provide water for municipal or environmental purposes from agriculture.

1.1 Key Definitions

Consumptive use is defined as liquid water that has been converted to water vapor, by either evaporation or plant transpiration. It is therefore no longer available for use. In some limited cases, water can also be considered “consumed” if liquid fresh water flows to a salty water body. This also makes it unavailable for crop and most human uses. It is still available for environmental purposes, however. Water that is diverted but not consumptively used becomes return flows, liquid water that returns either immediately to the stream as surface runoff, or as delayed groundwater. Return flows are heavily relied upon by downstream diverters in the West. In many basins in the West, the total diversions vastly exceed the total flows in the river, which provides strong evidence for how important return flows are.

Improving irrigation efficiency refers to the act of saving non-consumptive-use water, sometimes called “saved water.” This might typically occur by reducing ditch conveyance losses, which would allow for smaller headgate diversions for the same volume of water reaching the field at the end of the ditch.

Water conservation, by contrast, is the act of saving consumptive-use water. Water conservation is further broken into two types. Savings from reducing non-productive consumptive use such as occurs by phreatophytes is called ‘salvage water’ under Colorado law. It might have different names in other states. This water in most states is not legally transferrable and thus there is little incentive to reduce this use. In addition, the generation of salvage water can impact amenity values including mature trees on ditches. By contrast, conserved consumptive use water comes from reductions from crop consumptive use or ancillary consumptive use necessary to get water to crops such as evaporation from canals. This water is generally legally transferrable.

In general, greater quantities of saved water can be created than water saved from reducing consumptive use, in large part because in flood irrigation, the most common form, 50% of the diverted water is not consumed and becomes return flows. A farmer can generate significant saved water without affecting consumptive use, a key driver of crop yields. On the other hand, reducing conserved consumptive use leads to crop yield reductions and therefore has economic impacts. Reducing consumptive use affects fewer water users because this water was already used, and not available for reallocation via return flows.

1.2 Understanding Irrigation Efficiency

The term “irrigation efficiency” is most commonly defined as a percentage:

\[
\text{Irrigation Efficiency} = \frac{\text{Crop Consumptive Use}}{\text{Total Stream Diversions}}
\]
This definition leads to misunderstandings because in most engineering fields, efficiencies of less than 100% imply a loss or waste, such as wasted heat in energy applications. In water, however, the loss or “waste” is still liquid water that will ultimately be recycled as a return flow at some point in space and time. Return flows are highly valuable, and should not be considered “waste.”

1.3 Critical Nature of Return Flows

Return flows provide water supplies for many downstream users and thus are important in many river basins in the West. Farms using flood irrigation are often only 50% efficient, meaning that 50% of their diversions return to the river for recycling. Because of recycling, “stacked” farms that rely on irrigation return flows can obtain high collective efficiencies, a feature sometimes known as the “basin approach.” Sprinklers and drip can reach 80 to 90% efficiency with commensurate reductions in return flows.

A water mass balance, which is merely the application of the law of conservation of mass\(^1\) to a suitably large geography and time period to account for all the consumed and non-consumed flows of water (both liquid and vapor), can help to understand how water is being used. Mass balances can indicate the importance of return flows, among other purposes.

There is a vigorous debate over whether return flows are good or bad — and implicitly, whether efficiency improvements (which almost always change return flows) are good or bad. The answer depends on the soil, runoff contaminants, if any, water temperatures, changes to the natural hydrograph, local geography, the location, and priorities of other diverters, and even the values of the observer. When return flows change, there are often winners and losers, including nature, which also influences the answers to this question.

1.4 On-Farm vs. District-Wide Efforts to Improve Efficiency

Irrigation efficiency improvements can be broken into on-farm and district-wide efforts. On-farm efforts include increasing the delivery efficiency from headgate to the field by lining or piping canals and increasing the field application efficiency, defined as the amount of water consumed by crops divided by the total amount applied to the field. Field application efficiencies can be increased by laser leveling, tailwater recovery (capturing water at the end of the field and reusing it), installing sprinklers or drip, and other methods. Irrigation scheduling can increase efficiency by only applying water when it is needed, which can reduce unnecessary soil evaporation.

District-wide efficiency measures include similar actions to on-farm measures but done on a larger scale, such as canal lining. With large systems involving tens of miles of canals and many hours of water travel times, keeping canals full, especially near the end of the canal after many laterals have withdrawn water has historically been challenging. Operators would often rather spill water from the tail end of the canal than run short, which has meant that the river segment between the headgate and the tail end of the canal has had less water than it might. Computerized canal check structures – small movable, vertical dam-like structures within a canal can keep canals full when they have less water, while reducing spills at the end of the canal. Small operational reservoirs, often near the end of a lengthy canal, can capture and allow reuse in the difficult-to-serve lower canal reaches.

---

\(^1\) The law of conservation of mass says that matter can neither be created nor destroyed. It is a fundamental tool used in almost all engineering and physics studies.
1.5 Co-Benefits of Increasing Irrigation Efficiency

Co-benefits of irrigation efficiency improvements that reduce diversions are important. These benefits include increased water quality due to reductions in saline or chemical-laden farm runoff, less groundwater pumping in groundwater dependent systems, and higher reliability of diversions due to the need for less carriage water. Increased efficiencies can increase productivity, yields, and economic gain. In the 21st century these improvements can be as important as considerations of total water quantity, which has heretofore dominated water supply conversations.

Many irrigation systems are decades old, and in need of infrastructure maintenance and improvements. Efficiency improvements generally provide modern automated management, which reduces labor and increases flexibility. This is another co-benefit.

1.6 Increased Consumptive Use from Improved Irrigation Efficiency

Improving irrigation efficiency often has the paradoxical effect of increasing consumptive use. This has been known for many years and proven in many field-level and modeling studies, yet it is frequently misunderstood by the public. Technologies that improve field application efficiency apply water more uniformly in space, and often remove a time and labor constraint associated with flood irrigation. By flipping a switch, crops on sprinklers or drip can receive water whenever needed, not just on a set schedule dictated by canal capacity and/or labor. Many farm operations are constrained by delivery capacities (i.e., are “water-short”); improvements allow more diverted water to be applied to the crop rather than lost as a return flow. In these water short systems, yields and consumptive use can go up because more of the diverted water makes it to the crops that were previously unintentionally deficit irrigated. Increased consumptive use thus means fewer return flows for use by downstream diverters.

Improved irrigation efficiency is often portrayed as leaving more water in the stream, downstream of the headgate of the improver. While this is one outcome, others are possible. The efficiency improvement can lead to the same diversions, more consumptive use, and less return flow as described above. Under another scenario, if the saved water is not diverted, under prior appropriation the next-in-line diverter may be upstream, not downstream. In this case, there will be a reduction in flow from the next-in-line diverter’s headgate down to the headgate of the diverter installing the efficiency improvement. This is a paradoxical outcome that is rarely mentioned, and one that is not often envisioned by the promoters of irrigation efficiency.

1.7 Water Conservation Opportunities

Water conservation measures include reducing non-beneficial consumptive use, reducing crop and non-crop transpiration, reducing runoff into saline water bodies, and utilizing rainfall more effectively. Several studies suggest that savings from reducing non-beneficial evaporation from soil can be from 20 to 40%. Reducing other forms of non-beneficial evaporation such as phreatophyte removal may harm amenity values associated with trees and other vegetation. Reducing crop transpiration will reduce yields. Reducing weeds can provide additional water.

Reducing runoff to saline water bodies is a different kind of consumptive use reduction. Most consumptive use occurs when liquid water is evaporated or transpired to water vapor. This method, however, involves stopping fresh liquid water from being converted to unusable saline water. In arid areas throughout the world, saline water bodies can support important biological activities and thus this
kind of consumptive use reduction impairs the environmental values of the saline body. Mono Lake, Owens Lake, and the Salton Sea are three examples in the Western United States and there are many elsewhere around the world. There is little opportunity for more effective rainfall utilization in the West as rainfall provides only a small portion of crop water needs in many of the most important irrigation areas.

Some projects that have focused on salinity control such as canal lining efforts are also irrigation efficiency projects. While these improvements can lead to higher consumptive use, they also improve the quality of agricultural runoff and hence enhance stream water quality for downstream users.

If changes in return flows are a concern, one solution is to make efficiency improvements at the end of a river first, and then work up-river. This approach minimizes return flow impacts to downstream diverters, while potentially improving instream flows and water quality downstream of the improvements, provided that saved flows can be “shepherded” downstream rather than being taken by upstream next-in-line diverters.

1.8 Case Studies

There are many cases of irrigation efficiency improvement projects in the West. The Metropolitan Water District of Southern California has an on-going program at the Imperial Irrigation District to save approximately 100,000 acre-feet of water every year. The Yuma area in Arizona has used about 250,000 less acre-feet per year, in part due to different crops and in part due to sprinklers, high flow turnouts, laser leveling and other efficiency methods. In Colorado, one large irrigation district near Grand Junction saved nearly 40,000 acre-feet per year in some years by lining canals, automating gates, installing check structures, and using a reservoir near the end of a long canal with no loss of agricultural output.

2 Introduction

This chapter describes two related concepts, irrigation efficiency and water conservation. These concepts are related because improving irrigation efficiency and improving water conservation both lead to reductions in water use. The two terms as defined herein, however, deal with distinctly different kinds of reductions in water use. Each concept has different physical and legal ramifications, especially how they affect other uses and users. Both concepts can potentially provide water for municipal or environmental purposes from agriculture.

For the purposes of this chapter, improving irrigation efficiency refers to the act of saving non-consumptive use water, sometimes called “saved water.” Conversely, water conservation is the act of saving consumptive use water. Consumptive use is defined as liquid water that has been converted to water vapor by evaporation or plant transpiration and hence is no longer available for use. In some limited cases water can also be “consumed” if liquid water flows to a salty water body which also makes it unavailable for crop use. In general, greater quantities of “saved water” can be created than water saved from reducing consumptive use.
The term irrigation efficiency itself is most commonly defined as a percentage with total crop water use in the numerator\(^2\), and total stream diversions in the denominator:

\[
\text{Irrigation Efficiency} = \frac{\text{Crop Consumptive Use}}{\text{Total Diversions}}
\]

Irrigation efficiency is thus a typical engineering efficiency where an output (crop water use) is divided by an input (total water diversions). In most engineering fields, a higher efficiency is considered uniformly good. In water use, however, higher irrigation efficiencies can have both beneficial and non-beneficial outcomes. This is because diverted but not consumed water is still available for use and is often recycled, unlike other engineering disciplines such as energy where inefficiency generally results in an unusable waste output (e.g., heat). These recycled flows are commonly known as return flows. In this chapter, we are specifically interested in cases where irrigation efficiency increases because the total diversions (the denominator) are decreased. This will result in the creation of “saved water” because less water is diverted from the stream.

When irrigation efficiencies improve through either decreases in total diversions or increases in crop consumptive use, the water recycling that formerly occurred will shift to different places and times, often benefiting one user at the expense of another. In the legal sphere, saved water is generally not legally transferable, although a water user would be free to use the savings so long as acreage is not increased or the historical uses are not changed. For example, the installation of sprinklers is a common irrigation efficiency improvement that could result in reduced stream diversions. A water user is free to use this saved water on his existing acreage and current uses, but not to transfer it to another use or user.

In this chapter, water conservation is defined as reducing consumptive use. These water savings might come from reductions not directly related to the original purpose of the diversion (soil evaporation, phreatophyte reduction, lake or canal evaporation), or by reducing the consumption of the desired output (e.g., less crop yield or a change in crop). These two different types of consumptive use savings have two different names: “salvage water” is the Colorado term for the savings from non-productive consumptive use of water which is not transferable, and “conserved consumptive use water” for the savings which is transferable in some states. Water conservation, like irrigation efficiency, can have many effects that ripple to other water users and the public. The creation of salvage water, for example, can harm wetlands or trees along canals.

It should be noted that these two concepts as presented herein are not always separate and distinct. Reducing runoff to a saline water body is considered a water conservation measure because it provides additional consumable water. It can also be an irrigation efficiency measure when this runoff does not need to be diverted in the first case (see Salton Sea, below). Irrigation scheduling is an efficiency measure because it can reduce the overall water delivered to the plant by delivering water timely. It is also a water conservation measure because it can reduce soil evaporation, a consumptive use. Nevertheless, the key distinction between these two concepts — saving consumptive vs. non-consumptive water — is critically important.

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\(^2\) This includes any legally allowable water use in delivering the water the crop such as canal evaporation necessary for the water delivery and soil evaporation that results from the application of water in the field.
Given the importance of water and its increasing scarcity, there are numerous papers on these topics, many in the last twenty years. This chapter surveys and synthesizes this literature. Some of the literature is contentious, including the idea of whether on-farm irrigation efficiency improvements are good or bad (See: Irrigation Efficiency Improvements: Good or Bad?). This literature almost always discusses how improving the efficiency of water delivery systems has many ripple effects for downstream water users in the location, quantity, quality, and timing of return flows. Some writers have called for new terminology to replace the term irrigation efficiency because they view it as a loaded term with its implicit and often wrong sense of “waste” or “loss.” They argue that many areas with low on-farm efficiencies can have high basin-wide efficiency due to the reuse of return flows. Others have argued that the terminology and concept is still important including its good connotation of doing more with less on an individual farm. These writers point out that the concept of irrigation efficiency forces us to understand how individual water use affects water quantity and quality within the basin. In their view, it is not enough just to consider the system as a whole.

This chapter proceeds as follows. It first discusses basic hydrology issues including return flows. It then discusses general concepts and methods to improve irrigation efficiency. The co-benefits of improved irrigation efficiency are presented. It explains how and why irrigation efficiency measures can paradoxically lead to increased consumptive use. Water conservation measures are discussed next. The chapter then provides several case studies on these concepts, both outside and inside the Colorado River Basin. Two sections present important topics, one on whether efficiency improvements are good or bad, and another on basic terminology. An appendix highlights key papers on these topics.

3 Water Balances, Return Flows, On-Farm vs. Basin Efficiency

The popular perception is that irrigation water use is wasteful; many recoverable losses exist, and if we could only capture these losses, we would have plenty of water for other purposes (Getches, 1987; Postel, 2013a). Unfortunately, this view is simplistic; there are far fewer recoverable losses than supposed. The only true losses in water use are evapotranspiration by crops, weeds, and soil, and the relatively rare flows of liquid water into an unusable saline sink\(^3\). Everything else is not a loss or waste, but a reusable return flow, albeit usable at some time and place distant from the original use.

The proper tool to help us account for and understand water use is a water balance based on the law of conservation of mass (See Terminology Section). The law of conservation of mass tells us that mass is neither created nor destroyed, and thus provides a theoretical way to account for all movement of water, be it liquid or vapor. The water balance must encompass enough time and space to account for all water flows. It is a powerful conceptual tool because it serves to remind us that even invisible mass must be accounted for, even if it is sometimes difficult to implement because we cannot see flows of aboveground water vapor and underground liquid water. In many cases, though, we have reasonably accurate ways to estimate hidden evapotranspiration and subsurface flows, thus reducing the water balance uncertainties.

\(^3\) A saline sink can be groundwater that is too salty to use, an aboveground salty lake, or the ocean. Note that a loss to the ocean is not generally “waste” — it serves important biological and geological functions. This is similarly true with saline above groundwater bodies. The Salton Sea and many other saline lakes, for example, are important resources for many bird species.
Return flows are a critical part of the water balance and are highly prevalent in river systems in the American West. Their presence was acknowledged as early as 1896 in the South Platte (Carpenter, 1896) and investigations in the 1920s further quantified their importance (Parshall, 1922). Additional work in the 1960s by engineers and attorneys acknowledged the interconnectedness of individual farms and water users downstream, through surface and sub-surface return flows (Bagley, 1965; Hartman & Seastone, 1970, 1965; Jensen, 1967; Wright, 1964). In 1978, the newly created EPA investigated the importance of return flows (Radoskevich, 1978).

In many engineering studies, return flows are assumed to make up 50% of all water diverted for irrigation. In some porous areas, like the Snake River Basin in Idaho, the number can exceed 60% (Huffaker, 2008). In a water balance of the Lower Colorado River Basin, return flows from various districts make up a significant part of the river flow (Owen-Joyce & Raymond, 1996). In the Upper Green River near Pinedale, Wyoming, a study put return flow portion at 70%, with 90% of the flows returning during the irrigation season and the remainder during the winter (Blevins, 2015; Wetstein, Hasfurther, & Kerr, 1989).

Return flows have a number of benefits: recharge to unconfined aquifers; dampening of flood flows or redistribution of flows over time; cooling of stream flows during droughts to benefit plants and wildlife; reduction of salt-water intrusion; and the creation of wetlands (Allen, Clemmens, & Willardson, 2005; CAWA, 2008; Interagency Task Force, 1979; C. J. Perry, 1999; Willardson, Allen, & Frederiksen, 1994).

Return flows also have several negatives. In general, return flows are lower quality than water left in the stream because they pick up salt, nutrients, pesticides, and sediment. Return flows can increase stream water temperatures by reducing the volume of water below the point of diversion, and, at least for surface returns, and by providing warmer water back into the stream. Return flows also distort the natural hydrograph, and can eliminate the hydrologic cues some species use to trigger reproduction or migration or other behaviors.
There can be significant differences between measured on-farm and basin-wide irrigation efficiencies because of return flow recycling. Even when relying on flood irrigation, basin-wide efficiency can be relatively high compared to on-farm efficiency due to reuse of surface and subsurface runoff (C. Burt, Canessa, Schwankl, & Zoldoske, 2008; C. M. Burt, 1999a). A thorough water balance can reveal that the potential water savings is often less than projected. In California, for example, one paper indicates that the potential of “new” water from agricultural water use efficiency is only 1.3 percent of the current amount used by the state’s farms, much less than what is possible on a single farm (CIT, 2011). The concept of considering water efficiency on a basin-wide basis rather than a single farm basis is known as the “Basin Perspective” or “Basin Approach.”

Two cases illustrate how on-farm and basin efficiencies can be very different. Allen and Brockway (1983) document an irrigation district in Idaho where on-farm irrigation efficiency is relatively low, but the overall district irrigation is high. On the Little Willow Irrigation District, on-farm efficiency was only 30 percent, but the total district efficiency was 60 percent. The district is in a long, narrow mountain valley that allows rapid reentry and reuse of return flows.

The Westland Water District in California is a similar case but has completely different characteristics. The district has a piped distribution system, so seepage and deep percolation from the conveyance system are not important factors for the water balance. All surface water runoff is captured and reused. High water tables also supply a large portion of the crop ET on downslope fields. In this system, there is thus no loss of water through conveyance systems or runoff across the boundaries of the district. Deep percolation contributes to on-farm “inefficiencies” but the ET supplied by the high water table makes the overall district far more efficient than individual farms (C. M. Burt, 1999a).

4 Irrigation Efficiency and Water Conservation Terminology

The terminology around efficiency and water conservation is often confusing. This section describes terminology used in this paper.

**Irrigation Efficiency:** This term usually is defined as the amount of water consumed by crops divided by the amount of water diverted from a stream (Jensen, 2007). In general, this would include consumptive use that is necessary for the crops to transpire, such as evaporation from canals. This is the traditional engineering view of efficiency where an output is divided by an input, and the result is expressed as a percent. In many engineering disciplines, the difference between 100% and the measured efficiency is considered “waste” or “loss” such as heat energy that is no longer useful. In water systems, the “waste” term is mostly liquid water that becomes a reusable return flow.

**Delivery Efficiency:** This is the efficiency of the carriage system used to transport diversions from the river to the location of the water application to the field. Canals are subject to evaporation, seepage, and transpiration of plants along the canal.

**Field Efficiency:** This is the amount of water used by the crops divided by the amount of water applied, generally shown as a percentage. Large amounts of on-field runoff (“tailwater”) reduce the field efficiency.
On-Farm Efficiency: This is the overall “irrigation efficiency” of an individual farm. With flood irrigation, this number is typically 50% or less, although there are highly efficient laser-leveled flood irrigation techniques. It is the product of the delivery efficiency times the field efficiency.

Basin-Approach: This is the overall “irrigation efficiency” of a number of stacked farms in a basin or a district that recycles diversions\(^4\). In general, because return flows are recycled the basin efficiency is much higher than individual farm efficiency.

Fractions: The fractions approach to water accounting was first put forth in the early 1990s as a way of removing the connotation that efficiency measures are always good and that inefficiencies result in ‘waste’ (Willardson et al., 1994). The fractions approach parcels out the different components of water use in an irrigation system into three different categories, or fractions, of use. The fractions all sum to 1 thus implicitly applying the law of conservation of mass to water use. The three fractions are: (1) changes in storage, both positive or negative, (e.g., reservoirs, aquifers); (2) a consumed fraction consisting of beneficial consumptive use for an intended purpose (e.g., transpiration from a crop) and non-beneficial consumptive use for purposes other than the intended use (e.g., weeds, soil surface evaporation); (3) a non-consumed fraction consisting of a recoverable fraction (e.g., surface and subsurface return flows) and a non-recoverable fraction (flows to saline sinks, the ocean). “Losses” in this terminology are consumptive uses and non-consumed non-recoverable flows. Importantly, the terminology avoids using the term “inefficiencies” which is often but wrongly equated with “losses”. Among many water lawyers and engineers throughout the West, this terminology has been simplified to ‘consumptive’ and ‘non-consumptive’ use with the implicit understanding that these two components sum to 1.

Water Conservation: For the purposes of this paper, water conservation is defined as techniques that reduce consumptive use of water. These techniques include reducing evaporation from soil and canals, reducing crop and non-crop transpiration, and reducing runoff into saline water bodies. Water conservation potentially makes previously consumed water available for new uses, as opposed to irrigation efficiency improvements which frequently just moves return flows from one water user to another. Water conservation is sometimes said to create new supplies but it only does so by moving consumptive use from one water use to another; technically, water is never created.

Consumed Water: Also known as consumptive use, this is water that is either evaporated from soils or transpired from plants. In both cases, liquid water has been converted to water vapor and the vapor has moved to another part of the hydrologic cycle. This is often broken into two sub-components, beneficial and non-beneficial consumptive use. In water law “beneficial use” is a term of art meaning an allowed use. In non-legal terms, however, one person’s non-beneficial use, e.g., wetlands, might be another person’s “beneficial use.” Water can also be considered consumed if it flows to a saline sink.

\(^4\) Calculating the irrigation efficiency of a basin or district is perhaps best conceptualized as having a single large diversion canal serving multiple farms where the return flows are accessible for use within the district. The output (numerator) is the total crop consumptive use from all farms and the input (denominator) are the total diversions from the single canal. If the basin is actually lots of small stacked diversions, the total diversions (denominator) is conceptually the sum of the diversions that are not from return flows. This number is generally not knowable, hence the first conceptualization above as a single large diversion ditch with reusable return flows.
**Non-Consumed Water**: Also known as non-consumptive use, this water was diverted for use but not consumed and thus returned to the system as either a surface or subsurface return flow. This water is still in liquid form and is generally available for use, even if degraded in quality, by another downstream diverter. That use will be later in time, perhaps much later if a subsurface return flow. Collectively, consumed and non-consumed water comprise two fractions that must total to one. In the fractions terminology, non-consumed water can be recoverable as discussed above, or non-recoverable. Non-recoverable, non-consumed water typically flows to a saline sink of some sort. Non-recoverable water thus looks like consumed water in that it is no longer available for use.

**Water Balance**: A water balance is an accounting of water that uses the law of conservation of mass as its fundamental principle (C. M. Burt, 1999b). All mass must be accounted for as mass is neither created nor destroyed. A water balance defines a spatial and temporal extent and then includes all inflows, outflows, and changes in storage within the defined space and time. The financial analog to a water balance is an income statement showing income and expenses, and a balance sheet showing how these financial transactions impact bank account balances.

**Salvaged Water**: In Colorado, salvaged water is consumptive use water that was formerly used by phreatophytes or other non-productive consumptive use of water\(^5\) (CAWA, 2008). In a famous Colorado Supreme Court case, a salvager wanted a new water right free from call after eradicating water-stealing plants on his property (Castle & Caile, 2007). The requested water right would have been the same as a “developed” transbasin water right, which is also free from call by other diverters. The Court ruled that this “salvaged” water was part of the overall river system rather than belonging to the salvager. While salvaged water might be potentially beneficial, according to the court, to allow the salvager use of this water would be to encourage several destructive practices including destruction of riparian habitat, and planting and then later eradication of phreatophytes. The Court termed the phreatophytes “water thieves” and said the salvager had no right to step into the shoes of the thieves. The court encouraged the legislature to address this topic but to date no such legislation has been passed. Several unsuccessful attempts were made in the legislature to fix this problem in the 1980s and early 1990s. In 1992, the Colorado Water Conservation Board wrote an excellent memo on the issues (CWCB, 1992).

**Saved Water**: In Colorado, this term is often used to mean water that was once diverted from a stream but was not consumed and was hence a return flow (CAWA, 2008). An irrigation efficiency improvement usually creates saved water by reducing on-farm delivery or application losses. Saved water, for example, might arise from a more efficient canal system or from a more efficient field application method (e.g., sprinklers). Saved water can be consumed by the crops or left in the stream. Because the saved water was not consumed historically, it is not available for transfer by the saver. It is, however, available for use on the property where it is saved, as long as it does not go to new uses or new acreage. Saved water can potentially be used to supply water to crops that were previously under-irrigated thus ultimately increasing consumptive use. If saved water is left in the stream, the next-in-line diverter, whether upstream or downstream, will have rights to that water, as with other natural flows. (When

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\(^5\) in Montana, “salvage” means to make water available for beneficial use from an existing valid appropriation through application of water-saving methods.” (Mont. Code Ann. § 85-2-102(21))
saved water is described, it is often erroneously described as flowing downstream from the location of the savings).

**Conserved Consumptive Use Water**: In Colorado, this is water that was formerly associated with crop water consumption (CAWA, 2008). This water might be made available by reducing acreage, changing crops, or reducing a consumptive use that is allowable in the calculation of historical consumptive use such as evaporation from soil necessary for crop growth. This water is technically available for use or transfer by the saver. This term was popularized by the Colorado Agricultural Water Alliance in 2008, to distinguish between this kind of water and salvage water. The distinction is important because this water is potentially transferable while the latter is not.

5  **Irrigation Efficiency Improvements: Good or Bad?**

Increasing the efficiency of irrigation almost without fail affects reusable return flows, water quality, and instream flows. The local geography (e.g., mountains or deserts), the soils (alluvium or clay), the distance to the river (floodplain or uplands) and water rights geography (are controlling senior diverters and next-in-line diverters upstream or downstream?) may help provide answers to the question of whether improving irrigation efficiency is good or bad. Sometimes the answer to the question lies in the eye of the beholder. Here is a brief sampling of cases regarding how irrigation efficiency actions can affect other uses and users. Burt et al., (2008) and Gleick et al., (2011a) provide two contrasting views on this polarizing issue.

**All-American Canal Lining**. Reducing seepage out of the All-American Canal reduced losses by almost 70,000 acre-feet per year. This benefited the United States and specifically the San Diego County Water Authority but hurt Mexico which relied on the seepage for groundwater dependent farms in the Mexicali Valley. Lining the canal also eliminated the source water for the Andrade wetlands, desiccating an important habitat in the desert (Hinojosa-Huerta, Nagler, Carrillo-Guerrero, & Zamora-Hernández, 2002).

**Colorado Hay Meadows**. Colorado ranches sometimes divert in excess of 10 acre-feet per acre for their hay meadows but the hay crops typically only use one to two acre-feet of the diverted water. The remainder returns to the streams later in the year, perhaps at what would otherwise be low flow and possibly high temperature times. Peak runoff is, however, reduced by these diversions.

**Grand Valley Water Users Association** – Between 20,000 acre-feet and 40,000 acre-feet is now left in the main stem Colorado for the benefit of the endangered fish in the 15-mile reach due to modernization of the Highline Canal, the main canal of the Grand Valley Water Users Association (GVWUA). Consumptive use in the GVWUA is unchanged and end of canal spills are now negligible. The Orchard Mesa Irrigation District completed a similar effort in 2015. This is a case where there were few Colorado diverters below the infrastructure – the canal sits close to the state line – and in any case consumptive use did not go up.

**IID Efficiency Transfers (Salton Sea)** – Irrigation Efficiency improvements in the IID funded by Metropolitan Water District of Southern California and the San Diego County Water Authority have reduced return flows into the Salton Sea. These missing return flows now benefit MWD and SDCWA and provide IID with a more modern system. On the other hand, the state of California estimates that to
mitigate the economic and public health damages from the loss of return flows into the Salton Sea may cost $10B.

6 Irrigation Efficiency Improvement Measures

Using our definition of irrigation efficiency as the amount of water used by the crop divided by the total amount of water delivered, irrigation efficiency can be increased by decreasing total diversions (making the denominator smaller), by applying more of the delivered water to crops (increasing the numerator) or by a combination of the two. As efficiency increases, surface and lagged return flows will generally decrease — and in many cases, flows immediately downstream of the diversion will increase\(^6\). The timing and quality of water availability below the location of the efficiency improvements will thus change. Some consider these impacts to be negative (e.g., CAWA (2008)), especially if downstream diverters are reliant on the return flows generated by the inefficiencies. Efficiency improvements may or may not affect consumptive use (See Section 8 below, Improved Efficiency Can Increase Consumption) which in turn means that efficiency measures may increase, decrease or not change overall water availability in the stream.

There are both on-farm and basin-wide (or district-wide) efficiency measures and these are discussed below. Efficiency measures often go hand-in-hand with irrigation modernization and automation, and thus provide new operational flexibility at the farm and/or district level. A key farm input, labor, is often reduced with efficiency measures. Finally, other co-benefits are associated with efficiency improvements, and these are discussed in Section 7, Co-Benefits of Increased Irrigation Efficiency.

6.1 On-Farm Efficiency Improvement Measures

6.1.1 Increase the Delivery Efficiency from Headgate to Field

Earthen canals can leak substantial amounts of water, especially ones built from coarse soils. Canals can be lined with concrete or with exposed or unexposed membranes to reduce seepage losses. Polyacrylamide (PAM), can be applied to help seal earthen canals. Alternatively, formerly open canals can be piped, which reduces both seepage and evaporation. By cleverly using elevation, piping in some places in the West can also generate pressure for sprinklers or drip irrigation without the need for pumping. Canal lining is sometimes done primarily to reduce salinity and selenium, and in these cases efficiency improvements from seepage reductions are a co-benefit.

6.1.2 Increase the Field Application Efficiency

Farmers can use a variety of techniques to maximize the efficiency of water applied to crops once the water is at the field. The presence of tailwater – water that runs off the low end of the field – is, by definition, inefficient. In flood irrigation, farmers can laser level fields to get uniform application of water across the entire field. In the absence of leveled fields, water can pool in low spots, percolate

\(^6\) Note that under prior appropriation, the next-in-line diverter might be upstream. In this case, the not-diverted flow would be taken by the upstream diverter. Thus, paradoxically, there would be less flow in the river from the point of that diverter’s headgate downstream to the improver’s headgate. This is generally not the outcome expected from an efficiency improvement as they have been classically presented. The Orchard Mesa efficiency improvements, discussed below, may result in this unusual outcome in some limited cases, according to the Environmental Impact Statement.
beyond the root depth at the upper end of the field, and not have enough time to fully sink in at the low end of the field. This leads to non-uniform water application, a known limitation to maximizing crop yields. Surge irrigation in furrows to optimize percolation depths has been used successfully. High flow turnouts have been used to apply water to fields quickly and evenly in combination with "bola" wheels that create smooth furrows that allow for rapid water movement. (See Noble (2015) for a description and photo of these wheels).

Many forms of sprinklers can be used for uniform water application. Subsurface drip irrigation can avoid or reduce evaporation of water at the soil surface, which according to CAWA (2008) can be 20 to 30 percent of the consumptive use. Examples of laser leveling and furrow improvements can be found in Yuma AZ (Noble, 2015) and the installation of sprinklers has been widespread in the West due to NRCS financial assistance. Tail water recovery is another method to increase efficiency and has been used in the Imperial Irrigation District (IID, 2000). In this case, water that runs off the field is recovered for use, either on a downstream field or pumped to an uphill location for reapplication to the original field. IID’s efficiency program for SDCWA features tailwater recovery among many methods (IID, 2015a).

6.1.3 Irrigation Scheduling

Buchleiter et al. (1996) presents the economic benefits of computerized irrigation scheduling which has increased yields by preventing yield reducing plant stress and limiting over-irrigation. They report an average water savings of 20 percent. Dockter (1996) describes the AgriMet system: a cooperative meteorological collection system for agricultural consumptive use modeling. It obtains crop consumptive use in regions near stations and then provides the data to farmers to help with irrigation scheduling. In the Umatilla Basin in Oregon, this system has been used over an area of 150,000 acres, achieving 15 percent in water savings. In Montana, one project has saved 16 inches of applied water where this is used. In Washington, some farmers have seen reductions of 50 percent in their water use. Irrigation scheduling can reduce non-beneficial evaporation from soil surfaces by wetting them less frequently. Colorado State University runs a number of weather stations in Colorado ("COAgMet") that provide farmers with a real-time crop consumptive use calculations. In addition, the University provides a free irrigation scheduling application.

Irrigation scheduling is one of the rare methods that improves irrigation efficiency -- by reducing diversions -- while also being a water conservation method. It is a water conservation method because it reduces soil evaporation, and thus reduces consumptive use.

6.2 District-Wide Efficiency Measures

Canal systems of major irrigation districts can extend for miles with travel times in some systems that exceed 24 days. In order to reliably supply water when it is needed so that crops do not suffer, canal operators traditionally kept canals completely full, spilling the excess back into the river system at the tail end of the canal system. This practice ensured reliability at the expense of river flows in the reach between the diversion structure and the end of canal return flow. Many efficiency techniques based on canal automation, order scheduling, and small operational reservoirs can be used to reduce canal diversions and keep more water in the river reach, between the diversion structure and the end of canal return flows, without harming delivery reliability. The Grand Valley Water Users Association and more recently the nearby Orchard Mesa Irrigation District have employed several these measures. In the Lower Colorado, the Imperial Irrigation District also implemented several these techniques. All three are discussed below in the Case Studies.
7 Co-Benefits of Increased Irrigation Efficiency

There are several co-benefits of increased irrigation efficiency. These improvements occur even if efficiency improvements do not provide any new water, or if the benefits shift water from one user to another due to changes in return flows. According to Gleick et al. (2011b), water management in the 21st century should not just consider the total volume of water used as in the “basin approach,” but also should evaluate how irrigation efficiency affects other factors. Efficiency improvements can: (1) enhance equity among users by reducing the need for excess carriage water, (2) increase yields (but see Section 8 Improved Efficiency Can Increase Consumption), (3) reduce maintenance of aging delivery systems, (4) reduce pumping costs, (4) reduce leaching of fertilizers and other chemicals from excess water application, (5) reduce soil erosion, and (6) sustain flows in stream segments that are threatened by low flows (Allen et al., 2005; Allen & Willardson, 1997; Christian-Smith et al., 2010). Irrigation efficiency can also be a valuable tool to address waterlogging and saline conditions in groundwater (Allen & Willardson, 1997; A. J. Clemmens, Allen, & Burt, 2008; C. Perry, 2011; Wolthers, 1992).

Higher irrigation efficiency can increase the productivity of water in agriculture, often measured as the dollar value of the item produced per unit of water. Society should have an interest in seeing that water is put to higher economic uses and thus be concerned with water productivity. The basin perspective considers only the total volume of water used without considering the value produced from that water. Almost invariably, increased efficiency leads to higher value crops, in part because the expense requires higher economic returns. Gleick et al. (2011a) asserts that “the real purpose of water is to not be measured in total volume, but to measure the goods and services it provides by that water use.” Others argue similarly that the productivity of water is actually more important than valuing the volumes of water use (Lankford, 2012; MacDonnell, 2011a).

Increasingly, NGOs are suggesting that irrigation systems must be modernized – which almost always means more efficient – as a first step before pursuing any other methods to conserve water. Many irrigation systems in the West have infrastructure that is between 50 and 100 years old. This infrastructure is leaky, labor intensive, inflexible and is often data poor. Efficiency measures and modernization go hand in hand and are fundamental to most other water saving measures and ideas (Evans & Sadler, 2008a). Efficiency measures ensure that water use can be monitored, and that the basic tools are in place to support crop switching, deficit irrigation, temporary fallowing, or any other technique to save water.

8 Improved Efficiency Can Increase Consumption

The idea that higher efficiency of water use can lead to increased consumptive use may seem like a paradox. After all, in many cases of increased efficiency, diversions from the stream decline as efficiency increases and it thus appears that the crops are getting less water. Several factors, however, can lead to increased consumptive use from efficiency improvements. Even though total diversions decrease, in many cases efficiency measures actually increase the amount of water delivered to, and consumed by the crop. Delivery capacity limits can be removed with more efficient delivery and application methods.

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7 As discussed previously, the intersection of the doctrine of prior appropriation and increased efficiency through reduced diversions means that in some cases the stream reach between the improver and an upstream next-in-line diverter will see less water rather the expected result of additional flows below the improver’s headgate.
such as canal linings, sprinklers, and drip. Efficiency improvements on these ditches, often termed “water-short”, can increase consumption. Sprinklers and drip irrigation can be automatically turned on when crops need water rather than having to wait for a labor-intensive scheduled flood irrigation delivery. Sprinklers, drip, and laser leveled fields ensure that all crops in a field receive the optimum amount of water rather than having some plants receive too much and some too little. Thus, ditches with poor delivery “uniformity” can increase consumptive use after efficiency improvements. Farmers may shift to crops with more consumptive use with a new system that can deliver more water to crops during high need times. And in some cases irrigated acreage or “effective irrigated acreage” may increase (CAWA, 2008; Albert J. Clemmens & Allen, 2005; Evans & Sadler, 2008b; Huffaker, 2008; Schaible & Aillery, 2012).

Apart from increasing acreage, these practices are generally legal under most water law systems that focus on headgate diversions, not consumptive use, so long as the water right is not being changed. In most of these examples, headgate diversions decrease, water applied at the field increases, crop consumptive use increases, and return flows decline. In the absence of an upstream next-in-line diverter, the immediate result is that below the headgate river flows increase at the time of the diversion and downstream river flows dependent on lagged subsurface return flows decline.

9 Uniform Water Application, Removal of Labor, and Timing Constraints

Increased irrigation efficiency may result in more water applied and consumed, even when acreage or crops are unchanged. Traditionally, irrigation water is not spread uniformly over a field. Flood irrigation typically over-irrigates the top of the field and under-irrigates the lower portions of the field. Plants are either over-watered or under-watered, both of which can reduce yields. Efficient irrigation spreads water more uniformly, reducing both over-irrigation and under-irrigation. Figure 2 illustrates this issue. The dashed horizontal line represents the ideal level of irrigation as infiltrated depth of water in the soil. The downward sloping curve is the irrigation adequacy: the percentage of area receiving a given infiltration depth of water. Increasing efficiency will “flatten” the slope of cumulative frequency distribution and increase the amount of applied water consumed by crops (Huffaker, 2008).

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8 For example, growing crops in what were previously furrows.
Irrigation efficiency improvements, such as sprinklers that supply water more frequently than flood irrigation, allow the plant to transpire more water over a longer period of time. With irrigation scheduling and automated water delivery possible with sprinklers or drip, a plant can be supplied with water whenever the plant needs it, not just on a set delivery schedule. This increased transpiration results in higher consumptive use (Albert J. Clemmens & Allen, 2005). Increasing irrigation efficiency also shifts the production function curve, encouraging an irrigator to apply as much water as possible to achieve higher yields. Figure 3 shows the benefits of improved irrigation efficiencies due to better scheduling and increased uniformity in space of water application. Curve 1 represents an “old” irrigation system and curve 2 is an improved system. These curves represent the average yield vs. water applied for the two different irrigation systems. As efficiency increases, the curve shifts upward thereby increasing yield for the same amount of applied water. The maximum potential yield (indicated by points A and B), is where growers like to operate because it has the lowest risk if water is not limiting. This results in higher yields and likely higher crop consumptive use.
Another consequence of irrigation efficiency improvements, is that with a more efficient irrigation system, an irrigator can apply water previously used on one field to other crop acreage that is under-irrigated. In many areas, farmers are currently under-irrigating crops because the capacity of their current flood irrigation system is inadequate to meet the full consumptive needs of the crop or because the system has too much acreage relative to the size of the water rights ("water short")\(^9\). Water short systems are quite common in the West. This practice, sometimes known as “water spreading,” allows a farmer to operate within their water right and divert the same amount of water but fully, rather than partially, irrigate the same amount of land. This practice is legal, so long as the acreage does not increase. In this case, no water is being saved and most likely more water is being consumed through crop ET, resulting in higher yields (Ellis, Lacewell, & Reneau, 1985a; Schaible & Aillery, 2012; Scott, Vicuña, Blanco-Gutierrez, Meza, & Varela-Ortega, 2014).

Improved irrigation also creates a new economic incentive for producers to switch to higher-value crops that need more water. In the High Plains, improved irrigation efficiency can translate to lower pumping costs. This has allowed farmers to shift from wheat and sorghum to corn, thus increasing water use while improving economic returns\(^10\) (Evans & Sadler, 2008b; Huffaker, 2008; Schaible & Aillery, 2012).

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\(^9\) Note that these two concepts are very much related even if phrased differently. One nuance is that a system might only be water short at high ET times of the year and thus have inadequate capacity only for brief periods. Another nuance might be a farmer who chooses to substantially under-irrigate two fields on a regular basis rather than fully irrigate one field.

\(^10\) Groundwater pumpers have a built-in economic incentive to reduce pumping and thus diversions. This can be quite different from producers who use pumps to generate pressure for sprinklers on a surface water system.
Drip and sprinkler irrigation can also increase consumptive use for simple physical reasons. Drip and sprinkler irrigation removes the need for furrows, and the furrow space can be occupied by plants, thereby increasing the “effective irrigated acreage”. Depending on the crop and root depth, drip tape can sometimes be placed well below the surface, thus reducing evaporation from the soil surface. (It should be noted that soil water evaporation, by keeping the area near the surface cool, does reduce the need for a nearby plant to transpire water for cooling. Hence, water evaporation from the soil surface is not entirely a non-beneficial use of water).

9.2 Modeling and Case Studies on Increased Consumptive Use

Significant research backs up claims of increased consumptive use when efficiency measures are implemented. Modeling studies of efficiency improvements like sprinklers have shown that such improvements do increase irrigation efficiency, but also can lead to increased consumptive use (Cai, Rosegrant, & Ringler, 2003; Contor & Taylor, 2013; Ellis, Lacewell, & Reneau, 1985b; Scheierling, Young, & Cardon, 2006; Ward & Pulido-Velazquez, 2008a). The Colorado Department of Water Resources State Engineer carefully administers flood to sprinkler irrigation conversions in the Arkansas Valley to minimize the potential for increased consumptive use and hence violations of the Arkansas Compact (Wolfe, 2009).

Studies on actual irrigation efficiency projects also support these findings (Johnson, Sullivan, Cosgrove, & Schmidt, 1999; Kendy, Molden, Steenhuis, Liu, & Wang, 2003; MacDonnell, 2011b; Pfeifer & Lin, 2010; Scott et al., 2014; Venn, Johnson, & Pochop, 2004). These studies point out that on-farm efficiency improvements increase on-farm consumptive use, decrease return flows, limit aquifer recharge, and increase overall basin consumptive use, contrary to the conventional wisdom that efficiency improvements increase water supplies. These studies are discussed below in the section on Case Studies.

One study on the USDA Environmental Quality Incentives Program (EQIP), which provides subsidies for on-farm efficiency improvements, also shows similar results. These studies all cite increased on-farm production, yields, and profits for irrigators. But such subsidy programs also increase consumptive use, and generally do not conserve water. A study of the New Cache La Poudre Irrigation Company in Weld County, Colorado assessed the effects of conservation subsidies. They determined that such policies are unlikely to provide real water conservation savings. Increased irrigation efficiency leads to less leaching of fertilizers and pesticides, and controls soil erosion. Yields and gross revenues would slightly increase with more irrigation improvements, but the operation and maintenance costs increase at a faster rate. They also include a table that shows for all scenarios that consumptive use is unlikely to decrease and will most likely increase. Such a subsidy policy would not bring about any “new water” downstream (Scheierling et al., 2006).

10 Water Conservation Measures

Water conservation measures that reduce crop and non-crop consumptive use are another way to reduce water use. Reductions in consumptive use can occur by reducing evaporation from canals, by reducing crop and non-crop ET (which can affect yields in the case of crop ET if the crop is not changed), by reclaiming water that would otherwise flow into saline bodies of water, and by more effectively utilizing rainfall (CAWA, 2008; A. J. Clemmens et al., 2008; Schaible & Aillery, 2012). These options reflect the fact that the only real “losses” from an irrigation system are evaporation from open water
surfaces and moist soil, transpiration from vegetation, and flows into saline sinks (Allen et al., 2005; Allen & Willardson, 1997). These options are more limited, however, than ways to increase efficiency, and some methods will reduce yields and thus profits. Note that the efficiency improvement methods discussed above may increase, decrease, or not change consumptive use, unlike the methods discussed in this section which are strictly focused on reducing consumptive use. A subset of water conservation methods are sometimes called “water salvage” methods. In Colorado, this term has come to mean methods that reduce evapotranspiration from phreatophytes, or the reduction of non-productive consumptive use. Water obtained in this fashion is not available for a separate water right or for transfer.

10.1 Reducing Non-Beneficial Evaporation

In any irrigation system, some fraction of the applied water goes to evaporative losses from canals, ditches, reservoirs, and wet soil in fields. Drip or trickle irrigation, cover crops, mulching, and conservation tillage are all ways to reduce evaporation (Allen et al., 2005; Allen & Willardson, 1997; Blum, 2009; CAWA, 2008; Molden et al., 2010; C. Perry, 2011; Schaible & Aillery, 2012; Seckler, 1996; Shock, 2006). Two studies in Australia with wheat indicate that between 33% and 40% of water loss is by evaporation from soil (French & Schultz, 1984; Siddique, Tennant, Perry, & Belford, 1990). CAWA (2008) suggests that evaporation from soil is 20 to 30% of consumptive use. Targeting reductions in water loss by soil evaporation could present the best opportunity to conserve water (Blum, 2009). Gleick et al (2011) claim that we do not know much about pure evaporative losses associated with consumptive use.

This is one area where water conservation measures may actually create water for new uses, rather than move it between uses. In deep subsurface drip, these surface losses can be largely eliminated. Note, however, that germinating seeds and small plants with shallow roots must be watered at the soil surface with sprinklers or flood irrigation. Evaporative soil losses are larger when the plants are small and the soil is exposed to direct sunlight. Later when the soil is shaded by plant growth, these losses go down. It should be noted that evaporation from wet soil affects the microclimate around the crop by increasing humidity, and reducing the rate of transpiration required to achieve a specific yield (C. Perry, 2011). Compared to crop transpiration, evaporation of moisture in fields can be easier to control with techniques like mulching. Most evaporative losses occur in the planting season before crop cover is established when the sun can directly strike the soil (Seckler, 1996). Computerized irrigation scheduling has the potential to reduce evaporative losses by only watering when necessary. This topic is covered in Section 6.1.3 above Irrigation Scheduling.

10.2 Reducing Crop and Non-Crop Transpiration

Reducing the consumptive use of crops can also be achieved by limiting the amount of transpiration. However, decreasing transpiration in almost all circumstances will result in decreased biomass and yields. There is a linear relationship between plant biomass and transpiration, and there is a limit to how much improvement is possible in increasing the water productivity of crops when it comes to transpiration (Molden et al., 2010). Less than 1 percent of water is used for fluids in the plant, but the rest is transpired to control the heat of the plant, similar to perspiration in humans (Seckler, 1996).

Reducing transpiration can be accomplished by decreasing irrigated acreage, i.e., fallowing, changing to a cool season crop, changing to a cultivar that matures faster, or applying less water to crops when they can tolerate the stress through deficit irrigation (CAWA, 2008; Schaible & Aillery, 2012). Decreasing
acreage and deficit irrigation will likely reduce yields. Shifting to a cool season crop or a crop with a shorter growing season may also affect a farmer’s income through reduced marketable yield. Reducing weeds or other non-cropped plants in waterlogged parts of a field will reduce non-beneficial transpiration. There are also often plants along canals and ditches. Removing these kinds of plants can reduce transpiration, but they also serve other beneficial purposes such as wetlands habitat or provide desirable esthetics (Allen et al., 2005; Schaible & Aillery, 2012).

10.3 Reducing Runoff into Saline Water

If surface or subsurface return flows into a body of water that cannot be reused, capturing and reusing this water can increase water supplies (Allen et al., 2005; Allen & Willardson, 1997; CAWA, 2008; A. J. Clemmens et al., 2008; Gleick et al., 2011b; Schaible & Aillery, 2012). Saline water bodies can include subsurface salty groundwater, the ocean, and above ground salty lakes like the Great Salt Lake.

Perhaps the best-known example of reductions in flows to a saline water body are actions that the Imperial Irrigation District have undertaken to reduce flows into the Salton Sea. These actions were originally forced on IID by a 1984 California State Water Resources Control Board decision to reduce waste. The ruling was instigated by an IID farmer and landowner whose land was being submerged by a rising Salton Sea fed by IID runoff. Since that time, IID has undertaken many measures to reduce inflows into the Salton Sea with the perverse outcome that the Salton Sea is now threatened (Cohen, 2014). One such action is a large water transfer to the San Diego County Water Authority (see cases below). Without additional inflows, the Salton Sea will become hypersaline, and the main fish upon which millions of birds depend will die. In addition, exposed shorelines will allow for airborne dust. This is discussed further below in the case study on the Salton Sea.

The Salton Sea example provides a complicated case that has elements of both water conservation and improved irrigation efficiency. Reducing runoff into saline water is considered a water conservation method because it “increases” water supplies in a basin, albeit in an unusual manner. Most water conservation methods somehow decrease the consumed (i.e. vaporized) fraction of water, thus freeing up liquid water for other purposes. This method effectively converts a previously non-consumed but non-recoverable fraction of water into a non-consumed and recoverable fraction. It thus provides usable water where they did not previously exist.

The example also has elements of increased irrigation efficiency because headgate diversions in some cases can be reduced by the amount of the non-recoverable return flows. For example, return flows into the Salton Sea are being decreased to provide additional water for the San Diego County Water Authority and the Coachella Valley Water District. These reductions in return flows are taken by SDCWA without the need for IID to even divert these flows. The reductions thus increase the overall irrigation efficiency of IID by reducing diversions.

One could argue, however, that the flows into the Salton Sea were already being “consumed” by the fish and birds. In this case, this sort of transfer looks less like a water conservation measure that creates more water and more like an irrigation efficiency measure that moves return flows from one user (birds and fish) to another user (humans). It needs to be noted that environmental issues with reductions in inflows into saline above ground lakes are quite common. Severe environmental problems from inflow reductions in the last fifty years have occurred at California’s Mono and Owens Lakes (Blumm &
Schwartz, 1995; Nagourney, 2015), Iran’s Lake Urmia (Stone, 2015), Bolivia’s Lake Poopó (Casey, 2016) and Asia’s Aral Sea (Micklin, 2007).

10.4 More Effective Utilization

Another option is to better utilize rainfall to irrigate crops. Rain-fed agriculture relies on using and directing rainfall in a way that will irrigate entire fields of crops. Planting crops more densely where rainfall is higher and utilizing precipitation capture and moisture retention techniques can improve rainfall utilization (A. J. Clemmens et al., 2008; C. Perry, 2011; Schaible & Aillery, 2012). In most parts of the Colorado River Basin, this technique would have little applicability because of the arid nature of the basin. Rainfall in the Imperial Irrigation District historically has perversely led to spills of irrigation water due to a lack of operational storage of previously ordered and impossible to stop irrigation water. In recent years, IID has added operational storage, including the Drop 2 (“Brock”) reservoir on the All-American Canal to handle such events. It is not known if better rainfall capture in the Upper Basin is possible.

11 Non-Colorado River Cases

11.1 California

Christian-Smith et al. (2010) identifies, describes, and analyzes successful examples of sustainable water policies and practices in California. They note that many different practices and technologies can improve on-farm water-use efficiency, but focus on smart watering systems, in-field monitoring, irrigation scheduling systems, and drip irrigation. One of the cases discussed is smart irrigation scheduling on an almond ranch. There were significant water reductions on water applied to fields (20 percent) and higher yields due to a system that measures soil moisture and informs the farmers when and how much to irrigate. It is not clear how reductions in applied water decreased and yield increased without increased consumptive use. Some studies have shown that irrigation scheduling can drastically reduce non-beneficial consumptive use evaporation from bare soils and this may explain at least some of the paradox (French & Schultz, 1984; Siddique et al., 1990).

11.2 High Plains Aquifer

Pfeiffer and Lin (2010) examined the effect of widespread conversion from center pivot irrigation to higher efficiency dropped-nozzle center pivot irrigation in western Kansas. They used panel data from over 20,000 groundwater-irrigated fields in western Kansas from 1996 to 2005. They concluded that the shift in irrigation systems increased consumptive use and groundwater extraction. Applied water per acre increased on average by 0.03 to 0.05 acre-feet per acre with dropped nozzles, a 2.5 percent increase. Farmers used more water per acre on irrigated fields, irrigated slightly larger proportions of their fields, and were less likely to leave fields fallow or plant non-irrigated crops. After the irrigation improvement, farmers were more likely to plant water intensive crops like alfalfa, corn, and soybeans.

A study on the economic impact of new irrigation systems and limited tillage practices on the Texas High Plains concluded that new irrigation technology will not lengthen the life of groundwater resources. Water use will increase because producers will have an economic incentive to apply more water per acre on the same crop for greater yield (Ellis et al., 1985a).
11.3 Salt River, Wyoming

Venn et al. (2004) conducted a hydrologic analysis of improved irrigation efficiencies in the Salt River Basin in Wyoming, along the Idaho Border. The Salt River, a tributary to the Snake, supports intensive agricultural activity; it provides 95 percent of the water used for irrigation in the area. The nearby Greys River has a similar flow but it has not been impacted by changes in irrigation like the Salt River. The Greys River was thus used as a control to determine impacts associated with the change in irrigation.

Along the Salt River, irrigation systems have been converted from flood to sprinklers. The two rivers were examined from 1954 through 2000. After the installation of sprinklers, stream flows were considerably altered in the Salt River Basin. Flows increased 34 percent in May and 50 percent in June, but decreased 14 percent in August and 15 percent in September. These changes reflect the fact that deep percolation, seepage, and groundwater recharge from flood irrigation were eliminated when sprinklers are used. The late season river flow reductions occurred when irrigation water is under its greatest demand. Yields increased from 1.6 tons/acre to 2.1 tons/acre. The overall efficiency of the area increased from an assumed 50 percent for flood irrigation to 70 percent for sprinkler irrigation. There was an increase in average annual flow of 53,200 acre-feet, 9 percent of the average.

The study does not mention changes in consumptive use, but it is likely there was an increase in consumptive use since yields increased. The increase in annual flow is likely due to decreased diversion amounts. Since the increased consumptive use is not coming from the flow of the river, there may be impacts to the groundwater in the area. It is also possible that there are reductions in non-beneficial consumptive use.

11.4 Yellowstone River, Wyoming, and Montana

In the early 2000s, there were critical water shortages in Montana and Wyoming along the Tongue and Powder Rivers, tributaries of the Yellowstone River. Montana claimed that Wyoming violated the Yellowstone River Compact and should have regulated water post-1950 rights that were appropriated after the compact. Wyoming responded that post-1950 diverters were in fact curtailed. In 2007, Montana filed its complaint with the U.S. Supreme Court. According to Montana, the change from flood to sprinkler irrigation in the basin led to an increase of consumption from 65 percent of water diverted to 90 percent, reducing return flows from 35 percent to 10 percent. A Special Master determined that these improvements did lead to increased consumptive use, but declared that these actions did not violate the Compact. The Supreme Court found that changes in irrigation methods due to efficiency are within the scope of the Compact (MacDonnell, 2011b).

The Compact is somewhat unusual in that it does not refer to consumptive uses, only diversion amounts. It also never anticipated cross-state application of priority. The movement to sprinklers did not involve a change in place of use, time of use, purpose of use or point or diversion, the typical factors under prior appropriation that are not allowed to change without a legal review of the water right. State courts have found that on-farm efficiency improvements such as ditch lining, pipeline installation and other methods are within the scope of water rights and do not constitute injury to downstream users.

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11 It should be noted that the Salt River has a wide valley suitable for agriculture while the Greys River is in a narrow confined canyon. Although they join the Snake at about the same location, they do have very different basins.
MacDonnell notes that often, in the West, irrigators are “water short”, meaning they are unintentionally deficit irrigating. With more efficient infrastructure, an irrigator may be able to deliver a full supply of water to a crop that will lead to increased consumption. It is also not clear that efficiency improvements lead to overall economic losses in the basin although there are individual winners and losers.

MacDonnell (2011b) argues that the rigidity of the basin approach to water management doesn’t allow farmers to adapt to contemporary problems by installing better technologies such as sprinklers. To completely protect downstream users from harm is to prevent needed and necessary changes for the 21st century. In his view, it doesn’t make economic sense to prevent potential economic gains to prevent harm to inefficient, low technology users. Sprinklers have a host of benefits including reduced stream diversions and higher crops yields. In addition, reduced return flows mean less fertilizer and pesticides coming into streams, as well as less salinity and selenium. Such improvements may reduce return flows, but downstream users will be inclined to also adjust and install sprinklers as well.

11.5 Snake River Plain, Idaho

The Snake River Plain aquifer in southern Idaho has experienced declining aquifer levels due to diminished recharge from reduced surface irrigation and increased irrigation pumping. From 1975 to 1995, about 350,000 AF was depleted from the aquifer every year. The State of Idaho has been implementing a program of intentional recharge with little beneficial result. Reductions of flows from springs have impacted commercial fish production, irrigation, and hydropower generation (Johnson et al., 1999).

Originally, the aquifers in the area were recharged from canal seepage and surface irrigation application more than ET. This system elevated the water table and increased the flows of springs discharging into the Snake River at Idaho Falls. Water users became dependent on the recharge from surface water irrigation. In the late 1800s and early 1900s, 900,000 acres of irrigated land contributed to the recharge of the aquifer and increased the elevation of groundwater levels. The volume of the water stored in the aquifer increased by 15 maf from 1915 to 1955. Annually, 340,000 af were being added to the aquifer. In the mid-1950s, irrigation technology began to change with the gradual conversion from flood, furrow, and sub-irrigation practices to sprinklers, and the lining of canals. Surface water recharge declined significantly. Since the 1950s, 800,000 acres of groundwater irrigated land have been brought into production. The State has placed a moratorium on new irrigation pumping and created groundwater districts to measure pumping to mitigate the issue with mixed results (Johnson et al., 1999).

11.6 Rio Grande

An analysis of possible water conservation policies in the Elephant Butte Irrigation District in the Rio Grande Basin, found that as subsidies for irrigation improvements increased, so did ET, crop yields, and farm incomes. There was also a decrease in return flows, aquifer levels, and total water conserved (Ward & Pulido-Velazquez, 2008b). The findings “suggest that some programs subsidizing irrigation efficiency are likely to reduce water supplies available for downstream, environmental and future uses.” In addition, “where reduced return flows and lost aquifer seepage block another’s water use, conservation poses a serious question for water rights administration because those effects are often hard to measure and often occur with considerable delay”.

23
12 Colorado River Basin-wide Cases

12.1 Colorado River Basin Salinity Control Project

The 1944 U.S.-Mexico treaty covering the Colorado River provided a minimum annual delivery of 1.5 maf of water to Mexico. The treaty did not, however, explicitly mention water quality. Irrigation and municipal water projects built in the early and mid-20th century contributed to salinity increases through high salinity return flows originating from naturally saline ground and reductions in the water for dilution from out-of-basin diversions.

Nearly half of the salinity in the Colorado River is from natural sources: saline springs like Glenwood Springs and Blue Springs on the Little Colorado River in the Grand Canyon, and erosion of saline geologic formations. Human activities increase salt by two separate effects: (1) salt loading, and (2) salt concentration. Salt loading is the process by which water picks up salts from contact with soil and then return flows carry these salts to the river. Salt concentration occurs when plants evaporate pure water, leaving the salts behind. Reservoir evaporation also concentrate salts. Out-of-basin diversions create an additional salt concentration problem. These diversions generally occur high in the basin where salt loads are low. Thus, there is less water left to dilute salts from downstream salt loading and salt concentrating processes. Irrigation contributes 3.4 million tons of salt per year by dissolving salts found in the underlying saline soil, mainly Mancos shale. Contrary to common thought, much of the salt originates in the Upper Basin.

Salinity levels began to increase considerably in the Lower Basin and even near Grand Junction, Colorado in the 1950s and 1960s. In addition, the Wellton-Mohawk Irrigation and Drainage District (WMIDD) began pumping excess saline groundwater (6000 ppm total dissolved solids) into a drain, the Main Outlet Drain (MOD), which emptied into the Gila River just above Mexico’s main diversion. The WMIDD’s groundwater problem arose after the district began receiving Colorado River water beginning in the 1950s. Shortly after the pumping began, Mexican farmers began to have problems with crop yields and the Mexican government formally protested to the U.S. in November of 1961.

There were several temporary attempts to solve the problem beginning when Mexico first protested. In 1965, Minute 218 was signed, requiring the U.S. to construct a 12-mile extension (the MODE) from the existing MOD terminus on the Gila River to below Mexico’s main diversion at Morelos Dam, thus bypassing the saline flows. A permanent solution was not reached until 1973 with Minute No. 242 (Bickell, 1999).

Under the 1973 agreement, the U.S. must deliver water of approximately similar quality to Mexico that was delivered to major diverters at Imperial Dam. No longer could the U.S. meet its delivery requirement by using highly saline return flows. The Colorado River Basin Salinity Control Act, authorizing government entities to control the salinity of water delivered along the Colorado, was enacted shortly after the Minute in 1974. The act established the Colorado River Basin Salinity Control Program (CRBSCP), authorized the construction of the Yuma Desalting Plant, provided funding for Mexico to build a 53-mile extension to the MODE to deliver approximately 100 kaf/yr of WMIDD highly saline flow and/or reject water from the Yuma Plant to the Santa Clara Slough (now known as the Cienega de Santa Clara), and enacted the Wellton-Mohawk Irrigation Efficiency Improvement Program and a companion program to reduce acreage in WMIDD by up to 10,000 acres (Bickell, 1999).
At first, the CRBSCP only applied to the Lower Basin with a focus on the WMIDD. However, because much of the salt originates in the Upper Basin, the program was expanded. A multi-agency effort including Reclamation and USDA NRCS has significantly reduced salt loading in the Colorado River and its tributaries. In the past 30 years, the CRBSCP has found that salinity projects to reduce irrigation water contact with saline soils is the most effective control measure (Quality of Water, 2013). The program identifies salt source areas, develops conservation plans to reduce salt loads, installs conservation practices, and then monitors and evaluates those projects (Bickell, 1999). Projects are also “owned” by the proponent like an irrigation district or ditch company, not the Bureau of Reclamation as were the first projects (Quality of Water, 2013).

Annually, 7.7 million tons of salt accumulate in the Colorado River. As of 2012, the CRBSCP is removing over 1.295 million tons of salt per year. The 2020 target is 1.85 million tons. Meeting this and future goals would require a significant increase in funding for the Bureau of Reclamation, NRCS, and the Bureau of Land Management (Quality of Water, 2013). Many of the cheaper projects have been completed and the cost per ton of measures has increased from an average of about $50 in 2005 to $125 in 2011 (USDA, 2011).

These projects are designed, first and foremost, to control salinity. The techniques used in many of the projects — conversion to either lined canals or pipes, and the installation of sprinklers — are also typical irrigation efficiency projects. Hence, these projects have an important co-benefit of improving irrigation efficiency in many locations along the river.

### 13 Colorado Cases

#### 13.1 Grand Valley Water Users Project

Just upstream of Grand Junction, Colorado, large amounts of water are diverted out of the Colorado River by five different entities to irrigate 69,000 acres in the Grand Valley (Uilenberg & Norman, 1999)\textsuperscript{12}. The Grand Valley is about 12 miles wide and 35 miles long. Irrigation feeds apple, peach, and pear orchards, but most acreage is devoted to forage crops like corn, alfalfa, wheat, and other crops like beans and seed crops. In 1910, the Grand Valley Irrigation Project received federal funding to divert water from the Colorado River through a dam and four canals over 90 miles long including the 55-mile Government Highline Canal. This diversion is the single largest diversion on the Colorado River in the state of Colorado with annual average diversions of 770 kaf (USBR, 2013b). The project also included a power plant associated with the project, the Grand Valley Power Plant (Simonds, 1994). In recent years, the Grand Valley Project has provided 60 percent of the water delivered to the five irrigation districts in the area (Uilenberg & Norman, 1999).

The Upper Colorado Endangered Fish Recovery Program, an interagency partnership to recover the endangered Colorado pikeminnow, razorback sucker, humpback chub, and bonytail chub, was created in 1988 (MacDonnell, 1999a; USBR, 2013a). The Program quickly sought to improve the fish habitat in the Colorado River, especially in an area known as the “15-mile reach" because it is a critical spawning area for endangered fish. The 15-mile reach extends from just below a major diversion structure for the

\textsuperscript{12} There is an additional diversion on the Gunnison River – Redlands Water and Power -- which also serves land in the Grand Valley on the west side of the Colorado River.
Grand Valley Irrigation Company near Palisade, Colorado to the confluence of the Gunnison and Colorado rivers in Grand Junction. In Colorado, this stretch is affected more by depletions than any other section of the river (USBR, 2013a). In dry years and later in the summer, so much water was diverted historically that the river would sometimes dry up in the 15-mile reach until return flows rejoined the river downstream. The construction of ten major upriver dams in 80 years also significantly altered the hydrology and habitat of this section of the Colorado River. Many native fish relied on the historical temperatures, floodplains, spring floods, and turbidity in the water.

The Grand Valley Project supplies 60% of the diversions in the Grand Valley to four of the six diverters \(^\text{13}\) including the Grand Valley Water Users Association and the Orchard Mesa Irrigation District. The GVWUA operates a gravity system that runs a continuous flow in the Government Highline Canal through the season to ensure that water is available to meet farmer needs. There had been on-farm improvements over the years like lining ditches with concrete, and installing siphon tubes and gated pipe — but no effort had been made to improve the main conveyance system (MacDonnell, 1999a). Other on-farm improvements had decreased the impact of salinity on downstream users by decreasing deep percolation through the underlying salty shale soil (A. J. Clemmens et al., 2008). These improvements, however, did not save water. There was little incentive to change this system because it was simple and relatively inexpensive (MacDonnell, 1999a).

In 1992, the Bureau of Reclamation analyzed a multitude of possibilities to address low flows in the 15-mile reach. The most cost-effective method was to reduce diversions from the Grand Valley Water Users’ Association (GVWUA) part of the Grand Valley Project. With automation and new facilities, studies indicated that nearly 28,500 af/year of excess carriage water could be rerouted to the 15-mile reach (MacDonnell, 1999a; Styles, Burt, Khalsa, & Norman, 1999).

A total of $8.2 million of improvements were completed by 2002 to automate the delivery system (Khalsa, Styles, Burt, & Norman, 2002). Travel time along the 55-mile length of the 1600 cfs \(^\text{14}\) Government Highline Canal was approximately 72 hours which challenged operators to balance supply and demand. Historically, the operators kept the canal as full as possible so that the canal always had the water necessary to meet demand anywhere along its length. This meant, however, that sometimes the canal had too much water in it, which was returned to the river below the 15-mile reach. By adding automated check structures in the main canal, diversions could be reduced. The check structures allowed subsections of the canal to maintain the necessary height for diversions to laterals. In addition, expanded use of a small existing Colorado Parks and Wildlife recreation reservoir at the end of the canal allowed for the temporary storage of excess water, and met end-of-canal needs at times when the canal did not have enough water. New main office control facilities allowed for centralized control of all the automated equipment.

Legally protecting (“shepherding”) the water in the 15-mile reach created by the improvements from other diverters required legal creativity. Environmental use was not compatible with the uses of the

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\(^{13}\) The diverters are Grand Valley Irrigation Company (north side), Grand Valley Water Users Association (north side), Palisade Irrigation District (north side), Mesa County Irrigation District (north side), Orchard Mesa Irrigation District (south side), and Redlands Water and Power District (south side, west of the Gunnison River.)

\(^{14}\) The canal splits at the mouth of Debeque Canyon with about 800 cfs going to GVWUA and the other half to the Orchard Mesa Irrigation District via a siphon under the river and I-70.
existing water right for the GVWUA. Under Colorado water law, another user downstream or upstream could legally appropriate the newly created excess water. It would difficult and even cost-prohibitive to obtain a decreed change of use for the water right (Uilenberg & Norman, 1999).

Through litigation known as the Orchard Mesa Check Case, the U.S. government, GVWUA, and the Orchard Mesa Irrigation District obtained a Colorado water court-sanctioned settlement agreement that provided the legal foundation for protecting conserved water from other diverters. The GVWUA receives stored water from Green Mountain Reservoir when natural flows are insufficient to satisfy irrigation demand. If the volume of reservoir water available exceeds the amount required to provide a full water supply to all eligible users, a special surplus condition is declared. Reducing diversions for the Grand Valley Project increases the occurrence of a surplus condition.

The Grand Valley Power Plant ultimately provided one of the legal mechanisms to protect deliveries of surplus storage water to benefit the fish habitat. The plant has a relatively junior right and unused capacity in the late summer months when the streamflow is lowest. Under a new contract with Reclamation, surplus water from Green Mountain Reservoir is used to fill the unused capacity at the power plant and the plant conveniently discharges water immediately above the 15 Mile Reach. The other legal mechanism was another new contract between Reclamation and the cities of Grand Junction, Fruita, and Palisade to deliver surplus Green Mountain water for instream recreational flows in the 15-mile reach (Uilenberg & Norman, 1999). The improvement of the canal system has exceeded expectations with water diversion savings exceeding 28,500 acre-feet per year (C. M. Burt, 2003). Recent estimates are that in some years nearly 40,000 af/year remains in the Colorado River.

13.2 Orchard Mesa Irrigation District Canal System Improvement Project

The Orchard Mesa Irrigation District (OMID) was organized in 1904 and became a part of the federal Grand Valley Project in 1922. The OMID main canal splits from the Government Highline Canal about 4.6 miles downstream of the GVIP dam (“the Roller Dam”), and goes under the Colorado River and I-70 in an inverted siphon at the mouth of Debeque Canyon, just upstream of Palisade, Colorado. The district provides water for 6,700 landowners irrigating 9,200 acres (USBR, 2013b). The customers are a mix of residential and agricultural water users, and support a diverse agricultural economy: orchards, vineyards, vegetables, alfalfa, and small grains. Through funding from the Bureau of Reclamation and the National Resource Conservation Service, the district had been able to make some improvements like alkalinity and salinity mitigation, and some on-farm improvements. However, like the GVWUA prior to modernization around 2000 (see above), the main canal for the OMID had not been upgraded and required a significant amount of carriage water that led to spills (Widener, 2015).

Initial studies were performed in 2007 and 2012 (ITRC, 2007, 2012). Beginning in 2014, the Orchard Mesa Irrigation District (OMID) undertook a similar project as the GVWUA modernization to benefit the Upper Colorado River Endangered Fish Recovery Program. The project involves improving and automating the OMID canal system. A $16.5 million budget included a regulating reservoir, check structures on the canals, remote monitoring system and electronic flow meters (SCADA), increased pump capacity, interties and upgrades to canal end spills, lining and piping, and improved operational procedures (Moving Forward, 2015; USBR, 2013b).

In most cases, the saved water will be used to augment flows in the 15-mile reach (Moving Forward, 2015). This will be accomplished by diverting flows as normal, and then running them through the OMID
power plant at the head of the 15-mile reach rather than pumping the saved water up into the OMID delivery canals as done previously. In a few low flow cases, the water savings may go to other water rights. The existing Orchard Mesa Check Case provides the legal technique to protect the saved water from diversion in most cases (MacDonnell, 1999b).

Canal structures were completed in 2014, and regulating the reservoir was planned to be completed in 2015. The project is expected to result in 17,000 acre feet/yr in savings from reduced canal spills, and spills in urban areas. The project should be fully operational for 2016 (Moving Forward, 2015).

13.3 No Chico Brush

No Chico Brush is a farmer-led group in the Gunnison River Basin in western Colorado that pushes a “farmer-first” approach to dealing with agricultural water issues. The name refers to the group’s goal of preserving irrigated agriculture and not allowing agricultural lands to be covered in native desert plants like greasewood, or “Chico brush.” The goal of the group is to pursue irrigation efficiency improvements to assist both farmers and the environment (Denison, 2015; Harold, 2014).

By modernizing irrigation systems, improving wildlife habitat, and limiting downstream impacts of salinity and selenium though soil and water conservation, No Chico Brush wants to ensure that the agricultural sector will not be a target in the future for potential water supplies (Denison & Harold, 2015).

The group pushed to have the USDA designate the Colorado River Basin as a Critical Conservation Area to enhance their ability to participate in the Regional Conservation Partnership Program (RCPP) funded by the 2014 Federal Farm Bill (Harold 2014). Several entities including NCB, the Nature Conservancy, and the Colorado River Water Conservation District were successful in obtaining a $16 million RCPP award in 2015. The RCPP project targets improving irrigation efficiency and diverting less water to improve river and fisheries health (Trout Unlimited, 2015). The project also includes research on comparing furrow irrigation to overhead sprinkler, drip, and “big gun” irrigation systems to assess the consumptive use of certain crops, application efficiency, and how much water returns to the system (WRSA Grant Application, 2014). No Chico Brush has yet to report significant progress, in part due to landowner reluctance to participate.

14 New Mexico Cases

14.1 Drip Irrigation Investigation in New Mexico

The New Mexico Interstate Stream Commission funded a series of conversion projects in Southern New Mexico from flood to drip irrigation to promote water conservation (Moving Forward, 2015). A follow-up study examined the water consumption of drip- and sprinkler-irrigated fields versus flood-irrigated fields. A total of 103 fields were identified. Crops included alfalfa, chiles, corn, cotton, milo, and pecans. There were 63 fields with drip irrigation, and 40 fields were irrigated with flood or center-pivot (INTERA, 2013).

Remote-sensing-based techniques were combined with ground data collection to find consumptive use (Martinez, Jordan, Whittaker, & Allen, 2013). Surface temperature of crops showed that lower temperatures were present for drip-irrigated fields. This usually shows a correlation with more water
consumption. The normalized difference vegetation index (NDVI), an indicator of “greenness” using remote sensing, also determined that drip-irrigated fields had more biomass and hence higher yields. For 2012, fields that were drip irrigated had 8 to 16 percent higher consumptive use, more robust crop growth, and higher yields (INTERA, 2013).

Since water rights were based on diversion rates and not consumption rates, farmers were able to operate within their water decree and increase their consumptive use. A larger percentage of pumped groundwater was converted into ET, reducing percolation into the groundwater system that recharges the aquifer (INTERA, 2013; Martinez et al., 2013).

15 Utah Cases

15.1 Ferron Salinity Control Project

In Emery County, Utah, farmers have used flood irrigation for decades. The county includes the Price and San Rafael River Basins which contribute a large amount of salt to the Colorado River, nearly 430,000 tons a year. Almost 60 percent of that amount comes from irrigation runoff and canal seepage (Carroll, 2006).

The Ferron Salinity Control Project was a partnership effort under the Colorado River Basin Salinity Control Program to reduce salinity runoff near Ferron, Utah though improved agricultural practices on the lands of a local irrigation district (Carroll, 2006). The project began in 1998 and took eight years until completion (Stoddard, 2006). The project included new pipelines and laterals of pressurized pipe, and regulating ponds. There were 175 miles of pipe installed and 10,000 acres of agricultural land were converted to pressurized sprinklers (Moving Forward, 2015).

The Bureau of Reclamation and NRCS funded the $20 million project, which has reduced salt loading by 40,000 tons per year (Moving Forward, 2015). In the past, it has cost the Bureau $100 for every ton of salt reduced, but the Ferron project worked out to be $30 per acre ton, a financial success (Stoddard, 2006). Irrigation efficiency of the system has also increased significantly, from around 30 percent to 67 percent (Carroll, 2006).

Water savings were not quantified, but anecdotal accounts say that there is greater water availability (Moving Forward, 2015). In the past, water sources would be depleted by late summer, but now there is a continued supply into the fall (Carroll, 2006). Crop yields have increased by one-third, fourth cuttings of hay are more common, deep percolation was eliminated, furrow reduction means more farming ground, and runoff has been reduced (Stoddard, 2006).

16 Arizona Cases

16.1 Diamond Ditch Improvement Project

The Verde River, Arizona’s only Wild and Scenic River, runs 195 miles south from its headwaters located in the middle of a triangle bound by Prescott, Williams, and Flagstaff into the Salt River near Phoenix. The 42 diversions along the river and its tributaries were mostly built in the late 19th and early 20th centuries, and have not changed substantially to this day. The river supports many different animal species including listed endangered species and is valued as an ecological hotspot. A several-mile-long
stretch in lower Verde used to become severely depleted or dry late in the irrigation season (Hutchinson, 2015; Postel, 2013b).

The most downstream ditch is the Diamond S, a five-mile-long ditch that brings water to 80 users irrigating approximately 400 acres near the town of Camp Verde. Working alongside The Nature Conservancy (TNC), the Diamond S Ditch has recently automated the ditch to reduce diversions and increase flows in the Verde by 5 cfs during the dry summer periods, approximately doubling the existing flows. Computer and radio-controlled systems were added to the ditch gates to keep a constant flow of water in the ditch, automatically lowering and raising the gates so that the ditch delivers a volume of water closer to what the users actually need (Postel, 2013b). Prior to the upgrade, the extra carriage water was returned to the river at the end of the ditch.

TNC signed a “diversion reduction agreement” with the ditch company, stating that TNC will cover the costs of the ditch improvements if the irrigators reduce their diversions by an agreed-upon amount. The agreement even included bonuses if the irrigators reduce diversions beyond the target. Overall, the project returns water to the river for less than $10 per acre-foot (Postel, 2013b). It appears that the water left in the river might be subject to use by another diverter, possibly located upstream, but for now it remains in the river.

16.2 The 1980 Groundwater Management Act

16.2.1 Original Irrigation Efficiency Goals

Under a serious threat from the federal government to cut off funding for the Central Arizona Project unless statewide groundwater management was enacted into law, in 1980 Arizona passed its landmark Groundwater Management Act with the intention of bringing groundwater pumping into “safe yield” by 2025 (Connall Jr., 1982). The legislation was and probably still is the most far reaching groundwater legislation in the U.S. (Megdal, 2012). The act created four Active Management Areas, one of which was later split into two areas. At the time, Arizona was experiencing severe groundwater overdrafts of up to 100 meters and also in some cases 6 meters of land subsidence (Tillman & Leake, 2010). The act dealt with all groundwater uses including municipal, mining, and agricultural use. Under the act, each Active Management Area creates and enforces new plans to achieve the goals of the act every 10 years.

Expansion of irrigated agriculture was prohibited. Henceforth, irrigation would only be allowed on farms that had been producing for the five years prior to the enactment of the act, and those farms would be assigned Irrigation Grandfathered Rights (IGFRs) based on that historical production record (Maguire, 2007). A mandatory conservation program was established with initial water allotments based on the maximum historical annual groundwater use during the five-year base period. The key conservation part of the act was to require increasing irrigation efficiency through time, thus slowly reducing farming water allotments. Initial irrigation efficiency values were 50 percent to 70 percent and were projected to reach 85 percent by 2010. These efficiency goals were manifested under a per acre “duty of water” set by the Director of the Arizona Department of Water Resources. The act established a system of annual credits and debits for farms based on use relative to the IGFR historical allotment, thus allowing farmers flexibility to store unused water and temporarily overdraw if necessary.

For a number of reasons, the agricultural conservation program has been only marginally effective (Jacobs & Holway, 2004). It allocated too much water per farm, with farmers by 2000 accruing large credits that were either partially transferable or usable in future years (Maguire, 2007). As of 2001, it
appeared that both the Tucson and Phoenix AMAs would not hit their safe yield goals by 2025 (GWMC, 2001). A 2008 review of the Management Plans concluded that the effectiveness of the conservation plans could not be determined from the data available in the plans (Megdal, Smith, & Lien, 2008). This review indicated that water use data reported annually in a consistent format for all sectors was a prerequisite for future management efforts.

16.2.2 2002 Best Management Practices Amendments

By the early 2000s, there were several concerns and problems with the existing conservation program. Reporting requirements were complex. In order to pass the act, several carve-outs were made for existing users. By 2000, so many credits (~15 maf) had been established that the conservation program was viewed as ineffective (Maguire, 2007). In addition, some farmers thought their IGFRs were unfairly low; for example, fallowed lands in the historical base period were not counted. In response, in 2002, the Arizona Legislature passed a significant modification to the act that established an alternative conservation program, the Best Management Practices (BMP) Program, and it also reduced the Irrigation Efficiency goal to 80 percent from 85 percent for the next management period. The BMP program was initially a temporary program and was later made permanent.

The voluntary BMP program established many conservation practices under 4 different categories: Agronomic Management, Water Conveyance Systems, Farm Irrigation Systems, and Irrigation Water Management (Table 1). Each category has numerous practices with points assigned to each subcategory ranging from 1 to 3 points. Farmers need a total of 10 points to enroll, with a minimum of 1 point and a maximum of 3 points from each category. Farmers who enrolled in the program were freed from the allotment restrictions of their historical IGFR allotment, but in exchange they had to give up any accrued credits.

Only 6 percent of eligible lands were enrolled in the program and 70 percent of the enrollees had to make no changes to quality for the program. Farmers joining indicated that they wanted lower transaction costs and future water use flexibility by escaping their IGFRs. The BMP Program has also afforded some farmers the opportunity to increase their water use if they can demonstrate higher efficiency. Farmers can also increase their consumptive use substantially if they change their cropping patterns or shift to a crop like alfalfa.
Table 1: Arizona Best Management Practices (BMP). Source: Arizona Department of Water Resources.

<table>
<thead>
<tr>
<th>Category</th>
<th>Practice</th>
<th>Points</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Conveyance System</td>
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<td></td>
<td></td>
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<tr>
<td>Improvements</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>Concrete-lined ditch</td>
<td>1.0 to 3.0</td>
<td>% of total acreage determines points</td>
</tr>
<tr>
<td>1.2</td>
<td>Pipelines</td>
<td>1.0 to 3.0</td>
<td>50-54% = 1, increases by .2 every 4%</td>
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<tr>
<td>1.3</td>
<td>Drain back System</td>
<td>1.0 to 3.0</td>
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<tr>
<td>Farm Irrigation Systems</td>
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<td></td>
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<tr>
<td>2.1</td>
<td>Slope Systems without uniform grades with tailwater reuse</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2.2</td>
<td>Uniform slope systems without tailwater reuse</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2.3</td>
<td>Uniform slope systems with tailwater reuse</td>
<td>2</td>
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<tr>
<td>2.4</td>
<td>Uniform slope that captures and redistributes return flows</td>
<td>2</td>
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<tr>
<td>2.5</td>
<td>Modified Slope Systems</td>
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<td>2.6</td>
<td>High Pressure sprinkler systems</td>
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<tr>
<td>2.7</td>
<td>Near level systems</td>
<td>2.5</td>
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<tr>
<td>2.8</td>
<td>Level systems</td>
<td>3</td>
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<tr>
<td>2.9</td>
<td>Low Pressure Sprinkler systems</td>
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<td>2.10</td>
<td>Trickle irrigation systems</td>
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<tr>
<td>Irrigation Water Management</td>
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<tr>
<td>3.1</td>
<td>Laser touch-up</td>
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<td>3.2</td>
<td>Alternate row irrigation</td>
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<tr>
<td>3.3</td>
<td>Furrow checks</td>
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<td>3.4</td>
<td>Angled rows/contour farming</td>
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<tr>
<td>3.5</td>
<td>Surge irrigation</td>
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<tr>
<td>3.6</td>
<td>Temporary sprinklers</td>
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<tr>
<td>3.7</td>
<td>Participation in education irrigation water management program</td>
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<tr>
<td>3.8</td>
<td>Participant in consultant or district sponsored irrigation scheduling service</td>
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<tr>
<td>3.9</td>
<td>Increase Flexibility of water deliveries</td>
<td>1</td>
<td></td>
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<tr>
<td>3.10</td>
<td>Measure flow rates to determine amount applied</td>
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<tr>
<td>3.11</td>
<td>Soil moisture monitoring</td>
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<tr>
<td>3.12</td>
<td>Computerized irrigation scheduling</td>
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<tr>
<td>3.13</td>
<td>New, substitute practice</td>
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<tr>
<td>Agronomic Management</td>
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<tr>
<td>4.1</td>
<td>Crop Rotation</td>
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<td>4.2</td>
<td>Crop Residue Management</td>
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<td>4.3</td>
<td>Soil and Water Quality Testing</td>
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<td>4.4</td>
<td>Pre-irrigation surface conditioning</td>
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<td>4.5</td>
<td>Transplants</td>
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<td>4.6</td>
<td>Mulching</td>
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<tr>
<td>4.7</td>
<td>Shaping furrow or bed</td>
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<tr>
<td>4.8</td>
<td>Planting in Bottom of Furrow</td>
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<tr>
<td>4.9</td>
<td>New, substitute practice</td>
<td>1</td>
<td></td>
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</table>
16.2.3 Analysis

The results on actual water conservation with the BMP Program are inconclusive. (Bautista & Waller, 2010a; Bilby & Wilson, 2013). However, one study found that farms participating in the new BMP Program have water use that consistently exceeds their base program allotment from the IGFRs. (Bautista & Waller, 2010b).

University of Arizona economists conducted several interviews to determine if the Arizona Groundwater Management Act (GMA) incentivized growers to conserve water. In interviews with irrigation district managers, Arizona Department of Water Resources (ADWR) staff members, water experts, and growers, interviewees indicated that while farmers did make efficiency improvements in the 1970s and 1980s such as ditch lining, laser leveling, and improved management, most of these improvements were not caused by the GMA. In addition, the interviewees indicated that the act did not establish an effective water constraint for many reasons. Acreage was set too high in many cases, ADWR set a high (5.05) acre-feet/acre water duty, and land set aside for USDA commodity programs received a water allowance thus providing windfall credit water. Thus, the authors found that the GMA did not create incentives for on-farm water conservation and practices, contrary to its intent (Wilson & Needham, 2006). The study indicates water use in the agricultural sector has remained constant from 1980 to 2000, and any variability in water use during this time was due to changes in crop prices and rainfall, not conservation. Some farmers use the same amount of water today that they did in 1980, even though their irrigation efficiency has increased substantially (Costa, 2014).

16.3 Wellton-Mohawk Irrigation and Drainage District

Upstream of Yuma, Arizona on the Gila River, the Wellton-Mohawk Irrigation and Drainage District (WMIDD) sits east on an elevated plateau, slightly higher than the rest of the area. Water is conveyed to the district up the Gila River valley by a large canal from Imperial Dam with three lift stations, irrigating 59,000 acres of alfalfa, cotton, wheat, lettuce, and citrus as part of Reclamation’s Gila Project authorized in 1937 and 1947. The overall project water use efficiency is higher than most places in the U.S. A fully lined concrete canal system and on-farm irrigation improvements contributed to the district efficiency exceeding 60 percent in the early 1990s (Palmer, Clemmens, Dedrick, Replogle, & Clyma, 1991). A more recent analysis of WMIDD indicates that efficiency district-wide has increased and is closer to 75 percent (Noble, 2015).

Many of the efficiency measures in WMIDD were in response to a series of salinity issues in the district (Blackman Jr, Rouse, Schillinger, & Shafer Jr, 1973; Getches, 1993). Before the Colorado River water was available, farmers used and reused water pumped from wells, and the return flows seeped back into the groundwater, making it even more saline. The WMIDD portion of the Gila Project was substantially completed by 1952 and brought in less saline Colorado River water, some of which could be used for leaching. However, the land was over a closed groundwater basin and the salty groundwater rose into the root zone of the crops since it had nowhere to infiltrate horizontally. In response, the district constructed the Main Outlet Drain (MOD) to a location on the Gila just below the district. This drain contained water more than 6,000 ppm of total dissolved solids, and this pushed the salinity in the Colorado River main stem river to 1,500 ppm.
The saline water led to complaints from Mexico in November of 1961. After a series of short-term measures, in 1965, Minute 218 was signed, providing for an extension to the MOD canal (the “MODE”) to deliver water to just below Morelos Dam, the main Mexican diversion point. In 1973, Minute 242 was signed, effectively imposing a requirement on the U.S. to deliver water only slightly more saline that that used in the Yuma area. In 1974, Congress passed the federal Salinity Control Act to assist with solving the Colorado River salinity problem. The Yuma Desalting Plant was constructed in 1992 to process WMIDD’s saline return flows. The plant only operated for a short period of time before a Gila River flood knocked out the headgate. There was also significant buying and retiring of high water use land in WMIDD to reduce saline return flows (wmidd.org, n.d.). The Mexicans, using U.S. funds from the 1974 act, built a 50+ mile extension to the MODE envisioned by Minute 242, the “Bypass Drain”, to what is now the Cienega de Santa Clara.

From 1975 to 1986, the Wellton-Mohawk One-Farm Irrigation Improvement Program was carried out to reduce saline return flows from the district. Besides the retirement of 10,000 acres of citrus on sandy and highly saline soils, there were significant on-farm improvements throughout the district. The Soil Conservation Service assisted farmers to plan, apply, and evaluate efficacy measures like irrigation scheduling, laser-leveling of fields, and lining ditches (Bathurst, 1988; wmidd.org, n.d.).

The improvements cost about $29 million, around $600 per acre. After the improvements, water was applied faster and more uniformly. There was less need for irrigation labor, yields increased, the amount of irrigation water used was reduced, and there was less deep percolation and runoff. The average water applied per acre decreased after the program (Bathurst, 1988).

Comparing the water use of the major crops in WMIDD before and after the improvements, there was an increase in crop consumptive use per acre. Diversion rates and return flow volumes were both reduced. The overall district consumptive use declined because of the reduction of 10,000 acres of irrigated cropland. The return flows from WMIDD are still too salty to be useful for downstream agriculture and are routed into the Cienega de Santa Clara not far from the Sea of Cortez. The U.S. thus does not receive credit under its Mexico delivery obligation for these flows (A. J. Clemmens et al., 2008).

17 California Cases

The following cases involve efficiency projects undertaken in the Imperial Irrigation District on behalf of both the MWD and SDCWA, and to a lesser extent, CVWD over the past nearly thirty years. IID is the largest diverter in the nation, with Colorado River water rights of approximately 3 maf/year. With its very large water supply, it has always been seen as a potential source of water for growing California municipal Colorado River users.

The initial MWD-IID efficiency agreement was made in 1988 when IID had outdated infrastructure from the early 1900s. The agreement was at least partially facilitated by a 1984 California State Water Resources Control Board (SWRCB) ruling that IID was wasting water in the form of large return flows into the Salton Sea. Although the SWRCB acknowledged that inefficient irrigation systems can contribute positively to groundwater recharge and enhance fish and wildlife resources, it considered the amount

15 The town of Yuma also had to move its drinking water intake from the Colorado River to one of the canals carrying water from Imperial Dam.
flowing into the sea to be waste. The ruling stemmed from a complaint brought by an IID landowner, John Elmore, whose land was slowly being inundated by the rising sea. The board ordered IID to take actions to improve its water conservation program (SWRCB, 1984).

Because of explosive growth in Los Angeles and San Diego over the last 30 years, IID has been an important potential source of water. Several efficiency-oriented transactions have occurred with MWD and SDCWA. At least some of these efforts to promote efficiency have reduced flows into the Salton Sea. These efficiency transactions have thus created another set of environmental and public health problems, also discussed below.

17.1 1988 Imperial Irrigation District – MWD Municipal Transfer

On the heels of the 1984 SWRCB ruling, in 1988, the IID and MWD came to a 35-year agreement to transfer approximately 100 kaf/year from IID to MWD (“Agreement for the Implementation of a Water Conservation Program and Use of Conserved Water,” 1988; Haddad, 1999). The 1988 agreement foresaw the need for California to ultimately live within its agreed 4.4 maf/year limitation once the Central Arizona Project became fully operational in the early 1990s. The agreement acknowledged that MWD would need to cut back from the 1.2 maf/year it had been taking from the Colorado River via its Colorado River Aqueduct to the 550 kaf/year that it would be allowed under a 4.4 maf/year limitation. IID agreed to take conservation measures to free up a targeted 100 kaf/year for MWD’s use with the entire effort to be financed by MWD.

IID agreed to pursue structural and non-structural measures including canal lining, operational reservoir and interceptor construction, gate installation and automation, and monitoring and management measures. The agreement set forth 24 separate projects. A Program Coordinating Committee consisting of three members, one appointed by each party and a third mutually agreed to by the original two members, was created to oversee the agreement. The committee was designed to coordinate, exchange information, and review and approve actions. IID agreed to construct all projects of the program within 5 years of the date of the agreement. MWD agreed to pay all capital costs, a one-time payment of $23m to cover indirect costs, annual costs of the non-structural components of the program, operation, maintenance, and replacement costs of the structural components during the term of the program. The 1988 agreement set the term at 35 years after the date of the final construction, which occurred in 1997, five years after the anticipated completion date. Prior to the 2003 amendments, which extended the program, the agreement would thus have ended in 2028.

The conserved water is taken by MWD at its upstream Lake Havasu pumping plant for the Colorado River Aqueduct and a commensurate reduction in deliveries are made to IID. Because PVID and CVWD sit between IID and MWD in California’s priority system, a “forbearance agreement” in which the intervening parties agreed to not call for the conserved water was needed. This additional agreement was signed in 1989, a year after the original agreement (IID, MWD, PVID, & CVWD, 1989; MWD & CVWD, 1989). That agreement also modified two of the original anticipated construction projects.

The 1988 agreement was amended in 2003 as part of the QSA documents, and again in 2007 and 2014. The 2003 amendments, among other changes, extended the agreement to December 31, 2041 the date for the termination of the Quantification Settlement Agreement. The 2007 amendments created a temporary Measurement Committee to advise IID on devices and techniques to measure the water
savings under the program. The 2014 agreement adjusted some efficiency projects and 107,820 af of savings in 2015 and 105,000 af/yr in the following years.

In 2000, IID released a lengthy report detailing all the construction efforts undertaken in accordance with the agreement. By 1999, these projects conserved over 100,000 acre feet per year (IID, 2000, 2015b). Under the agreement, five small operational reservoirs were constructed saving 7,000 af/year, 270 miles of laterals were lined saving 26,000 af/year, 34 lateral interceptors were built saving 30,000 af/year, 12-hour deliveries saved 30,000 af/year, and system automation saved 12,000 af/year for a total annual savings of 105,000 af. In 2015, MWD paid $11.7m to IID for costs associated with this effort.

17.2 1998 Imperial Irrigation District – SDCWA Transfer

From 1992-94 California experienced a severe drought and MWD imposed substantial water cutbacks on its participating members. After enduring these impacts, The San Diego Country Water Authority (SDCWA) decided to pursue its own more secure Colorado River supplies to avoid future cutbacks and thus began negotiations with IID. In 1998, IID and SDCWA signed an agreement to transfer conserved water from IID to SDCWA. The agreement set forth an annual transfer of between 130 kaf and 200 kaf to SDCWA to be delivered via MWD’s Colorado River Aqueduct, the only way to physically move the water. Initially, the conserved water was to be obtained by fallowing, but over time an on-farm efficiency program would provide 100% of the savings. SDCWA will provide $7 billion over 75 years for the needed efficiency improvements. The agreement was for a 45-year term with a potential 30-year renewal. The agreement anticipated the need for both California Environmental Quality Act (CEQA) and National Environmental Policy Act (NEPA) studies.

Multiple issues arose after the signing of the 1998 agreement, which lead to a complicated process to resolve long-standing water rights issues involving all of California’s Colorado River diverters. This process led to what is now known as the Quantification Settlement Agreement (QSA). The QSA, signed in 2003, consisted of over 40 documents dealing with the various rights of California’s Colorado River diverters. The signing was not without drama. Initially, the IID Board of Directors voted against the QSA16. To encourage reconsideration, the Department of the Interior then limited the amount of water IID could receive from the Colorado River. The IID finally agreed to the settlement, which authorized the transfer of more than 30 maf over many years to several entities.

In the QSA, SDCWA obtained a commitment from IID based on its 1998 agreement to obtain 200 kaf/year in water ramping up from approximately 20 kaf/year to the full amount in 2020. (In separate agreements, SDCWA also obtained the right to 77 kaf/year from the All-American Canal and Coachella Canal lining projects for a total amount of 277 kaf/year). From 2003 to 2018, the water savings will come from a combination of on-farm efficiency measures and fallowing. Starting in 2018, SDCWA will receive the entire 200 kaf/year from on-farm efficiency measures paid for by SDCWA through a program administered by IID.

A wide range of conservation measures are available for growers that result in reductions of water use. These measures include irrigation scheduling and event management, group deliveries, tailwater

16 The local community was alarmed that taking land out of production would negatively impact local businesses and jobs. Since every registered voter can vote for IID board members, the board was concerned with impacts to the entire community, not just farmers and landowners as is the case with the farmer-controlled PVID board.
recovery systems with extended delivery, pressurized irrigation, drip irrigation, sprinkler irrigation, level basin irrigation and surface irrigation optimization. Growers can also submit new measures. Participants must submit a proposal which is evaluated and then any improvements are overseen and verified for amount of water conserved and changes in deliveries. Efficiency conservation payments are made based on the amount of water conserved (IID, 2015b).

From 2003 to 2014, a total of 1,242,283 acre-feet of Colorado River water was conserved, and there have been 143,306 acre-feet of efficiency-based conservation and 125,213 acre-feet from system conservation measures. Over that same period, over $90.7 million has been paid out to farmers. A $50 million community fund was also established to mitigate negative socioeconomic effects of the transfers. (This fund dwarfs the $5m fund established for the 2004 MWD-PVID fallowing agreement, although the Imperial Valley is substantially larger in both population and area). The money has been used to compensate local businesses and organizations that are farm services providers. Funds are also distributed for job training and programs that provide economic stimulus for Imperial County (Moving Forward, 2015).

In additional to the SDCWA transfers, the environmental impact analysis for the QSA required 15 years of environmental flows to the Salton Sea, to be obtained by fallowing in the IID. These fallowing flows were to be ramped up from 5,000 af/year in 2003, peaking at 150,000 af/year in 2017, and dropping to 0 in 2018. A total of 800 kaf for the Salton Sea was to be provided.

The original agreement set forth a complicated per acre-foot water cost to be paid by SDCWA involving a base rate. In the 2007 amendment, the parties changed this computation to a simple escalating figure. In 2015 the payment was $624 per acre-foot (SDWCA, 2015). The QSA parties agreed to supply $133m to a Salton Sea mitigation fund, with the state agreeing to assume costs beyond that amount.

17.3 All-American Canal Lining Project

The All-American Canal runs 80 miles from Imperial Dam at the Colorado River, near the California-Mexico border, to Calexico, California in the Imperial Valley. The canal annually moves approximately 3 maf of water from the Colorado River for the Imperial Irrigation District (IID) and the Coachella Valley Water District (CVWD) (Stene, 1995; USBR, 2006).

Even before water delivery began in 1940, there were problems with seepage during construction, and the Bureau of Reclamation had to make modifications (i.e. intercepting drains, compacted lining, etc.) to mitigate the seepage issues (Stene, 1995). A lengthy section of the canal traverses porous sand dunes near I-5 and the U.S. – Mexico border (USBR, 2006). Leakage was so significant that it caused high groundwater along the canal, damaging nearby crops and property (Stene, 1995).

In the late 1990s, it was estimated that almost 68,000 acre-feet of water per year could be saved by reducing seepage in the middle section of the canal which flows through the dunes. Lining the canal became an important piece of the 2003 Quantification Settlement Agreement, which provided that “recovered water” be counted for municipal use. The State of California and San Diego County Water Authority covered the $300 million-dollar cost. A 23-mile section of the canal was ultimately lined to prevent seepage. Since 2009, when the project was completed, the annual water savings have been stipulated to be 67,700 acre-feet. This water is delivered to San Diego via MWD’s Colorado River Aqueduct (Moving Forward, 2015; USBR, 2006).
Although the lining provided new water for the US, it negatively impacted groundwater levels in Mexico. For decades, seepage from the canal provided groundwater supply for the Mexicali Valley in Mexico (A. J. Clemmens et al., 2008). In the Mexicali Valley, 67 percent of users received their total supply of irrigation water from wells (Cortez-Lara & Garcia-Acevedo, 2000). According to Calleros (1991), 60 percent of the annual recharge of the aquifer of the Mexicali Valley is due to subsurface flows. Groundwater in the valley irrigated over 33,000 acres and serviced over a hundred wells. Prior to the project, economic damages from the canal lining were assumed to be $80 million per year.

The Environmental Impact Statement commissioned by the Bureau of Reclamation noted that there would be impacts to groundwater and deterioration of groundwater quality in the northeastern Mexicali Valley. Seepage from the canal was estimated to provide 10 to 12 percent of the aquifer’s recharge. After construction, groundwater would ultimately decline to pre-canal levels. A lawsuit determined that the National Environmental Protection Act (NEPA) does not require mitigation within the territory of a foreign country (USBR, 2006).  

17.4 Coachella Valley Canal Lining

In the QSA, the San Diego County Water Authority obtained the rights to the conserved water from lining the Coachella Canal. The 123-mile Coachella Canal is a branch of the All-American Canal. Thirty-five miles of parallel, concrete-lined canal were constructed next to the original canal. It was projected that annual savings would be 26,000 acre-feet due to reduced seepage (SDCWA, 2015). Actual savings have been 30,850 acre feet per year (Moving Forward, 2015). The entire project cost $71 million and was funded by the San Diego County Water Authority and the State of California (CVWD, 2012).

There has also been extensive environmental mitigation. Fish were relocated from the canal system, and a sports fishery pond was constructed. Also, 17 acres of marsh were constructed, providing new habitat for wildlife. There are ongoing costs of monitoring habitats in Dos Palmas Oasis and restoring 352 acres of desert riparian habitat from the new canal construction (SDCWA, 2015).

17.5 Brock Reservoir

Brock Reservoir (formerly Drop 2 Reservoir) is an 8,400 acre-feet operational reservoir located near Drop 2 on the All-American Canal. Completed in 2010 after two years of construction, the reservoir is designed to capture at least 70,000 af/year of Colorado River flow that would otherwise be inadvertently delivered to Mexico due to rain events or other operational issues in the Imperial Irrigation District. The $172 million in funding was provided by the Southern Nevada Water Authority ($115 million), the Central Arizona Project ($28.6 million), and the Metropolitan Water District of Southern California ($28.6 million). On a pro-rata basis, these entities will receive 600,000 af of

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17 Even though NEPA did not require mitigation of the effects of the project in Mexico, critics have argued that the project itself was a violation of Resolution six of Minute 242 of the International Boundaries and Water Commission. Minute 242 stipulates that Mexico and the United States must consult each other before starting any project related to groundwater that could affect the other party (Calleros, 1991; Cortez-Lara & Garcia-Acevedo, 2000).
Intentionally Created Surplus Credits in Lake Mead at a cost of $287/af. These credits can be taken between 2016 and 2036 at a maximum rate of 65,000 af/year. In its first 4 years of operation, IID estimates that flows to Mexico were reduced annually by an average of approximately 70,000 af/year, and the reservoir also provided an additional 50,000 af/year of conservation benefits to IID (IID, 2015c).

The reservoir was not without controversy. Environmental NGOs provided a lengthy letter (Gillon et al., n.d.) detailing perceived shortcomings in the 2007 Environmental Assessment (Reclamation, 2007). In particular, the groups were concerned about impacts to the 23-mile “Limitrophe” section of the Colorado River where the Mexico-U.S. border is defined by the river. Operation of the reservoir would curtail occasional but important environmental flows past Mexico’s Morelos Dam. These flows were said to be important for native and resident bird populations in the lowest reaches of the Colorado River, the section that is often completely dewatered. The NGOs were not against efficiency improvements in general but noted that the efficiency improvement in this case would curtail valuable and scarce environmental flows.

17.6 Salton Sea Efficiency and Transfer Impacts

The Salton Sea is a large saline sink created in the early 1900s after the early Imperial Irrigation delivery canal (known as the Alamo Canal) was completely taken over by the Colorado River during a flood. For a period of 2 years from 1905 to 1907 the entire Colorado River flowed into the Sea until heroic efforts by the Southern Pacific Railroad forced the Colorado River back into its normal channel running to the Sea of Cortez (Hundley, 2009). Initially, the Salton Sea was about 500 square miles with the surface 200 feet below sea level. Due to high evaporation in the area, by 1920 it shrank to about 260 square miles and dropped 50 feet (IID, 2016). As IID return flows increased throughout the 20th century, it slowly increased to its present size of about 350 square miles.

The Salton Sea is the largest water body in California by surface area (approximately 35 miles by 15 miles), but not by volume (Lake Tahoe is the largest), and is a shallow body, approximately 50 feet deep at its deepest locations but with many parts between 1 and 5 feet deep. The Sea sits in a bowl that is about 250 feet below sea level. Over 650,000 people live in the area surrounding the Sea. Since its inadvertent creation, it has become a key stopover on the Pacific Flyway with over 400 bird species partaking of its extensive fish and invertebrate resources. There are also permanent bird populations at the lake and several federal and state listed endangered species. The Sea is actually not new: In geologic time, the Sea would come and go as the Colorado River shifted its channel to fill the sea and then shifted again to flow to the Sea of Cortez.

By 2020, return flows will drop to 700-800 kaf/year from 1.2-1.3 maf/year in the 1980s and 1990s due to efficiencies and transfers, a 40 percent decline (IID, 2016). The surface will drop by 20 feet, and its volume will drop by 60 percent with over 100 square miles of the lake bed exposed. (Cohen, 2014). The water will get 3 times as salty (“hypersaline”) and it is already very salty. In 2010, the Salton Sea had a total dissolved solids concentration 47 percent greater than the ocean (IID, 2010). The increasingly hypersaline conditions will kill most of the fish within five to seven years which will then seriously compromise the lake’s wildlife values. These changes are expected to also decrease local property values, and as the water level declines, dust from the exposed shorelines will pose a significant health problem in the future. The area already does not meet state and federal air quality standards.
As part of the 2003 QSA, IID, SDCWA, and CVWD agreed to be responsible for the first $133 million in Salton Sea environmental mitigation. The State of California agreed to be responsible for the remaining funding. In 2007, the California Natural Resources Agency released a $9 billion plan to restore the Salton Sea ecosystem, but to date the California legislature has declined to allocate funding. The Pacific Institute estimates that the cost of inaction ranges from $30 to $70 billion. IID has already made some mitigation efforts on behalf of the Salton Sea by constructing some managed marsh complexes for aquatic wildlife. As part of the QSA, IID was required to provide freshwater inflow totaling 1.5 maf from 2003 to 2017 to mitigate the rising salinity and declining lake levels in the Sea (IID, 2010). IID has utilized temporary fallowing to provide these inflows (See Temporary Fallowing Chapter).

As should be evident, this is a very complex issue tying together irrigation efficiency, water conservation, water transfers to cities, human health, and environmental issues. Preventing water from flowing into a saline sink is considered a classic method to conserve water. However, in this case, as in many others, the Salton Sea is a valuable resource with significant human and wildlife benefits. Reducing inflows to the sink creates several serious problems that have yet to be dealt with.

### 17.7 Coachella Valley Water District Efficiency Improvements

Formed in 1918, the Coachella Valley Water District (CVWD) delivers irrigation and domestic water to over 1,000 square miles in southern California and over 300,000 residents. The district receives some supplies from local groundwater and recycled water, but most is imported from the Colorado River via the Coachella Canal, a branch of the All-American Canal finished in 1948 (CVWD, n.d.). In the Coachella Valley, temperatures exceed 100 degrees Fahrenheit more than one-hundred days a year, and the frost-free season is over 300 days. ET rates exceed 74 inches of water per year and annual precipitation is only 3 inches (NRCS, 2006).

In CVWD, there are approximately 50,000 irrigable acres, consisting of mainly niche crops like table grapes, citrus, dates, peppers, and lettuce (NRCS, 2006). In 2010, water supplies in the Coachella canal included both CVWD’s 330 kaf/year Colorado River right and an additional 38 kaf/year of water from several IID and MWD transfers. (One of the transfers from MWD is an interesting exchange of State Water Project (SWP) supplies. Because CVWD cannot physically receive SWP water, CVWD takes delivery of MWD’s Colorado River water via the Coachella Canal, and MWD takes a like amount of SWP water in the Los Angeles area).

From early on, a highly efficient irrigation infrastructure was established in CVWD, including a pipeline distribution system with metered deliveries. Subsurface drains almost eliminated surface runoff. There are no downstream diversions, only runoff to the Salton Sea (Christian-Smith et al., 2010). The district has funded many improvements to deal with decreasing groundwater, which was falling as early as 1915, including large aquifer recharge facilities. Despite 3.3 maf of artificial recharge since 1973, demand for groundwater exceeds natural recharge and thus there has been a significant decline in the aquifer (CVWD, 2012).

Over the last 30 years, CVWD water deliveries for agriculture have decreased, but the amount of cropped areas has increased due to double cropping. CVWD water used for irrigation per acre per crop

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18 Some of these acres are double cropped, leading to acreage totals of near 70,000 acres (NRCS, 2006).
has also decreased and stabilized around 4 AF per acre annually. For agriculture, Coachella Valley
Irrigation District provides approximately 240 kaf/yr and groundwater pumping adds another 60 kaf/yr
to the local agricultural supply. A wide variety of irrigation methods are practiced throughout the valley
including furrow irrigation, border strip irrigation, micro-sprinkler irrigation, drip irrigation, and sprinkler
irrigation. Many producers use some form of irrigation scheduling, sometimes with site-specific data, to
determine when and how much water to use on the crop (NRCS, 2006).

In 2003, the Secretary of the Interior signed the Colorado River Water Delivery Agreement with
California’s Colorado River contractors as part of the Quantification Settlement Agreement. The
contractors had to reduce their use of river water in certain years to pay back the use of excess water in
2001 and 2002. To pay back their water, the CVWD instituted the Extraordinary Water Conservation
Program (ECP), which documented more than 75,500 acre-feet of water savings over five years at a cost
of $40 per acre-foot (Christian-Smith et al., 2010). Participating farmers saved an average of about 17%
compared to a historic baseline (Cohen, n.d.).

The program included irrigation scheduling, salinity management, and conversion to micro-irrigation.
CVWD paid for the programs and farmers could participate for free. These conservation methods had to
be in excess of the normal conservation improvements. They also enrolled some people using
groundwater even though that water source was not counted for payback purposes. Irrigation
scheduling involved determining the optimal timing and volumes of water to apply to each crop based
on soil type, irrigation method, soil moisture, irrigation uniformity, crop cover, fertilizer application, and
root depth. The salinity program enabled growers to refine their application of water for leaching,
targeting areas of fields identified as high in salinity (Christian-Smith et al., 2010).

In the summer of 2015, CVWD launched a program to convert an estimated 667 acres of dates and other
trees from flood irrigation to drip. The program hopes to save an estimated 2,000 af/yr. Rebates of
$1,500/acre will be made available for each acre converted, approximately 75 percent of the cost of the
conversion. For five years, half of the conserved water will stay in Lake Mead, and the other half will be
used for groundwater replenishment in the CVWD. After 5,000 acre-feet, has been stored in Lake Mead,
all additional water savings will be used to reduce aquifer overdraft. Through 2045, an estimated 60,000
af of water will be available for use in the Coachella Valley through the program (CVWD Launching
Agricultural Conservation Rebates 2015).
18 Appendix: Selected Literature

Irrigation efficiency is a confusing topic and much has been written over the years about it. The following are especially informative articles sorted by date.

**An Analysis of Water Salvage Issues in Colorado**  
*Colorado Water Conservation Board 1992*  
This paper provides a very thoughtful look at the issues of water salvage, water savings, and irrigation efficiency. It covers federal programs, legal standards, resource impacts, policy issues, and provides conclusions. It also contains copies of failed bills that attempted to modify Colorado law to address salvage and saved water. This paper was ahead of its time.

**Elimination of Irrigation Efficiencies**  
*Willardson, Allen and Frederiksen, 1994*  
This is an oft-cited paper that began the move to discuss water use in fractions rather than in efficiencies.

**Irrigation Performance Measures: Efficiency and Uniformity**  
*Burt 1997*  
The author is a professor at California Polytechnic State University and Director of the Irrigation and Research Training Center. He has been involved in multiple efficiency improvements efforts in the West, including the Grand Valley Water Users improvements. This lengthy and very detailed article covers many of the technical details surrounding efficiency improvements. The paper has a nice 11-point summary that is useful for the reader with less time and energy.

**Irrigation Water Balance Fundamentals**  
*Burt, 1999*  
This relatively short and mostly simple article provides some fundamental considerations on how to construct a water balance for an irrigation system.

**Beyond Irrigation Efficiency**  
*Jensen 2007*  
Jensen was a USDA Agricultural Research Service scientist. This paper provides a history of the publications on irrigation efficiency and contains a good section on terminology.

**Efficient Irrigation, Inefficient Communication: Flawed Recommendations**  
*Perry 2007*  
This Netherlands based researcher provides a history of the discussion around irrigation efficiency terminology. He proposes a fraction based terminology to improve water management.

**Memorandum, South Platte Task Force**  
*Castle and Caile, 2007*  
Castle and Caile provide a short, informative summary of a famous Colorado Supreme Court Case on Salvage Water.
Agricultural Water Conservation and Efficiency in California – A Commentary  
Burt, Canessa, Schwankl, Zoldoske, 2008  
This is a spirited critique of “More with Less: Agricultural Water Conservation and Efficiency in California” by Cooley et al., 2008.

Water Conservation in Irrigation Can Increase Water Use  
Ward and Pulido-Velazquez, 2008  
The authors are academics in the U.S. and Spain. This paper is another oft-cited source of information on how efficiency improvements can lead to increased consumption.

Conservation Potential of Agricultural Water Conservation Subsidies  
Huffaker, 2008  
The author is an economist who has written multiple papers on the irrigation efficiencies. He shows how conservation subsidies for improved efficiencies can lead to increased water use. While the middle part of the part involves many equations, the text portions provide ample material for thought.

Methods and Technologies to Improve Efficiency of Water Use  
Evans and Sadler (2008)  
This paper provides a thorough and readable overview of most topics normally covered under efficiency. The two authors are USDA Agricultural Research Service employees, one from Montana and one from Missouri. It provides a balanced view of the topic covering both pros and cons of the various techniques to save and conserve water.

Accounting for Water Use: Terminology and Implications for Saving Water and Increasing Productivity  
Perry, 2010  
Chris Perry is the co-editor in chief of a key journal in the field, Agricultural Water Management. In this short piece, he summarizes the attempt to redefine water use terminology in “fractions” terminology.

Water-Use Efficiency and Productivity: Rethinking the Basin Approach  
Gleick, Christian-Smith and Cooley, 2011  
Peter Gleick and co-authors provided a spirited defense of the need to pursue irrigation efficiency, even if no consumptive use is saved.

Agricultural Water Use in California: A 2011 Update, Center for Irrigation Technology  
California State University, Fresno  
This is a thorough and lengthy review of how agriculture uses water in California and what opportunities exist for improved operations.

Fictions, Fractions, Factorials and Fractures: on the Framing of Irrigation Efficiency  
Lankford 2012  
This UK researcher provides a complex look at the issues surrounding the use of” irrigation efficiency,” especially how it can be misused.
Water Conservation in Irrigation Agriculture: Trends and Challenges in the Face of Emerging Demands
Schaible and Aillery, 2012
This is a key USDA Economic Research Service summary of water use by agriculture. It contains an excellent section on irrigation efficiency.
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