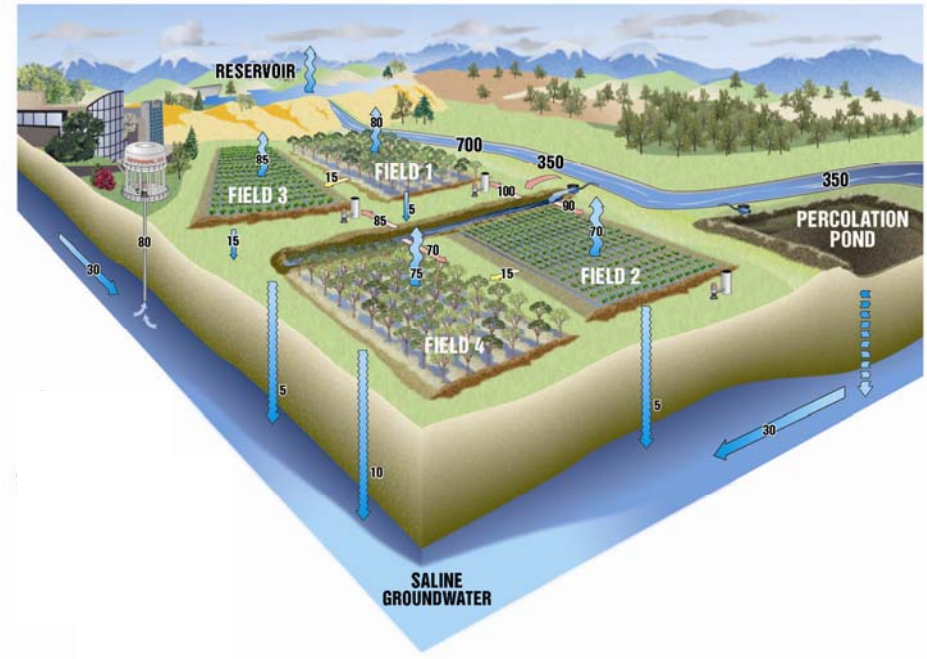
Agricultural Water Use in California:

A 2011 Update



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Agricultural Water Use in California
A 2011 Update

CIT Staff Report

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Agricultural Water Use in California: A 2011 Update
Executive Summary

Claims that California farmers are wasteful and inefficient when it comes to managing their water supplies are inaccurate. Despite assertions by some, large volumes of "new water" available through agricultural water conservation do not exist.

Agricultural Water Use in California: A 2011 Update is a thorough review of published research and technical data as well as State of California publications to assess the overall potential for agricultural water use efficiency to provide new water supplies. The report found that little potential exists for new water unless large swaths of agricultural land are taken out of production, which technically is not water use efficiency.

It is the intention of the author's that the paper serve as an important addition to the ongoing discussions about California water and specifically what decisions must be made to assure adequate supplies for the future. The scientific and technical information presented in this paper should provide a valuable tool in moving the discussions forward.

Among the study's key findings are:

- The estimated potential new water from agricultural water use efficiency is 1.3 percent of the current amount used by the state's farmers – about 330,000 acre-feet per year (at funding level PL-5 of the Department of Water Resources latest California Water Plan Update 2009). That represents about 0.5 percent of California's total water use of 62.66 million acre-feet.
- Groundwater overdraft of about 2 million acre-feet per year continues to be a serious problem in certain regions of California because of inconsistent and uncertain surface water supplies.
- Changes in irrigation practices, such as switching from flood irrigation to drip, have the effect of rerouting flows within a region (or basin) but generally do not create new water outside of the basin.
- Previous reallocations of agricultural water supplies for environmental purposes represent at least 5 percent of farm water diversions depending on water year.
- On-farm water conservation efforts can affect downstream water distribution patterns, with potential impacts on plants and animals, recreation, as well as human and industrial consumptive uses. The effects can be positive or negative and also inconsistent (e.g., on-farm conservation could reduce a city's water supply but improve the nonpoint source situation).

The study is the culmination of an effort by irrigation experts at the Center for Irrigation Technology to update the 1982 University of California Cooperative Extension report *Agricultural Water Conservation in California with Emphasis on the San Joaquin Valley* by David C. Davenport and Robert M. Hagan. Their report correctly framed the potential for agricultural water use efficiency and many of its findings are still relevant 30 years later.

Agricultural Water Use in California: A 2011 Update

1.0 Introduction

In the early 1980s water allocation and use in California were increasingly contentious issues. The State had suffered an extreme drought event in 1976-1977, drainage problems in the agricultural areas of the San Joaquin Valley were starting to materialize, the ecological health of the Sacramento-San Joaquin River Delta (the Delta) was becoming a concern, and California's population had increased to 23.7 by 1980 (up to 37.3 million in 2010[1]), driving increased urban and industrial water demands. The Central Valley Project (CVP) had progressed well since its inception but it was becoming clear that the State Water Project (SWP) with 4.2 million acre-feet (MAF) of annual contracted deliveries, was not going to be finished as originally envisioned and would only deliver about 50 percent of the total contracted amounts of water for the foreseeable future.

In response to the lack of understanding and data about agricultural water use, *Agricultural Water Conservation in California with Emphasis on the San Joaquin Valley* was published in 1982. It was written by David C. Davenport and Robert M. Hagan (DH Report) and published by the Department of Land, Air, and Water Resources at the University of California at Davis. The introduction describes the purpose for writing the DH Report as:

> *Water conservation is suggested by some as being a totally adequate solution to overcoming the state's water deficit (now reflected mainly as groundwater overdraft). Others feel conservation is only a partial solution, and still others believe that past and present conservation practices have reached their practical limits, so the state's projected deficit can only be met by further development and diversion southward of northern California water. These divergent views occur partly because of special interests, but mainly because of 1) misunderstandings over the uses, reuses, and final destinations of water, and 2) disregard for the impacts of water conservation/development actions on economic and environmental factors. This report attempts to clarify these issues.*[2]

Almost 30 years later the problems of water management in California are more serious, proposed solutions can be controversial and *misunderstandings over the uses, reuses, and final destinations of water* in agriculture continue.

The DH Report analyzed the potential for improved on-farm irrigation efficiency to decrease diversions to agriculture and thus, to develop **new water** – new water in the sense that agriculture could grow the same food/fiber with less water so any water savings would be "released" back to the system for use by municipal and industrial (M&I) users or the environment. One contention in 1982 (as it is now) was that increased on-farm efficiency by agriculture could reduce or negate the need for developing new water supplies.

[1] Farm Financial Indicators, State Fact Sheet - 2010, Economic Research Service, U.S. Department of Agriculture (see http://www.ers.usda.gov/StateFacts/CA.htm#FFI). 10/27/2011.

[2] Davenport, David C. and Robert M. Hagan. Agricultural Water Conservation in California, With Emphasis on the San Joaquin Valley. Department of Land, Air, and Water Resources. University of California at Davis. Davis, CA. October 1982.

There are several other issues associated with diverting water to agriculture, and how agriculture uses the water, that are the potential results of improving on-farm irrigation efficiency. These include:

- Reduced aquifer overdraft and possible resulting land subsidence
- Reduced impacts on natural habitats
- Reduced nonpoint source water pollution
- Reduced energy use (although it will be illustrated that increasing irrigation efficiency may lead to increased energy use)

The purpose of this paper is twofold: 1) to reintroduce the concept of recoverable and irrecoverable inefficiencies discussed in the DH Report to dispel the myth of gross irrigation inefficiency by California agriculture; and 2) to provide a summary discussion of the major contemporary issues and impacts regarding agricultural water use in California and in so doing, to provide a broader perspective of the role agriculture is playing to help solve the pressing water issues facing California.

The paper is divided into five sections:

Section 1 begins with an introduction that provides the reader with key definitions used throughout the paper (see Box A).

Section 2 discusses the volume of agriculture's consumptive water use and the potential to reduce that volume of water.

Section 3 points out some of the more important impacts that can result from water diversions for irrigation and identifies actions agriculture has taken, and continues to take, to help alleviate these impacts.

Section 4 looks to the future role agriculture can play in moving beyond a question of strict irrigation efficiency to a more holistic view of agricultural water use and its impacts.

Section 5 provides a summary and conclusions. Appendix material includes a list of acronyms, references, a table of irrigation system characteristics, energy consideration examples and the conclusions from the DH Report.

2.0 Agricultural Water Consumption

2.1 How Much Water Does Agriculture Use in California?

Depending on who is doing the talking, there have been many numbers and types of numbers used to portray the relative amount of water used by California agriculture. Two common ways are providing a comparative percentage (to other water uses) or reporting the actual volume of water used.

If a comparative percentage is used, the answer will depend on the statistical basis used to calculate the percentage. The 2009 Update to the California Water Plan (CWP) includes Volume 5-Technical Guide containing the raw data developed and used in preparing the CWP. Table "PA-eight-year balances 3-9-11" in the guide provides estimates of the eight-year average **dedicated water** (see Box A) balances in California for 1998 through 2005 and is partially summarized in Table 1 (all numbers are reported in million acre-feet per year – MAF).

Box A – Key definitions

Irrigation water management terminology may be unfamiliar to the reader. The following definitions will help provide a better understanding of the discussions in this paper.

consumptive use – a use of water that removes the water from the system so that it cannot be recovered for reuse by some other entity. Consumptive uses may be beneficial or non-beneficial. A beneficial consumptive use would be crop evapotranspiration.

dedicated water – as defined by the Department of Water Resources (DWR) is "water distributed among urban and agricultural uses, used for protecting and restoring the environment, or storage in surface water and groundwater reservoirs. In any year, some of the dedicated supply includes water that is used multiple times (reuse) and water held in storage from previous years. This is about 40 to 50 percent of the total annual water supply received from precipitation and imported from Colorado, Oregon, and Mexico." Context: Water Portfolio"[1]

Dedicated water includes water flowing in the Wild and Scenic Rivers. Many partially used (Eel) or unrestricted (Van Duzen) rivers could have been significantly diverted for use by M&I and/or agriculture. However, these waters have been dedicated by law to the environment. Other examples of dedicated water are the 800,000 acre-feet/year reallocated back to the environment by the Central Valley Project Improvement Act (CVPIA)[2] and the 647,000 AF/year reallocated back to the Trinity River for restoration of that river's fishery.[3, 4]

evapotranspiration (ET) – the amount of water transpired by plants, retained in plant tissues, and evaporated from plant tissues and surrounding soil surfaces.[1] **Crop evapotranspiration** is specifically denoted by the acronym **ETc**.

irrigation efficiency (IE) – the ratio of applied water that is beneficially used to the total amount of applied water. In some cases, improved irrigation efficiency can prevent or reduce irrecoverable fractions of water and thus, affect water conservation. Major beneficial uses of applied water include crop evapotranspiration, leaching for salinity control, and possibly as an aid in field preparation.

new water – defined in part by DWR as "water that is legally and empirically available for a beneficial use; can be developed through many strategies such as capturing surplus water, desalination of ocean water, and reductions in depletions. (Same meaning as real water)."[1]

recoverable fractions/irrecoverable fractions – in the context of this paper, these are the fractions of applied irrigation water that flow off a field and result in no benefit to the crop or field (i.e., maintaining soil productivity). These fractions can include surface runoff, immediate evaporation during the irrigation event, or percolation below the active root zone of the field. These fractions may be recoverable for reuse (e.g., immediately as a surface runoff flow directed to another field or later as groundwater pumped from an aquifer) or irrecoverable (i.e., they become a depletion of water).

water conservation – any act that serves to prevent an irrecoverable fraction of water and/or reduces potential alterations of water quality that would prevent some specific type of subsequent reuse.

1. California Water Plan Update 2009 Glossary. Department of Water Resources. Resources Agency. State of California
2. Central Valley Project Improvement Act, Title 34, Public Law 102-535, October, 1992.
3. Record of Decision. Trinity River Mainstem Fishery Restoration. Final Environmental Impact Statement/Environmental Impact Report. U.S. Department of the Interior. December 2000
4. Westlands Water District vs. U.S. Department of Interior. Case Nos. 03-15194, 03-15289, 03-15291 and 03-15737. Argued and Submitted Feb. 9, 2004 - July 13, 2004, United States Court of Appeals, Ninth Circuit

If the basis for the discussion is water consumptively used by only agricultural and M&I users, then agriculture's share would be estimated in the range of 80 percent of the total (24.66 MAF / (24.66 MAF + 6.51 MAF). However, if the percentage is based on dedicated water, which includes environmental uses, then agriculture's share is more in the range of 40 percent (24.66 MAF / 61.24 MAF).

Whatever basis is used to describe agriculture's consumptive water use, the actual volume of consumptive use by agriculture remains the same. In 2007 there was roughly 8 million irrigated acres in California.[3] If society wants/needs this mix of food and fiber production, or if the normal flow of business decides in favor of this level of production, then the result is a large volume of consumptive plant water use – evapotranspiration. This is simply a result of the physics of irrigated crop production.

[3] "Historical Highlights: 2007 and Earlier Census Years." Table 1, 2007 Census of Agriculture. California State and County Data. AC97-A-5. National Agricultural Statistics Service. U.S. Department of Agriculture. December 2009.

The purpose of using total dedicated water to calculate the comparative percentage is not to make agriculture's water use look somehow "better." Rather it is to remind us that 1) the environment is a water user, just as agriculture and M&I are users; 2) all users have legitimate needs; and 3) the real challenge is providing the most effective water stewardship by all users.

An important goal of this report is to affirm that the issue is not what total percentage of water agriculture diverts or consumes, it is whether or not agriculture is providing good stewardship over its allocation. As noted earlier, the DH Report was published in part as a response to "misunderstandings" that were leading to claims of water wastage within agriculture.[4] These types of claims continue along with reference to solutions that could be quickly or easily implemented.[5] [6] The authors of this paper, as did Davenport and Hagan, reject these claims and explain why based on the principle of recoverable versus irrecoverable fractions.

Table 1 – Summary of estimates of the eight-year average dedicated water balances in California for 1998 through 2005

MILLION ACRE-FEET	EIGHT-YEAR AVERAGE		
	Applied Water	Net Use*[1]	Depletion**[1]
Total Urban Use	**8.75**	**6.53**	**6.51**
Total Agricultural Use	**33.22**	**25.80**	**24.66**
Environmental Uses			
Instream			
Applied Water	7.17		
Outflow		2.69	2.68
Wild & Scenic			
Applied Water	26.01		
Outflow		20.12	20.12
Required Delta Outflow			
Applied Water	6.64		
Outflow		6.64	6.64
Managed Wetlands			
Applied Water	1.46		
Evapotranspiration of Applied Water		0.62	0.62
E&ET and Deep Percolation to Salt Sink			
Outflow		0.26	
Conveyance Applied Water	0.07		
Conveyance Evaporation and ETAW		0.00	0.00
Conveyance Deep Percolation to Salt Sink		0.00	0.00
Conveyance Outflow		0.00	0.00
Total Managed Wetlands Use	1.53	0.88	0.63
Total Environmental Use	**41.36**	**30.33**	**30.06**
TOTAL USE AND OUTFLOW	**83.33**	**62.66**	**61.24**

* Net water use (demand) – defined by DWR as "The amount of water needed in a water service area to meet all requirements. It includes the consumptive use of applied water, the irrecoverable water from the distribution system, and the outflow leaving the service area. It does not include reuse of water within a service area. *See also* applied water use. Context: Water Portfolio"

** Depletion – defined by DWR as "The quantity of water consumed, discharged to a salt sink within a service area, or moved outside the service area and no longer available as a source of supply within the service area. Context: Water Portfolio"

1. California Water Plan Update 2009 Glossary. Department of Water Resources. Resources Agency. State of California

Reference:

PA_eight_year_balances_3-9-11.XLSX. Bulletin 160 Update 2009 Volume 5 - Technical Guide. Department of Water Resources. Resources Agency. State of California @ http://www.waterplan.water.ca.gov/technical/cwpu2009/

[4] Davenport, David C. and Robert M. Hagan. Agricultural Water Conservation in California, With Emphasis on the San Joaquin Valley. Department of Land, Air, and Water Resources. University of California at Davis. Davis, CA. October 1982.

[5] Cooley, Heather, J. Christian-Smith and P. Gleick. More with Less: Agricultural Water Conservation and Efficiency in California. Pacific Institute. Oakland, CA: September, 2008.

[6] Cooley, Heather, J. Christian-Smith, P. Gleick, M.J. Cohen and M. Heberger. California's Next Million Acre-Feet: Saving Water, Energy, and Money. Pacific Institute. Oakland, CA: September, 2010.

2.2 The Key Concept – Recoverable versus Irrecoverable Fractions

The DH report lists thirteen conclusions that, with updated numbers and minor caveats, the authors feel are still valid today (see Appendix E). Conclusion 11 is particularly important with regard to the question of agricultural water use (emphasis added - Ed.):

> *It is erroneous to conclude that a particular irrigation system such as sprinkler or drip requires only a fraction of the water applied by systems such as furrow or border-strip...Because of the recoverability and reusability of field runoff and deep percolation, it is even more erroneous to conclude that decreasing runoff and deep percolation will proportionally reduce the state's net water deficit. Therefore, statements suggesting a 10-50% potential savings in agricultural water conservation by improving irrigation application systems are a disservice to the people of California because water policy and action programs based on such statements will substantially underestimate the state's needs for future water supplies* [7]

The main purpose of the DH Report was to explain the concept of recoverable versus irrecoverable fractions (note the DH Report used the term "losses" instead of "fractions"). When irrigation water is applied to a field to satisfy the needs of a crop, that water can end up in several different places sometimes termed the **destinations** or **fates** of applied water. Many scientists discuss the issue using the term **fractions** and this paper utilizes that terminology as well. These resulting fractions include:

- Storage in the root zone for extraction by the crop to satisfy evapotranspiration demands.
- Immediate evaporation during the irrigation event.
- Immediate surface runoff during or soon after the irrigation event.
- **Deep percolation** – water infiltrating the soil, but moving below what is considered the effective root zone and thus, not available for crop water use (also see Box B).
- **Leaching** for salt control – water that infiltrates the soil and then moves below the effective root zone and carries excess salts out of the root zone. Leaching is intentional deep percolation that is required to maintain root zone soil salinity below levels harmful to crop production or quality.

Different types of terminology can be used to further classify these fractions. They can be **beneficial** or **non-beneficial** fractions and also **consumptive** or **non-consumptive** fractions. Beneficial refers to whether the fraction furthers the purpose of the water's use, which in agriculture is to produce a profitable crop. For example, water stored in the root zone for use by the crop as a result of irrigation is a beneficial fraction. The term consumptive refers to whether the fraction is water that is left in the system (physically in or on the soil, in a useable aquifer, or in a canal, stream, river, etc.) or not. Examples of consumptive fractions are evapotranspiration by the crop and immediate evaporation during an irrigation event.

Soil water stored and then used for crop ETc (see Box A) is both a beneficial and a consumptive fraction. Deep percolation to maintain soil productivity that is beyond the required leaching fractions is considered a non-beneficial fraction but may be non-consumptive if the percolation moves to a useable aquifer.

[7] Davenport, David C. and Robert M. Hagan. Agricultural Water Conservation in California, With Emphasis on the San Joaquin Valley. Department of Land, Air, and Water Resources. University of California at Davis. Davis, CA. October 1982.

Non-beneficial fractions at the field level are the result of irrigation inefficiencies, therefore an obvious goal for the irrigator is to minimize non-beneficial fractions. However, the key distinction is whether surface runoff or deep percolation resulting from irrigation on one field, which would be considered an inefficiency, can be recovered and reused on another field or farm, for M&I purposes or for the environment. Thus, these **recoverable fractions** aren't true depletions – rather they are water that can be used at a different place and different time than the original diversion. In fact, recoverable fractions may be recovered and reused several times and possibly for different purposes – e.g. surface runoff from an irrigation event may support wetland habitats; deep percolation from an irrigation event can move to an aquifer and become an M&I water supply.

Irrecoverable fractions are the only true actual depletions resulting from inefficiencies (i.e. water volumes that are not available for reuse). These depletions occur when surface runoff or deep percolation resulting from irrigations move to another water body that is unusable for some reason. (It should be noted that during the runoff process there will be additional depletions such as free water surface evaporation and possibly consumptive uses by aquatic plants, streambank weeds and trees; these are considered minor in the context of this discussion.)

Box B
Deep percolation and irrecoverable fractions

There are those who would argue that some deep percolation losses, even though they might end up in a usable aquifer, are still considered irrecoverable fractions due to the amount of time it takes for the water to reach a "reusable state" (see for example CALFED [1]). It would be a more convincing argument if a specified time frame or a particular basin was mentioned. Conjunctive water management in the San Joaquin Valley has been practiced for decades and is being expanded. There are areas of California where the water supply of municipal and industrial and agricultural users is completely dependent on water percolating into an aquifer from rivers, rainfall, and excess irrigations (e.g., Salinas Valley and Santa Maria Valley, before the Coastal Aqueduct). In some areas it may take a significant amount of time for water to percolate below the root zone and reach a useable aquifer. This is an on-going process with patterns of use that have taken more than decades to develop. Seasonal or systemic overdraft of an aquifer can result in land subsidence (land sinking) and loss of aquifer storage and should be avoided, whenever possible.

1. CALFED. Final Report - Water Use Efficiency Comprehensive Evaluation. CALFED Bay-Delta Program Water Use Efficiency Element. August 2006.

The DH Report points out two facts that are central to the discussion of agricultural water use efficiency:

1. **Surface runoff, a non-beneficial fraction at the field level, may be captured and reused**
2. **Deep percolation above required leaching fractions, another type of non-beneficial fraction, may move to a usable aquifer**

Water moving off a field at the surface can be picked up, stored, and reused by agriculture, M&I, or the environment. In much the same manner, deep percolation from excessive irrigations (or just the need for leaching for salt control) can move to a usable aquifer where it can be reused through groundwater pumping. Many individual farms, as well as entire agricultural areas, rely on water that is pumped to the surface from an aquifer as their major source of water for the purpose of irrigation. Water percolates to an aquifer from natural rainfall, from nearby rivers and streams, unlined canals, or from spreading basins. Deep percolation from inefficient irrigations, while perhaps a concern because of energy use and water quality, will also return water to the aquifer and be available for future groundwater pumping. A prime example of a large agricultural area such as this is the Salinas Valley where percolation from rainfall, the Salinas River, and streams from mountains on both sides of the valley, along with deep percolation from irrigation, is pumped (or re-pumped as the case may be) to irrigate agricultural fields.

However, non-beneficial fractions may also be irrecoverable and would be considered true depletions. Examples are:

- Water that immediately evaporates during the irrigation event itself (although this evaporation may reduce ETc during the irrigation and thus, this loss may be offset somewhat in certain situations).
- Surface runoff that goes to the ocean or other highly saline water body.
- Deep percolation that moves to an aquifer that is economically unusable due to poor water quality (**salt sinks**), or possibly even depth (due to the cost of pumping from that depth)

In summary, the only true depletions (losses) in terms of water volumes are irrecoverable fractions. **All water users should continually strive to minimize irrecoverable fractions.** However, recoverable fractions are just that, recoverable. There may be other undesirable impacts, which will be discussed in later sections of this paper, and the range of uses (e.g., irrigation, recreation, human consumption, stock watering) may be diminished with each reuse and recovery, but nonetheless, they are available.

2.3 Recoverable versus Irrecoverable Concepts Illustrated

Figures 1 through 4 visually demonstrate the concepts of recoverable and irrecoverable fractions. The two sets of illustrations are intended to depict two major types of agricultural water use areas in California:

1. Figures 1 and 2 – a **flow-through** system before and after on-farm efficiency improvements
2. Figures 3 and 4 – a **closed-end** system before and after on-farm efficiency improvements

Improving on-farm irrigation efficiency is discussed at length in Section 2.4.3. Some major options include:

- Improving management of the individual irrigation events. This can occur with increased knowledge of the operating characteristics of the irrigation system or use of some for of irrigation scheduling in order to better match the irrigation to actual crop water needs
- improving maintenance of the system, especially micro and sprinkler systems, so the system operates at the intended efficiency
- changing the irrigation system type to one better adapted to crop and field conditions. An example would be switching to a sprinkler or micro system on a field that has two or more soil types (thus, making it difficult to irrigate uniformly with a flood-type system).

When examining these illustrations the reader is alerted to the following:

- Each field will have a red, numbered arrow depicting its water supply (field inflows)
- Each field will have a blue, numbered arrow pointing up depicting the crop water use (crop evapotranspiration)
- Each field will have a dark blue, numbered arrow pointing down depicting the deep percolation from that field
- Each field will have a yellow, numbered arrow at field bottom depicting surface runoff from the field
- In many cases, the surface runoff from one field will be part of another field's water supply
- Values are for illustration purposes only. Assume they represent total acre-feet for a season

Figure 1 – A flow-through system before on-farm efficiency improvements

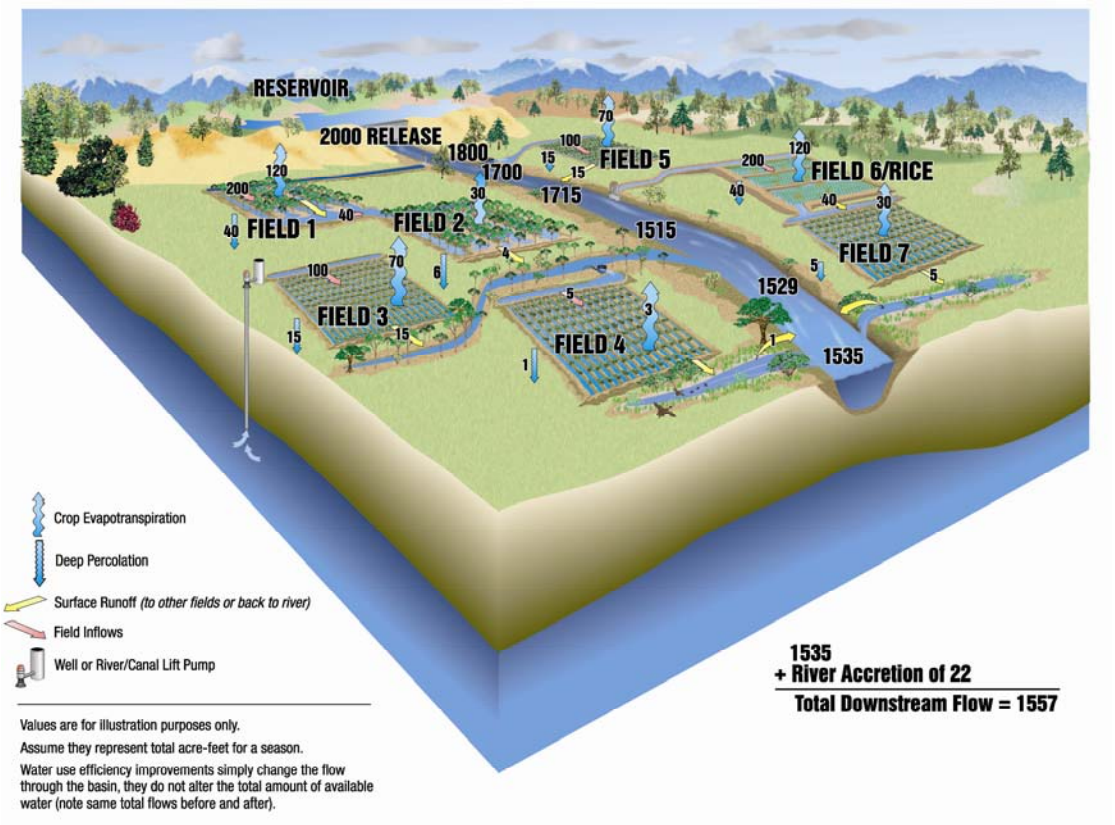
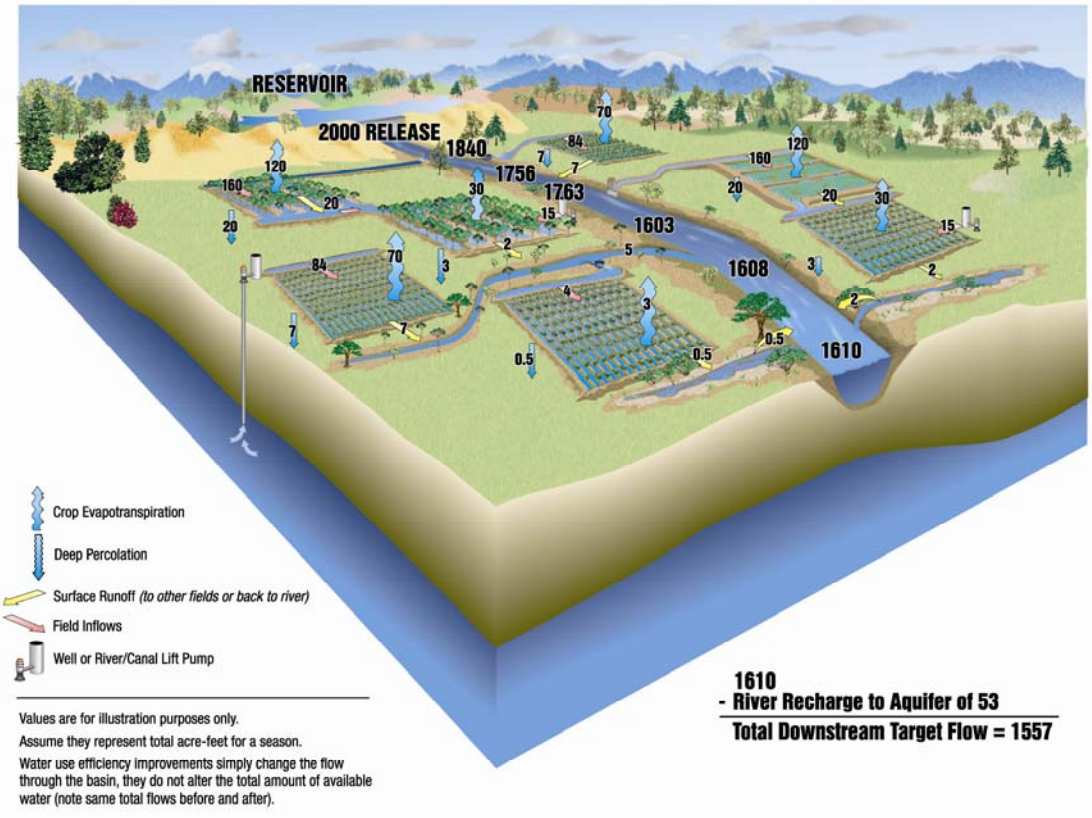


Figure 2 – A flow-through system after on-farm efficiency improvements



2.3.1 A Flow-through System Before and After On-farm Efficiency Improvements

Figures 1 and 2 are based on examples contained in the CALFED Record of Decision[8] and are representative of the flow paths in the Sacramento Valley. Water is diverted from the river to various agricultural areas. There are few areas of underground or surface salt sinks in the valley and thus, water that is diverted is largely consumed by crops or other plants, stored in the aquifer, or moves back to the river. A key assumption of the before and after scenarios depicted by Figures 1 and 2 is that the aquifer is kept in balance. Thus, there is the assumption in the before scenario of a movement of groundwater to the river (**accretion**), while in the after scenario it is assumed that the river recharges the aquifer to balance the increased well pumping and decreased deep percolation. (Tables 2 and 3 summarize the various destinations of diverted water and include summary statistics if the accretion/recharge is ignored.)

Examples of Recoverable Fractions – An example of a recoverable fraction in Figure 1 is the 40 units of runoff that flows off Field 1 and becomes Field 2's entire irrigation supply before improvement of efficiencies. After improvement (see Figure 2), Field 2 receives only 20 units of water from Field 1 and now has to pump 15 units from the aquifer. The same situation occurs at Fields 6 and 7. Initially, Field 6 produced 40 units of runoff that was Field 7's entire water supply. After improving on-farm efficiencies, Field 7 only receives 20 units of runoff from Field 6 and now pumps 15 units from the aquifer.

These situations can be characterized as shifting an indirect use of recoverable fractions to a (more managable) direct use of controlled water supplies. The concept is that while Field 2 is getting an irrigation water supply from Field 1, the underlying assumption is that Field 2 could use that flow efficiently (in terms of irrigation efficiency or crop development) whenever it arrived from Field 1. This may require constructing and maintenaning an on-farm reservoir at Field 2 to buffer the timing and amount of flows from Field 1. There may be water quality issues with the runoff to Field 2 (e.g., increased temperature, adsorbed chemicals on sediments, crop diseases, weed seeds). In the after scenario, 15 units of the 35-unit total supply is is now pumped and it is assumed on demand (i.e., whenever Field 2 needs it). The downside is the capital and operating costs of the well and the possibility of creating significant overdraft in the local aquifer. Note again the assumption that in the after condition, the river is recharging the aquifer by 53 units due to the increased pumping and thus, the aquifer remains in balance.

Examples of Third-Party Impacts – There are also impacts to the small stream that captures runoff from Fields 2 and 3, the stream that captures runoff from Field 7, and some wildlife habitat at the bottom of Field 4. Before improving irrigation efficiency, there were up to 19 units of water flowing in the stream fed by Fields 2 and 3 supporting some habitat. Afterwards, this has been reduced by about 50 percent and it is assumed the habitat will be adversely affected due to the decreased amount and quality of the water. The same effects can be seen at the bottom of Fields 4 and 7 – as runoff is reduced the habitat previously supported by it will be negatively impacted.

Also, one of the fields in this example is rice. Irrigated rice fields have been proven to provide much needed waterfowl habitat.[9] If this crop was shifted to one with less seasonal ETc and/or no standing water in order to leave more water in the river, this habitat would be reduced or lost altogether.

Total Impacts of Improving On-Farm Efficiencies – This example demonstrates that improving on-farm irrigation efficiency may beneficially affect flows and quality in the river within the use area. However, the example assumes that the groundwater recharge from the river after on-farm efficiency improvements occurs at the end of the use area (Reach 7 is at 1,610 minus 53 units recharge equals 1,557 unit flow at the end, the same as the initial situation). What if that recharge occurred farther up in the system – i.e., the recharge is continuous from the river throughout the use area? Then, the increases in river flows noted in Table 2 would be lower while still resulting in impacts to other users.

[8] CALFED. Final Report - Water Use Efficiency Comprehensive Evaluation. CALFED Bay-Delta Program Water Use Efficiency Element. Aug 2006.
[9] Hill, James, "Integrating Rice Cultural Practices and Waterfowl Habitat", Department of Agronomy and Range Science, University of California, Davis, September, 1999 @http://www.plantsciences.ucdavis.edu/uccerice/DUCKS/waterfwl.htm

Table 2 – Flows and uses in system before on-farm irrigation efficiency improvements (Figure 1)

FIELD	Field Inflows			Field Outflows			Field IE
	River	Well	Runoff	ETc	Runoff	Deep	%
1	200			120	40	40	60
2			40	30	4	6	75
3		100		70	15	15	70
4			5	3	1	1	60
5	100			70	15	15	70
6	200			120	40	40	60
7			40	30	5	5	75
River recharge to aquifer	-22						
Runoff return to river	-35						
Net river outflow	443	100	85	443			81
Net river outflow w/o accretion	465	100	85	443			78
Flow reach 2	1,800						
Flow reach 3	1,700						
Flow reach 4	1,715						
Flow reach 5	1,515						
Flow reach 6	1,529						
Flow reach 7	1,535						
River at end	1,557						

Table 3 – Flows and uses in system after on-farm irrigation efficiency improvements (Figure 2)

FIELD	Field Inflows			Field Outflows			Field IE
	River	Well	Runoff	ETc	Runoff	Deep	%
1	160			120	20	20	75
2		15	20	30	2	3	86
3		84		70	7	7	83
4			4	3	0.5	0.5	75
5	84			70	7	7	83
6	160			120	20	20	75
7		15	20	30	2	3	86
Aquifer recharge to river	53						
Runoff return to river	-14.5						
Net river outflow	443	114	44	443			80
Net river outflow w/o recharge	390	114	44	443			88
Flow reach 2	1,840						
Flow reach 3	1,756						
Flow reach 4	1,763						
Flow reach 5	1,603						
Flow reach 6	1,608						
Flow reach 7	1,610						
River at end	1,557						

Box C – Third-party impacts

Third-party impacts occur when the actions of one or more users create impacts on others not directly involved with those actions. Third-party impacts are real and are noticed by the courts. A recent injunction prohibiting the implementation of one aspect of the Delta Smelt Biological Opinion specifically noted that the National Environmental Policy Act (NEPA) requires that "major Federal actions significantly affecting the quality of the human environment" need to have an Environmental Impact Statement. [1] The injunction was issued in part because "The evidence establishes significant detrimental effects visited on the quality of the human environment by implementation of the BiOp's RPA Actions, which impose substantial restrictions on the water supply to California, solely to protect the delta smelt." [2]

1. Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project (CVP) and State Water Project (SWP), document 81420-2008-F-1481-5. Fish and Wildlife Service. California-Nevada Region. U.S. Department of Interior: December 2008.
2. Findings of Fact and Conclusions of Law RE Plaintiffs Request for Injunctive Relief Against Implementation of RPA Component 3, Eastern District of California, United States District Court, Case 1:09-cv-00407-OWW-DLB, Document 1013, August 31, 2011.

Thus, this example also identifies an important challenge for water management in California – balancing the benefit/cost ratio to the agricultural enterprises while providing benefits to the environment and addressing any third-party impacts. In this example there are benefits to the river habitat and fishery from improved on-farm efficiency but also an immediate third-party impact to some streamside habitat within the use area. There is also the possibility of loss of waterfowl habitat if cropping patterns or irrigation are significantly changed.

Table 4 – Flows and uses in system before on-farm irrigation efficiency improvements (Figure 3)

FIELD	Field Inflows			Field Outflows			Field IE
	Canal	Well	Runoff	ETc	Runoff	Deep	%
1	100			70	20	10	70
2	100			70	20	10	70
3	70		20	70	0	20	78
4	70		20	70	0	20[1]	78
Canal Loss						10	
City Pumping		80					
Natural Recharge						30	
Area Totals	340	80	40	280	40	100[2]	80[3]

1. These 20 units are lost to a salt sink
2. 80 units usable, thus aquifer is in balance
3. 80% area IE = 280 ETc / 350 total canal diversion

Table 5 – Flows and uses in system after on-farm irrigation efficiency improvements (Figure 4)

FIELD	Field Inflows			Field Outflows			Field IE
	Canal	Well	Runoff	ETc	Runoff	Deep	%
1	100			80	15	5	80
2	90			70	15	5	78
3	85		15	85	0	15	85
4	70		15	75	0	10[1]	88
Canal Loss						5	
City Pumping		80					
Natural Recharge						30	
Area Totals	345	80	30	310	30	70[2]	89[3]

1. These 10 units are lost to a salt sink
2. 60 units usable, thus aquifer is in overdraft
3. 89% area IE = 310 ETc / 350 total canal diversion

The examples shown in Figures 1 - 4 and Tables 2 - 5 serve as bookends for the different types of conditions that exist both above and below the Sacramento-San Joaquin Delta. They are simplified versions of reality (e.g., depletions due to immediate evaporation or consumptive use by phreatophytes in the drainage waterways are ignored and there is no consideration of any deep percolation as required, and beneficial leaching fraction). Any number of examples could be constructed and indeed, any number of examples exist (e.g., a bathtub basin such as the Salinas Valley).

However, both examples illustrate the concept of recoverable fractions and their impact on irrigation efficiency when the spatial scale is expanded (i.e., instead of one field, we consider the entire use area). Looking at Table 2 it is seen that the individual field efficiencies range from 60-75 percent while the efficiency of the use area as a whole (assuming the aquifer is kept in balance) is 81 percent. In Table 3, the on-farm efficiencies have been improved to a range of 75-86 percent but the use area efficiency is still about 80 percent (because of the assumption of recharge to aquifer from the river).

The illustrations in Figures 3 and 4 also demonstrate the concept. Table 4 indicates field efficiencies ranging from 70-78 percent but a use area efficiency of 80 percent. Improved efficiencies result in a range of 78-88 percent on-farm efficiency with a use area efficiency of 89 percent also resulting in a 20-unit overdraft of the aquifer (Table 5).

Box D – Unintended groundwater exchanges

A 2003 model of the Friant Water Management and Groundwater revealed approximately 65,000 - 70,000 AF/yr of unintended groundwater exchange occurs annually between adjacent water districts receiving surface water supplies and the Pixley Irrigation District (PID) which is largely dependent on local groundwater. The continued augmentation to PID's groundwater supply from outside the district appears to hold true over the approximate 30-year modeling period spanning 1971 through 1999.

This is a prime example where improving on-farm efficiency and/or lining irrigation canals in one district would directly affect the supply of a nearby district. As shown in this case, recoverable losses are picked up somewhere else and reused. Over time, local agricultural communities have become depend on these recoverable losses as part of their long-term water supply source. In this case, reducing or limiting groundwater recharge would have a negative effect on the operations within the Pixley Irrigation District.

Sources:
1. Rund, NC, T.Harter, GF Marques, NW Jenkins, JR Lund, 2003. Modeling of Friant Water Management and Groundwater, Final Report, US Bureau of Reclamation, 294pp.
2. http://groundwater.ucdavis.edu/Publications/Harter-Lund-USBR2003-Final%20Report%20for%20print.pdf

Figure 3 – A closed-end system before on-farm efficiency improvements

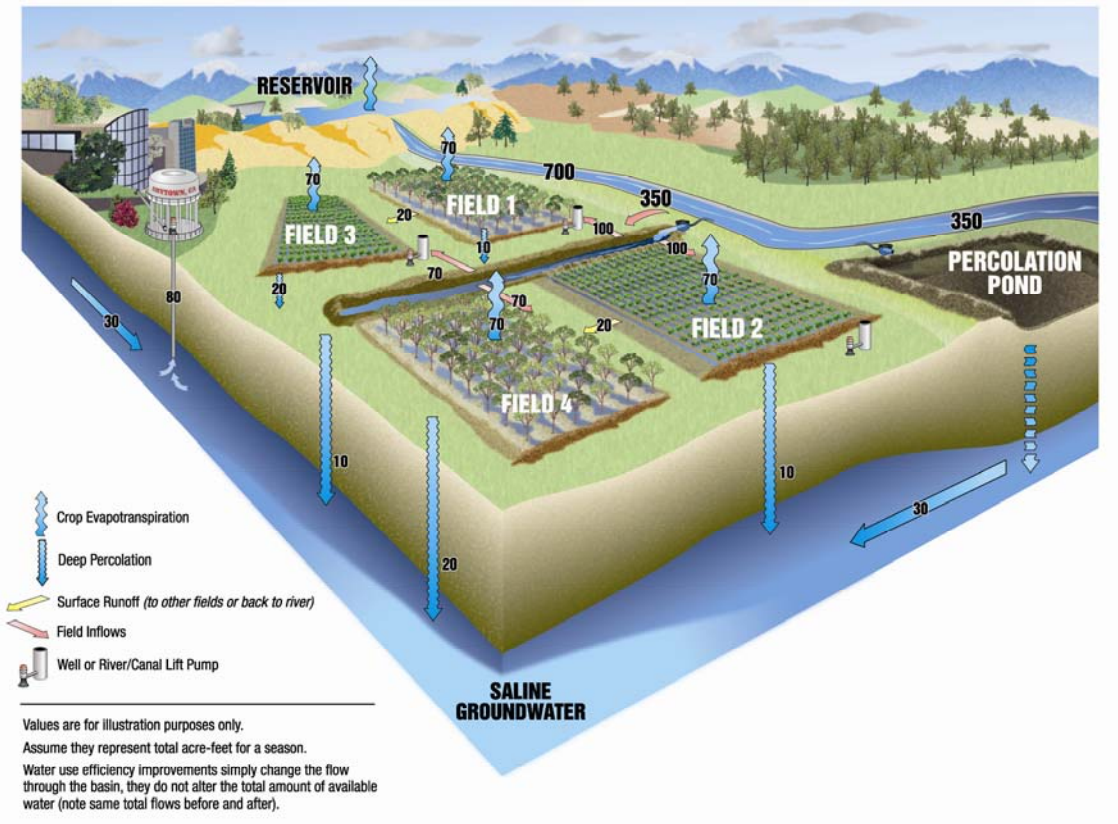
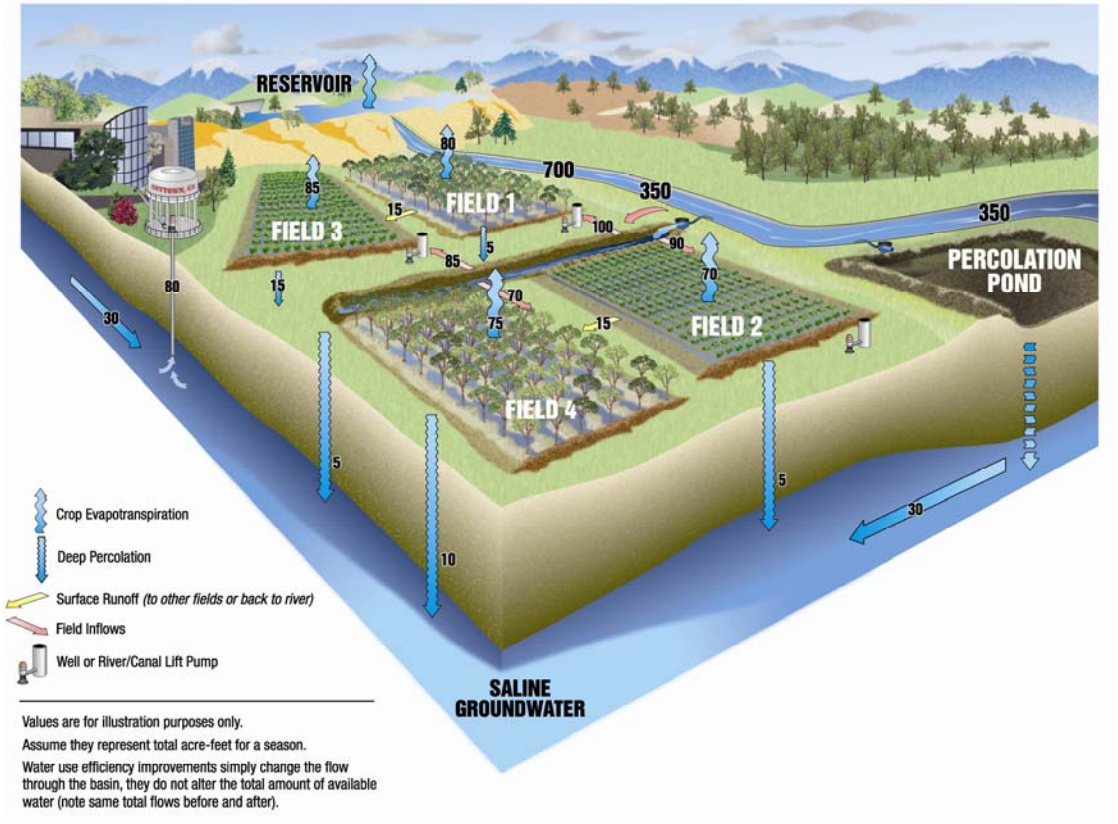


Figure 4 – A closed-end system after on-farm efficiency improvements



2.3.2 A Closed-end System Before and After On-farm Efficiency Improvements

The second example, illustrated by Figures 3 and 4, resembles the CVP Friant system of the San Joaquin Valley floor adjacent to the southern Sierra mountains and foothills, where the Friant-Kern Canal is fed by Millerton Lake (created by Friant Dam) and in turn supplies many water districts along the canal as it winds south from Fresno into Kern County. The entire southern San Joaquin Valley (Tulare Basin) is a closed basin and water does not move back to the San Joaquin River or out to the Pacific Ocean except in the wettest of years (a **closed-end** system).

As in the flow-through system example, the after situation (Figure 4) indicates improved on-farm irrigation efficiency. In the example illustrated in Figures 3 and 4, the before and after situations demonstrate the following:

Improved on-farm efficiency may not result in new water outside the use area – Improving on-farm efficiency may allow more irrigated acreage or more water-intensive crops to be grown Figure 4), as indicated by the higher ETcs on Fields 1, 3 and 4. There are water shortages (i.e., full contract amounts are not being delivered) in many agricultural areas south of the Delta and thus, with increased on-farm efficiency some fallowed land could be brought back into production. An important point of this example is that the additional water within the system resulting from improved efficiencies is used to irrigate more crops. The recovered fractions are not left in the reservoir or sent outside the district. Note that this water could be sold and transferred to another user.

Improved on-farm efficiency can create third-party impacts - Improving on-farm efficiency can impact third parties as is noted by the change from a balanced aquifer to a 20-unit overdraft of the aquifer (note reduced recharge in Figure 4). The city is completely dependent on groundwater for its supply. The overdraft could result in increased pumping costs to the city as groundwater levels decrease and could also threaten the long-term viability of the city's water supply. It is important to see that the previous deep percolation fractions were being recovered for use by the city. Now that they are being recovered for use on the farms, the city's water supply will be impacted. The improved on-farm efficiency did not create new water, it just changed the use of the affected water.

The overall impact on groundwater quality from reduced deep percolation is not clear. Less deep percolation could reduce the movement of nitrates and other soluable chemicals to the aquifer. If a salt balance is to be maintained in the soil to ensure crop production and quality, it may result in a higher salt concentration in the deep percolation that remains. This could eventually contribute to the overall salt concentration in the aquifer.

Box E – Overdraft as an issue

There is continuing and serious groundwater overdraft in the California and it is on par with the Sacramento-San Joaquin River Delta as a priority problem. DWR estimates the overdraft in the range of 1-2 MAF/year, although they note there has not been a comprehensive assessment since 1980.[1] However, satellite data compiled by NASA and the Jet Propulsion Laboratory indicates that as much as 30 cubic kilometers (about 24.3 MAF) has been lost from the aquifers of the Sacramento and San Joaquin Valleys between 2003 and 2009, with most of this loss occurring in the San Joaquin Valley.[2] This is not a sustainable situation.

1. California's Groundwater Bulletin 118 Update 2003. Department of Water Resources Resources Agency. State of California: October 2003.
2. NASA Data Reveal Major Groundwater Loss in California. Buis, Alan, press release of the Jet Propulsion Laboratory at the California Institute of Technology. Pasadena, CA: December 14, 2009 @http://www.jpl.nasa.gov/news/news.cfm?release=2009-194.

Improved on-farm efficiency can create new water – This example also demonstrates that by reducing irrecoverable fractions new water can be developed from improved on-farm efficiency. The deep percolation from Field 4 has been decreased by 10 water units that previously moved to an unusable salt sink.

Conjunctive water management – In Figures 3 and 4, there are three wells within the distribution area. When there are sufficient surface water supplies available from the Friant-Kern Canal groundwater sources may not be used. However, in times of scarcity groundwater is used to augment, or even completely supplant, the canal supply. This is the concept behind **conjunctive water management** and **water banks**. In times of plenty, water is transferred to dedicated recharge areas (note the percolation pond in Figures 3 and 4) so that the excess water is percolated and stored in the aquifer. This stored water is then used in times of drought. Intentional percolation using dedicated sites provides for high-quality water reaching the aquifer.

Beyond the concept of recoverable versus irrecoverable fractions these examples identify the complex interactions that exist in environments developed over time. Understanding the concept of recoverable versus irrecoverable fractions means understanding that agricultural water users can be linked to M&I users and the environment in symbiotic relationships that cannot easily be undone. Typically, recoverable inefficiencies from irrigation events are recovered somewhere by someone in the system – by agriculture, M&I or the environment – and are beneficially used.

Water use patterns in the California have developed over decades, especially those involving large storage/delivery projects, resulting in co-dependent partnerships. Careful analysis must be done to evaluate all impacts before simply calling for increased on-farm water use efficiency. Changes to these environments that result in perceived benefits to some users can also result in negative impacts to other third-party users. It is essential to identify and understand these consequences. As stated in Conclusion 1 from the DH Report (emphasis added - Ed.):

> *Within a crop season, water used in irrigation is either recoverable or is irrecoverably lost..." ; "...if seepage, surface runoff, and deep percolation make contributions to soil moisture available to crops, groundwater, or wildlife habitat and recreation that water cannot be regarded as lost"; "...high priority should be given to preventing water flow to highly saline sinks...because inefficiencies are irrecoverable. However, conservation decisions must take into account environmental and instream needs as well as the appropriate balance of potential water savings against net farm income, possible reductions in food and fibre production, infrastructural viability, and the ability of farmers to retain flexibility in their operations and remain competitive in the market.*[10]

[10] Davenport, David C. and Robert M. Hagan. Agricultural Water Conservation in California, With Emphasis on the San Joaquin Valley. Department of Land, Air, and Water Resources. University of California at Davis. Davis, CA. October 1982.

2.4 Options for Reducing Field Applications (with Emphasis on the Irrigation System Itself)

When analyzing irrigation efficiency, it is important that spatial scale be taken into consideration. That is, while the irrigation efficiency on an individual field may be poor, the irrigation efficiency of a farm, irrigation district, or the basin may be very high because the inefficiencies of one field (recoverable fractions) are picked up for use by others in a larger area. However, diversions in themselves can lead to negative impacts on other beneficial uses and users. Thus, in most situations it should be an imperative to improve field irrigation efficiencies by reducing the required diversion to any individual field and in so doing, reducing surface and subsurface drainage flows.

The following equation can be used for estimating required irrigation water diversions to a field:

$$AF/yr = AC \times ((ETc - RAINeff) / ((1 - LR) \times IE)) \quad [1]$$

where:

AF/yr	=	required applied water in acre-feet/year
AC	=	acres cropped
ETc	=	net crop water use in acre-feet/acre
RAINeff	=	rainfall effective in supplying crop ETc needs in acre-feet/acre
LR	=	required leaching ratio for salt control as a decimal (0 - 1.0)
IE	=	irrigation efficiency as a decimal (0 - 1.0)

The purpose of using the equation is to identify the variables involved and their relationships. The equation indicates that if the goal is to reduce the acre-feet per year diverted to a field, then one or more of the following must occur:

- Reduce the number of acres irrigated (AC)
- Reduce the crop evapotranspiration (ETc)
- Increase the effectiveness of rainfall (RAINeff)
- Reduce the leaching ratio (LR)
- Increase the irrigation efficiency (IE)

Further, one should strive to implement actions that do not work against the overall objective. For example, an action that increases the effectiveness of rainfall should not be taken if it significantly decreases irrigation efficiency.

The equation only describes actions that can be taken to reduce the amount of water volume diverted. Implementing actions to reduce that volume may have other impacts such as increased energy use (with possible air quality concerns as well) and/or reduced farm profitability.

Three areas will be discussed further to look at the available options to reduce field applications: irrigated acreage, crop evapotranspiration, and most importantly, improving irrigation efficiency.

2.4.1 Reducing Irrigated Acreage

Reducing irrigated acreage should not be considered a water conservation measure, but a transfer of water out of agriculture. The question is: how will this impact regional and state economies and food supplies? The contribution of California agriculture to the State's economy is significant. In 2010 California's 81,700 farmers and ranchers received $40.9 billion for their output.[11] Economic estimates suggest a multiplier effect from these receipts of around 2.1, implying that every dollar received results in an additional $1.10 of economic activity, leading to an additional $44.99 billion contribution from agriculture for a total of $85.9 billion. Agriculture is also an important source of employment in California. Agriculture's estimated direct effects from production and processing account for 591,812 jobs, with total effects – direct, indirect and induced – estimated to account for 1,356,998 jobs.[12]

2.4.2 Reducing Crop Evapotranspiration (ETc)

Reducing crop ETc is a second major option. Crop evapotranspiration is the combination of soil surface evaporation that occurs because of the irrigation water that is present (not the immediate evaporation from free water surfaces during and just after the irrigation event) and transpiration from the crop surfaces. Reducing ETc might be accomplished in different ways including reducing the soil wetted area, changing the crop or cultivar of the crop (a hybrid that produces more crop on less water) and changing crop management (mulches and soil covers, irrigating at night only). However, such changes in practices have to be balanced with other factors such as the economics or disease and pest management impacts of such decisions.

2.4.2.1 Changing the Crop

Changing the cultivated crop could lead to a shift from a water-intensive crop to one with lesser seasonal demand. This decision involves the economics of the crops involved as well as individual farm resources. Some farms grow a highly diverse mix of crops, others are involved in a particular crop rotation, and others may have a single crop such as an orchard or vineyard. Farmers have an investment in both equipment and expertise required to grow certain crops or rotations. Farmers also depend on established networks of suppliers and organizations to harvest, store, process, and/or market their crops. Shifting to a different crop or crop pattern may involve substantial expenditures for field preparation and planting, equipment (irrigation, planters, tillage, harvest, storing) and expertise – possibly requiring hiring advisory staff or changing infrastructure. These decisions are dependent on the availability of required support. Soil types and/or water quality may limit crop options.

Table 6 shows that there have been major shifts in the types of crops grown since 1978. **It is important to understand that these changes took place over 30 years and were the result of market factors.** This is a critical point. Some of these factors might have economic, political or legal origins (e.g., increases in water costs, reduced water supplies, new trade agreements); some may be natural (e.g., pest infestations, plant diseases); some may be research-based (e.g., new plant varieties, new cultural systems); and some may just be the evolution of consumer demand. However, the response to these factors was, and still is, dependent on the individual farmers, the environment and economic forces.

[11] Farm Financial Indicators, State Fact Sheet - 2010, Economic Research Service, U.S. Department of Agriculture (see http://www.ers.usda.gov/StateFacts/CA.htm#FFI)

[12] Paggi, Mickey, Center for Agricultural Business, California State University, Fresno, personal communications, 2011.

Table 6 – Acreages of various crop types in California as reported by USDA Census of Agriculture

	YEAR REPORTED				
TYPE OF ACREAGE	1978	1987	1997	2007	% CHANGE 78-07
Total Irrigated Land (acres)	8,505,824	7,596,091	8,712,893	8,016,159	- 5.8%
Rice Acreage	484,822	399,193	574,081	531,075	9.5%
Cotton Acreage	1,517,980	1,083,811	1,036,316	471,378	- 69%
Total Bales	1,911,050	2,619,934	2,543,194	1,418,751	- 26%
Bales/Ac	1.26	2.42	2.45	3.01	139%
Hay Acreage	1,501,143	1,532,777	1,698,773	2,183,761*	45.5%
Vegetable Acreage	900,401	882,741	1,209,259	1,169,786	30%
Orchard Acreage	1,892,077	2,152,664	2,582,084	2,826,291	49%
Dairy Cows	836,675	1,070,366	1,403,217	1,840,730	120%

* reported in the Census as 1,723,147 acres of "forage (hay, hay silage, grass silage, and green chop)" plus 460,614 acres of corn silage

SOURCES:

1. "Highlights of the State's Agriculture: 1992 and 1987", Table A, 1992 Census of Agriculture, Volume 1, Part 5 California State and County Data, AC92-A-5, Economics and Statistics Administration, Bureau of the Census, U.S. Department of Commerce, 1994
2. "Historical Highlights: 1997 and Earlier Census Years", Table 1, 1997 Census of Agriculture, California State and County Data, AC97-A-5, National Agricultural Statistics Service, U.S. Department of Agriculture, March 1999
3. "Historical Highlights: 2007 and Earlier Census Years", Table 1, 2007 Census of Agriculture, California State and County Data, AC97-A-5, National Agricultural Statistics Service, U.S. Department of Agriculture, December 2009

An important factor to consider in crop shifting, at a policy level, involves what is called **hardening of demand**. This occurs when a field is switched from growing an annual crop to an orchard or vineyard. In many cases this shift is due to a confluence of factors including higher profitability. Shifting from annual crops to orchards/vineyards can bring two major changes:

1. The economics of developing an orchard or vineyard dictate a preference for a micro irrigation system.

2. Permanent crop changes, in conjunction with the micro irrigation method, allow a viable cropping system (including a sufficient profit for the irrigator) that can optimize on-farm water supplies.

As noted, the disadvantage with this crop change is the water demand has now "hardened." In times of drought, a grower with annual crops could reduce cropped acreage or stop growing entirely for a period of time without long-term consequences. This is not a viable option with an orchard or vineyard that is expected to be in production for twenty years or more mandating a reliable water supply.

2.4.2.2 Changing Crop Management

There are a number of ways crop management can be changed to reduce ETc. These include:

- **Changing the cultural system –** An example of a change in the cultural system would be keeping the orchard floor bare instead of supporting a cover crop in a border strip-irrigated orchard. The ETc of the cover crop would be eliminated resulting in a net water savings. However this action may increase chemical use as the cover crop can serve as habitat for beneficial insects. This change could also affect irrigation efficiency as the hydraulics of flood irrigation could affect the infiltration rate of the soil. Increased runoff during rain events would likely increase due to the bare soil.

- **Regulated deficit irrigation** – Another option is to reduce the amount of applied water at specific crop growth stages commonly referred to as **regulated deficit irrigation (RDI)**. There has been, and continues to be, significant research in applying this concept on various crops, primarily vineyards and orchards.[13] [14] [15] Research is limited using RDI with other crops.[16] [17] More research is needed on

[13] Stewart, William, A. Fulton, W. H. Kruefer, B. Lampinen, K. A. Shackel, "Regulated deficit irrigation reduces water use of almonds without affecting yield", *California Agriculture* 65(2):90-95. DOI: 10.3733/ca.v065n02p90. April-June 2011.

the long term effects and uses of RDI and the ability to expand the RDI concept to additional crops or crop acreage. Another question, as far as the potential of RDI to create new water, is how much acreage might already be using RDI, whether as a formal procedure or as part of normal irrigation scheduling and crop management. The increased risk to production should also be noted.

Box F – Water conservation through shifts in cropping choices: alfalfa vs. fresh tomatoes

Replacing crops that are associated with high rates of applied water per unit area with those that use less water has been suggested as an alternative that can result in substantial water savings.[1]

Crop shifts may produce certain measurable changes in water use, however, the effects of such shifts on regional farm revenue are far from certain. Rather they depend on the speed of adjustment, overall market conditions, and the unintended consequences for third parties such as in the case where certain crops may be used as inputs in livestock-based production systems.

For example, assume there is a modest 1.5 percent shift in irrigated alfalfa acreage to fresh tomatoes. Such a change in cropping patterns, everything else being equal, would be expected to result in a reduction in water use of 4.62 AF per acre shift from alfalfa and an increase in use of 1.93 AF for every acre of fresh tomatoes brought into production for a net savings of 2.69 AF of water. A 1.5 percent shift in alfalfa acreage from a harvested total of 980,000 in 2009 would result in a 14,700 acre shift with a net water savings of 39,543 acre feet of water. However, if such a change occurs rapidly without regard to other market forces the impacts for producers would be mixed.

The demand for agricultural products are generally known to be price inelastic thus a percentage change in price results in a greater percentage change in quantity. For example estimates of the demand elasticity for alfalfa are around - 0.11 and for fresh tomatoes are - 0.25.[2] Simple price flexibility coefficients derived from these elasticities imply that a crop year shift of 1.5 percent decline in alfalfa production (14,700 acres, 2009) will lead to around a 14 percent increase in alfalfa price thus alfalfa producer revenue increases, all else being equal; however alfalfa is used as a primary input in the dairy industry. Increases to alfalfa prices lead to increases in cost of production for dairies which could lead to decline in net returns to dairy producers.

For the fresh tomato market, an additional 14,700 acres in one cropping period would be equivalent to about a 41 percent increase in production from the 2009 base. Based on the derived price flexibility for this commodity we would expect the price of fresh tomatoes to be reduced significantly resulting in declining producer revenues.

The consequences with regard to the market for fresh tomatoes, or any other commodity, must be considered in any decision designed to save water by diverting acreage from intensive water use crops to less water intensive use crops. Such shifts are likely better accommodated by gradual market-driven change, accounting for system wide effects and across the entire portfolio of crop alternatives if the dual goals of economic viability and water savings are to be achieved.

1. Cooley, Heather, Juliet Christian-Smith and Peter H. Gleick. More With Less: Agricultural Water Conservation and Efficiency in California: A Special Focus on the Delta. Pacific Institute: September, 2008.
2. Carlo Russo, R. Green, and R. Howitt. Estimation of Supply and Demand Elasticities of California Commodities. Working Paper No. 08-001. Department of Agricultural and Resource Economics. University of California: Davis, June 2008.

- **Changing the irrigation system** – Soil surface evaporation is related to how much of the field area is wetted during an irrigation event and how often irrigation occurs. For example, a flood irrigation system usually results in much, if not all, of the field surface area wetted. However, irrigations occur relatively infrequently. Conversely, a drip-micro system wets significantly less surface area but the systems are operated very frequently (perhaps daily). A third combination would occur with a center

[14] Goldhammer DA, Viveros M, Salinas M, "Regulated Deficit Irrigation in Almonds- Effects of Variations in Applied Water and Stress Timing on Yield and Yield Components", Irrig Sci. 2006. 24(2):101-14. DOI: 10.1007/s00271-005-0014-8

[15] Prichard T, Hanson B, Schwankl L, Verdegall P, Smith R, "Deficit Irrigation of Quality Winegrapes Using Micro-Irrigation Techniques, University of California Cooperative Extension, Department of Land, Air, and Water Resources, UC Davis, April 2004.

[16] Fulton, A, et al, "Current Understanding of Regulated Deficit Irrigation in Walnut", University of California Cooperative Extension, Department of Land, Air, and Water Resources, UC Davis, 2004.

[17] Simsek M, Comlekcioglu N, Ozturk I, "The effects of the regulated deficit irrigation on yield and some yield components of common bean under semi-arid conditions", African Journal of Biotechnology, Vol. 10(20), pp. 4057-4064, May 16, 2011. (see also their bibliography for more research on RDI)

pivot (and to a lesser degree with mini-sprinklers or foggers) resulting in wetting much of the field surface area on a frequent basis. Thus, the effects on wet soil evaporation from a change in irrigation system type vary depending on the crop and system methods involved. In some cases the beneficial impacts might be offset by an increase in the transpiration component due to more frequent irrigations and thus, a more optimum soil moisture regime.

2.4.3 Improving Irrigation Efficiency

The third and most important major option for reducing field applications is to improve irrigation efficiency. This can involve improving management of the existing system or changing to an irrigation system that makes it easier to achieve the inherent potential efficiency of the system. Options for improved on-farm irrigation system management include:

- Understanding system characteristics and operating parameters to better manage the individual irrigation event, which importantly involves measuring all applied water accurately.
- Using some form of irrigation scheduling to determine when and, more importantly, how much water to apply.
- Maintaining the system to achieve the intended irrigation efficiency (IE).

The potential water savings from any of these options depends largely on how well or poorly the current irrigation system performs. Many areas and growers in California already achieve high efficiencies.

2.4.3.1 Managing the Irrigation Event

Each irrigation system type has its own set of operating characteristics (refer to the table in Appendix C). The irrigator must be aware of these characteristics in managing the individual irrigation event. The initial goal is to achieve good distribution uniformity – that is, water should soak evenly into the ground throughout the field. Then, the irrigator must be able to control the total amount of water applied.

Managing individual irrigations may be relatively easy, as with a pressurized system such as field sprinklers, center pivots, or a micro system. In these situations the operator basically turns the system on and off. (It is assumed that the system was designed and installed correctly and is maintained.)

Managing flood-type irrigation systems such as furrow or border checks can involve a great deal of effort. With sprinkler and micro irrigation systems the rate of water infiltration into the soil is dependent on the system application rate (assuming the application rate is lower than the infiltration rate at all times). With flood systems water infiltration is dependent on the infiltration rate of the soil alone. This will change with time during the irrigation, sometimes very quickly (with clays and what are known as "cracking clays") and sometimes slowly (with sandier soils). The experience of the irrigator in adjusting the rate of water advance across a field and knowing when to terminate is critical to irrigation efficiencies with flood systems.

2.4.3.2 Use of Irrigation Scheduling

Irrigation scheduling is a generic term applied to any technique/practice that is intended to aid the farmer in determining when and how much to irrigate. Although some authorities will categorize these techniques as either “soil-based” or “plant-based” a more general terminology may be to divide them into two major families, “water budget” and “graphical.”

The science of irrigation scheduling is very well developed and in widespread use in one form or another. However, it is an exercise in information economics- that is, "how valuable is this information"? Irrigation scheduling can be practiced in a number of ways, some very expensive and complex, some very cheap and simple. For example, a very simple level would be using a soil probe and taking periodic samples, feeling the sample for moisture, and making a determination of when and how much water to apply based on knowledge of the soil's holding capacity and the crop's normal rooting patterns. This would be a form of graphical or "bottom-line" scheduling. The most complex would be use of automated soil moisture sensors sending data continuously to a central computer that inputs that data, along with data concerning irrigations, crop coefficients, daily weather, etc. into a water budget equation.

Irrigation scheduling is always listed as an effective management practice that can improve field irrigation efficiency. However, it is emphasized that irrigation scheduling is simply an aid in knowing when and how much to irrigate. It says nothing about how to irrigate (refer to the discussion in section 2.4.3.1). It may be that a scheduling system indicates a field requires 3.5 inches net application of water and that it should be applied next Tuesday. However, if the irrigator can't achieve a DU above 60 percent, or can't control the irrigation to apply a net 3.5 inches, or doesn't have the flexibility in the primary water supply that allows an irrigation on Tuesday (see Box G), then the information is of little value.

Box G – Flexibility in the farm's water supply

Water supplies have many characteristics including total quantity available, quality, cost, and priority of the right to use the water supply. Another characteristic is flexibility. Ideally, the frequency, rate and duration of water supplies should be flexible. That is, the irrigator can access the water at will (frequency of use), can obtain varying flow rates (i.e., gallons per minute water flow), and can turn the flow on and off at will (duration of use). Improving the flexibility of water supplies is an important management practice for improving on-farm water efficiency.

In real life, various aspects of flexibility may be lacking in any water supply:

- With a water well (assumed to be owned by the irrigator) water can be turned on and off at will, but perhaps it does not provide the original flow rate (the pump may be worn or there might have been a systemic change in the water table due to drought or increased pumping by other irrigators). The pumping water level may be such that the water costs too much to use for a particular crop. Possibly the water quality is poor.
- An irrigation district may be able to provide water on 24-hour notice but may be restricted in the flow that can be delivered (due to the design of the canal system) and may require 24-hour use durations (i.e., the irrigator could have water for one day, two days, etc.).
- Some older districts may only deliver water on a set schedule (e.g., the irrigator has access to water every two weeks, whether the water is needed or not) – although this is currently rare in California.

As an example of the importance of water supply flexibility:

- Assume an irrigator is using an accurate irrigation scheduling system that predicts the crop needs water on Monday and the application should be 4.5 net inches. Note that the identification of water needed on Monday is generally related to crop development. However, in certain situations it may be that the irrigation system is very efficient in applying 4.5 net inches or there may be a labor constraint (e.g., a standard impact sprinkler system is being used and labor is only available to turn it on and off in 12-hour increments).
- Ideally then, the irrigator is able to turn the water on on Monday, obtain a flow rate necessary to run the irrigation system efficiently, and is able to turn it off after 4.5 net inches has been applied.
- Any obstacle to turning the water on on Monday, operating the system efficiently, and turning off the water at the right time may impact crop development and/or irrigation event efficiency.

2.4.3.3 Changing the Irrigation System

Depending on the situation, one irrigation system may have inherent advantages over another. This may be an absolute advantage as would be the case with a field with a non-homogenous soil, which argues for sprinkler or micro types over flood systems. It may be relative where a particular situation would make it easier to obtain the potential efficiencies of one system rather than another.

Table 7 – Reported acreages of various irrigation system types in California, 1994 – 2008

YEAR REPORTED	TOTAL REPORTED	GRAVITY	SPRINKLER	DRIP	SUB
1994	8,023,965	5,185,677	1,848,697	933,696	55,895
1998	8,424,207	5,819,660	1,528,038	1,021,720	54,789
2003	8,749,684	5,261,073	1,723,040	1,706,916	58,655
2008	7,959,443	4,189,852	1,367,179	2,336,130	66,282
% Change 1994 - 2008		**-19.2%**	**-26.0%**	**+150.2%**	**+18.6%**

SOURCES:

1. "Land Irrigated by Method of Water Distribution", Table 4, Volume 2, Subject Series, Part 3, 1994 Farm and Ranch Irrigation Summary, 1992 Census of Agriculture, National Agricultural Statistics Service, U.S. Department of Agriculture
2. "Land Irrigated by Method of Water Distribution", Table 4, 1997 Census of Agriculture, 1998 Farm and Ranch Irrigation Summary, National Agricultural Statistics Service, U.S. Department of Agriculture
3. "Land Irrigated by Method of Water Distribution", Table 4, Farm and Ranch Irrigation Survey (2003), 2002 Census of Agriculture, Volume 3, Special Studies, part 1, doc AC-02-SS-1, National Agricultural Statistics Service, U.S. Department of Agriculture, November, 2004
4. "Land Irrigated by Method of Water Distribution", Table 4, Farm and Ranch Irrigation Survey (2008), 2007 Census of Agriculture, Volume 3, Special Studies, part 1, doc AC-07-SS-1, National Agricultural Statistics Service, U.S. Department of Agriculture, November, 2009

Just as cropping patterns in California have changed over the years (Table 6), so has the mix of irrigation systems in use as shown in Table 7 (as with the shift in cropping patterns, note the time frame of these changes). These trends are likely to continue as agriculture continues to adapt to market forces.

Every irrigation system has a variety of advantages and disadvantages depending on where and how it is adapted. The "Characteristics of Irrigation Systems" table in Appendix C lists some of the more important characteristics and considerations for the most common irrigation system types in use in California.

Table 8 lists typical estimated ranges of on-farm irrigation efficiency for various types of irrigation systems compiled from a number of sources. There are a myriad of these types of tables available in literature. All show basically the same things, that when considering single field irrigation efficiencies, sprinkler systems are generally better than furrows and that micro systems are generally the best. Some major thoughts that tend to validate this trend are:

- both sprinklers and micro systems provide management with easier control of the total application than a flood system (provided there is a flexible water supply).
- micro systems have better distribution uniformities (DUs) than sprinklers mainly due to the wind effects on overlap of sprinkler wetting patterns (note that linear sprinklers and center pivots will have generally higher irrigation efficiency (IE) ranges then standard field sprinklers and similar to micro systems, since one dimension of the overlap problem is negated by the continuously moving system).
- sprinkler and micro systems tend to minimize deep percolation inefficiencies since application rates are dependent on the system design and not the soil's infiltration rate.

Table 8 does not speak to the actual adaptation of any one system to a given situation. Rather the efficiencies listed are generally described as the results for well-adapted, well-designed, well-maintained, and well-managed systems (see notes to Table 8). Thus, it is implied that some form of irrigation scheduling is being

utilized in order to achieve the maximum values listed. Also, usually the surface irrigation system types are broken out by those using tailwater return systems and those that do not.

Table 8 – Typical range of application efficiencies presented for the major irrigation system types

	WATER APPLICATION EFFICIENCY					
SYSTEM TYPE	Tanji & Hanson[1] (S1)	SJVDP (S1b)	ATTRA[2] (S2)	KSUIE[3] (S3)	Howell (S4)	Hanson et al (S5)
Surface Irrigation						
Furrow	60-90	70-85	60-80	50-90	50-80	70-85
Furrow w/Tailwater					60-90	
Border	65-80	70-85	55-75	60-90	50-80	70-85
Basin	75-90			60-95	80-95	
Sprinkler						
Periodic Move	65-80	70-80	60-75	65-80	60-85	70-80
Continuous Move	75-85	80-90		70-95	70-98	80-95
Center Pivot			65-90[4]		75-98[5]	
Linear Move w/ spray heads			75-90		70-95	
Solid Set	85-90	70-80	70-85	70-85		70-80
Drip/Trickle	75-90	80-90				80-90
Trickle (point source)			85-95	75-95	70-95	
Subsurface Drip			85-95	70-95	75-95	
Microspray			85-90		70-95	

Notes:

- Described in the reference as "In the past 20 years, considerable efforts have been made to improve irrigation application efficiencies in order to save water. Table A6.2 shows data from well-designed and well-managed irrigation systems in California, the United States of America and potential maximum values for application efficiencies determined in irrigation evaluations in the San Joaquin Valley Drainage Implementation Program as mentioned in FAO (2002)."
- Described in the reference as "These are only average values for well-managed and well-maintained systems."
- Described in the reference as "Efficiencies can be much lower due to poor design or management. These values are intended for general system type comparisons and should not be used for specific systems."
- Described in the reference as "75-90 for low pressure, 65-80 for high pressure"

1. Tanji, K.K. & B.R. Hanson. 1990. Drainage and Return Flows in Relation to Irrigation Management, in B.A. Stewart & D.N. Nielsen, eds. Irrigation of Agricultural Crops, Agronomy Monograph No. 30. Madison, WI, USA. American Society of Agronomy
2. Morris, M. & V. Lynne. Measuring and Conserving Irrigation Water. National Center for Appropriate Technology. Butte, MT. 2006
3. Rogers, D. H., et al. Efficiencies and Water Losses of Irrigation Systems., Irrigation Management Series. Kansas State University. MF-2243. May 1997.
4. Terry Howell, Irrigation Efficiency, Published in Encyclopedia of Water Science DOI: 10.1081/E-EWS 120010252, Published 2003 by Marcel Dekker, Inc. after: Howell, T.A. Irrigation Efficiencies. In Handbook of Engineering in Agriculture; Brown, R.H., Ed.; CRC Press, Boca Raton, FL, 1988; Vol. I, 173–184. Merriam, J.L.; Keller, J. Farm Irrigation System Evaluation: A Guide for Management; Utah State Ref 11 = 11. Hart, W.E. Overhead Irrigation by Sprinkling. Agric. Eng., 1961, 42 (7), 354–355.
5. Hanson, Blaine, L Schwankl, A. Fulton. Scheduling Irrigations: When and How Much Water to Apply. Div of Ag and Natural Resources publication 3396. UC Irrigation Program. UC Davis, 1999.

If the only concern is water conservation in order to create new water, it would be easy to say that all farmers should switch to some form of pressurized irrigation, noting the highest estimated efficiencies with sprinkler or micro system types. However, choosing an irrigation system requires balancing many factors including initial and on-going maintenance costs of the system; crop economics (i.e., commodity prices versus production costs); physical restrictions on irrigation practices created by the soil, terrain, or crop; water supply quality, flexibility, and reliability; labor availability and ability; support infrastructure for a particular type of system; and management ability. While one system may have an inherently higher potential field efficiency than another (e.g., point source micro versus furrow) all of these factors may combine so that in a given situation a furrow system may provide the same irrigation efficiency as micro, as well as being the better business decision .

The reader is alerted to the wide, and often overlapping, ranges of irrigation efficiencies listed in Table 8. The importance of management as a determining factor of field efficiencies cannot be emphasized enough. The best-designed and maintained micro system in the world will only be 50 percent efficient if run twice as long as needed. Informed management is needed to:

- Make the right choice of irrigation system type initially and help the designer to adapt that system type to grower needs and local conditions.
- Ensure that system operators understand how to maintain and operate the system correctly
- Ensure that some form of irrigation scheduling is being used

Box H – Drip paradox

In conjunctive use districts such as Consolidated Irrigation District (CID), the benefits of agricultural water conservation measures are realized in a reduction in the use of both surface water supplies and groundwater. However, the reduction in surface water use presents other issues that must be addressed in the long-term water management strategy of the District. While applicable to all agricultural water conservation measures, this is particularly true in regard to the replacement of furrow/flood irrigation methods by drip irrigation systems.

In most cases, land converted to drip irrigation foregoes use of surface water and becomes strictly groundwater dependent due mainly to the high frequency requirements. In drier years, the forgone surface water is delivered elsewhere within the District resulting in minimal impact to District operations and area groundwater supplies. However, in wetter years, the reduced acreage utilizing surface water means reduced acreage providing the incidental recharge that invariably results when surface water is applied through normal irrigation practices. A situation is created resulting in greater groundwater pumping coupled with less recharge in years when surface water is plentiful or even in excess (It is noteworthy that ag to urban land conversion associated with expanding cities has a similar impact).

CID has a longstanding groundwater recharge program that relies on incidental recharge along with 1,300 acres of dedicated ponds to offset most of the groundwater pumping that occurs within the District. The District is underlain almost entirely by coarse-grained soils that allow for significant incidental recharge within the District boundaries for future use. In recent years, the number of acres within CID that use drip irrigation has increased significantly while demand for surface water has fallen.

The loss of incidental recharge via surface irrigation causes lower water tables and higher pumping costs. In order to maintain a sustainable conjunctive use water supply, the change to large acres of drip irrigation will necessitate the District to add additional recharge basins, at significant cost, if the area groundwater resource is to be maintained.

Source: Personal correspondence. Phil Desatoff, P.G., C.E.G. General Manager. Consolidated Irrigation District

Most importantly, Table 8 does not speak at all to the issue of recoverable versus irrecoverable fractions. While Table 8 may list attainable furrow IE as 90 percent while micro irrigation IE is listed as 95 percent, switching a water basin to drip from furrow is very likely not to create 12 percent new water. The reason being, as noted throughout this paper, that the inefficiencies from any irrigation system, either surface runoff or deep percolation, may be picked up for reuse by some other farm, or for municipal/industrial or environmental uses.

2.4.3.4 Maintaining the Irrigation System

It should be evident that achieving high irrigation efficiency with an irrigation system in disrepair will be difficult if not impossible. Different irrigation system types have different aspects to maintenance (see Appendix C). The following are some of the more important aspects for system maintenance:

- For flood irrigation systems:
  - Maintaining a smooth field surface graded to the appropriate slope.
  - Sufficient flow delivery capacity.
  - Maintaining sufficient drainage and/or tailwater return system capacity.
- For sprinkler systems:
  - Insuring that the correct nozzle size is used throughout a field (may include flow control).
  - Insuring that nozzles are not excessively worn or clogged.
  - Insuring that correct pressures are maintained during the irrigation.
- For micro systems:
  - Insuring the correct number and type of emission device (may include pressure compensation) is used throughout the field.
  - Insuring that system pressures are correct.
  - Insuring that emission devices are not worn or clogged.

Maintenance issues are critical with micro systems due to the large number of devices in the field and their relatively low individual flow rates. The low flow rates imply very small flow passages and the increased potential for clogging. Filtration and chemical additives are essential for keeping sediments, algae and/or precipitants from blocking emission devices.

2.5 The Role of Water Agencies in On-Farm Water Management

Box G identified flexibility as an important issue affecting on-farm irrigation efficiencies. If all or part of the water supply to the farm is delivered by a water agency (irrigation district, water district or private water company) then that agency has a role in providing for any needed flexibility. However, besides flexibility issues, water delivery agencies can influence on-farm water management in a number of ways.

A Memorandum of Understanding (MOU) was developed by the Agricultural Water Management Council to serve as a guide for districts to improve their operations. The MOU contained a list of potential improvements classified at three levels. They are:

List A – Generally Applicable Efficient Water Management Practices—Required of all signatory water suppliers

1. *Prepare and adopt a water management plan*
2. *Designate a water conservation coordinator*
3. *Support the availability of water management services to water users*
4. *Where appropriate, improve communication and cooperation among water suppliers, water users, and other agencies*
5. *Evaluate the need, if any, for changes in policies of the institutions to which water supplier is subject*

List B – Conditionally Applicable Efficient Water Management Practices – Practices Subject to Net Benefit Analysis and Exemption from Analysis

1. *Facilitate alternative land use (drainage)*
2. *Facilitate use of available recycled water that otherwise would not be used beneficially*
3. *Facilitate the financing of capital improvements for on-farm irrigation systems*
4. *Facilitate voluntary water transfers that do not unreasonably affect the water user, water supplier, the environment, or third parties*
5. *Construct improvements (lining and piping) to control seepage from ditches and canals*
6. *Within operational limits, increase flexibility in water ordering by, and delivery to, the water users*
7. *Construct and operate water suppliers' spill- and tail-water recovery systems*
8. *Optimize conjunctive use of surface and groundwater*
9. *Automate canal-control structures*

List C –- Practices Subject to Detailed Net Benefit Analysis without Exemption

1. *Water measurement and water use report*
2. *Pricing or other incentives*[18]

[18] Efficient Water Management Practices by Agricultural Water Suppliers in California, Agricultural Water Management Council, Sacramento, CA January 1999.

Currently there are 77 water delivery agencies that have signed the MOU. In addition, 5 environmental organizations and 42 other water-related organizations have endorsed it.

Practice 1 of List A in the MOU is to develop and submit a Water Management Plan. It is noted that even before the MOU was finalized, all water agencies that were supplied through Federal Bureau of Reclamation contracts had to submit annual water management plans. The Bureau plans are deemed sufficient as meeting the criteria for the MOU.

The MOU necessarily incorporates language that allows for exemption from a Practice for a number of reasons. This is due to the wide diversity of water delivery agencies. Some aspects defining a district include:

- type of agency (drainage district, water supply district, conjunctive water management district, water bank; public or private; agricultural or municipal)
- governance of agency (e.g., irrigation districts are governed by one-man, one-vote while water districts are governed by one-acre, one-vote)
- type of supply (Bureau of Reclamation project, State Water Project, groundwater, district-owned facilities)
- contractual characteristics (cost schedule per unit water, total supply, rate of supply, timing of supply, reliability of the supply)
- quality of the water supply
- finances
- age of system
- size of system
- location of the system

It is important to remember that the irrigation or water district is owned by its member-farmers. They ultimately are responsible for financing any improvements and day-to-day operations. A district may have limited, if any, influence on the operations of individual farmers. The district, acting through the Board of Directors can form individual improvement districts within the district, they may charge differential rates based on total deliveries or where in the system the delivery occurs, they may prohibit discharges to district-owned facilities- but the control of the individual irrigation decisions are up to the farmer. (The reader is referred to Box G above that identifies the importance of flexibility of the water supply and Practice 6 of List B in the MOU.)

The district operation itself is a sort of on-going irrigation event in the sense that the act of delivering water can result in deep percolation losses through un-lined canals (or canals in disrepair), losses to evaporation from exposed water surfaces or phreatophytes in the water ways, and surface runoff through operational spill. Thus, physical district improvements may be related to increasing service to the individual farmers (e.g., flexibility) or to reduce water losses from the district operations themselves.

And like individual irrigation events, the surface runoff and deep percolation fractions may be recoverable or not. As was illustrated in Figures 3 and 4 earlier, deep percolation may become a significant source of supply to other users. Part of the deep percolation was contributed from the distribution canal and was being recovered, in this example by the city.

Although noted in the discussion, the role of the percolation pond and the conjunctive water management aspects of the example were not examined in depth. Districts may be strictly concerned with water supply, or concerned with water banking, or a combination of both. Thus, there may be competing goals as to the district functions. If the goal is to deliver timely crop irrigation water then the system needs to be configured to meet that goal. If the goal is conjunctive use to recharge groundwater then optimization will direct the improvements to accomplish that goal.

However, the difference in implementation paths between these two goals is noteworthy and has important implications for district finances and on-farm operations. In the first case the efficiency benefits accrue to the system users, any saved water is under the control of the entity making those investments. However, in the case where entities are in conjunctive use areas, the groundwater benefits are often accrued by a much larger area and beneficiaries, therefore the investments become regional in nature. To date mechanisms to adequately share the cost of such investments have often eluded the implementing agencies.

While there are complicated interrelationships between farm operations and delivery systems that can interfere with water use efficiency goals, there are many compelling reasons to improve delivery systems to optimize their ability to meet their intended goals. An example of this would be a district where farmers are switching to orchard crops while at the same time, adopting micro irrigation system types. Micro irrigation systems demand flexibility in water supply timing in order to achieve their potential efficiency. If the district cannot provide that flexibility the farmer may opt to use groundwater supplies instead. Using groundwater means that the farmer is not paying for water from the district. At some level, the finances of the district, and possibly day-to-day operations as water flow patterns in the delivery system are changed, can be impacted.

In addition to the complex decision of self-motivated efficiency investments by delivery agencies, water scarcity is driving government regulatory efforts that demand additional measurement, use evaluation and water management tools. Federal and State contract water users have had a mandated responsibility to develop management plans for some time and they have become very sophisticated. Recent legislation calls for new water measurement requirements (SBx7-7) that question the Federal measurement criteria when it differs from State directives. However, the water rights used by the Federal government are ultimately held in trust by the State and the Federal plans will therefore likely need to abide by the California rules.

Along with new specific measurement requirements, the legislation calls for measurement and efficiency plans from the balance of all the other agricultural water delivery organizations that are as comprehensive as the existing State and Federal plans. What was previously voluntary under the California Agricultural Water Management Council “guidelines” is now mandatory. The volumetric measurement requirement is particularly vexing for conjunctive use entities. Farm operators will have to measure groundwater levels under the new legislation (CASGEM) but not crop use, whereas the delivery agency will have to measure field deliveries (SBx7-7). Obviously the water use summary equation will still have a missing component to the extent groundwater pumping occurs.

Ultimately, the issues of statewide delivery system efficiency and conjunctive use will have to be standardized to attain sustainability and the tenet that “what is measured is managed.” Perhaps the most challenging issue is the cost of the investments needed to meet the goals. If the investment results in improvements and savings that are wholly retained by the implementing agency and their customers then

they should bear the costs. If the improvements involve third parties, regions and other beneficial water uses, new mechanisms are needed to afford the desired improvements.

Box I – A groundwater dilemma from the loss of conjunctive water use

An example irrigation district in the central San Joaquin Valley has a good surface water supply based on rights and location but nonetheless is substantially a conjunctive use district by virtue of timing of the supply (often gone by late August), variability of total supply (the river hydrology) and the soil types which are largely quite sandy and therefore need frequent irrigations to meet crop demands. The delivery system is rotational and mostly manually operated. Groundwater is used heavily and is shallow to moderately deep along a generally northeast-southwest transect. Some growers in the eastern part of the District decided to forego surface water deliveries as the timing did not coincide with their needs for crop production. To optimize their crops they connected their groundwater wells to precision application systems (e.g. drip micro). While they avoided water use charges they still pay land-based charges to the District but did therefore receive a benefit of some reduced operating costs. Their groundwater is recharged by upslope neighbors who continue to use surface water and also by the delivery system (including some intentional recharge facilities) and the natural contributions from the river system itself.

Unfortunately the area downgradient from the no longer surface irrigated land is occupied by a growing community. The community relies wholly on groundwater and in fact is likely "appropriating" District recharged groundwater as the per acre entitlement of the community's correlative right is less than what is extracted due to the population density and industrial capacity and hence water use of the city. The result of the lack of applied surface water by both the upslope groundwater users and community is severalfold. First, the district has lost income from the sale of water to the upslope users. Second, there is now a groundwater overdraft to users downgradient of the collective area of the upslope groundwater users and the community. Thirdly, the land-based charges are inadequate to capitalize replacement facilities to intentionally recharge water into the ground above the community.

To mitigate the impacts from the community, the impacted downgradient groundwater users, through the District, attempted to develop various user charges on the city. This approach ended up in ongoing litigation. Zone of benefit charges to the upslope irrigators were also suggested but any changes to land-based charges would have to apply district-wide and under the California law known as Proposition 218 a District-wide election would be needed to expand the tax. Land tax elections are not an easy proposition and furthermore the community would be tax exempt since their lands are de-annexed from the District. Finally, the District now also has a portion of its water supply that previously benefitted from groundwater recharge areas that is now forced through a delivery system that was not designed for the new level of service. This is a new dilemma of significant measure with multiple consequences and no easy solutions for the individual district that began as a consequence of motivated land operators wanting to improve their crop production and financial bottom line by installing precision irrigation application technology.

2.6 How Much New Water Is Available from Agricultural Water Conservation?

Understanding the concept of recoverable versus irrecoverable fractions is critical to any discussion of agricultural water conservation. The question posed is "How much new water is available from improved on-farm efficiencies." Or better stated, "What is the potential of agricultural water conservation to create new water supplies in California?"

Caution should be used when evaluating estimates of new water available through conservation. Decisions affecting agricultural water use are dependent on many variables including crop and irrigation system selection, soil management, available water delivery systems, and water quality. Agricultural water conservation estimates are, by necessity, based on generalizations involving these variables. The methodology used to derive new water estimates, especially the basis and science used in these generalizations, should be examined carefully.

The Agricultural Water Use Efficiency Strategy in Update 2009 of the California Water Plan (CWP) presents and discusses several estimates of attainable savings in both recoverable and irrecoverable water flows at different levels of investment (Projection Level or PL), as shown in Table 9. The basis for the estimates found in the CWP were calculated in the late 1980s using a model that was developed as part of the San Joaquin Valley Drainage Program. The model estimates were later updated during CALFED's Water Use Efficiency Comprehensive Evaluation process and were reported by CALFED in 2006. A detailed discussion of how the estimates were developed can be found within the CALFED report.[19]

Table 9 – Estimates of on-farm and water supplier recoverable and irrecoverable flow reductions

ESTIMATES OF 2030 ON-FARM AND DISTRICT AGRICULTURAL WATER USE EFFICIENCY POTENTIAL					
Projection Level (PL)	Local Agency Investment Assumption	CALFED Grant Funding Assumption	Recoverable Flows Applied Water (1,000s AF/Year)	Irrecoverable Flows Net Water (1,000s AF/Year)	Regulated Deficit Irrigation (1,000s AF/Year) *
PL-1	Historic Rate	Prop. 50 only	150	34	142
PL-2	Locally Cost-Effective	Prop. 50 only	150	34	142
PL-3	Historic Rate	Prop. 50 + $15 million/yr	565	103	142
PL-4	Locally Cost-Effective	Prop. 50 + $15 million/yr	565	103	142
PL-5	Locally Cost-Effective	Prop. 50 + $40 million/year (2005-2014 + $10 million/year (2005-2030)	947	190	142
PL-150	Locally Cost-Effective	Prop. 50 + $150 million/year (2005-2030)	2,006	620	142
PL-500	Locally Cost-Effective	Prop. 50 + $500 million/year (2005-2030)	2,930	888	142

* See Box J

Reference: Volume 2, Chapter 2, "Agricultural Water Use Efficiency", California Water Plan Update 2009, Department of Water Resources, Resources Agency, State of California

The Efficiency Strategy explicitly acknowledges the difference between recoverable and irrecoverable fractions, but more importantly the idea that the amount of potential water conservation depends on the amount of money invested. The Efficiency Strategy provides some context for the different Projection Levels (PL or funding levels) presented. DWR data indicates that California has provided only $25.2 million in funding

[19] CALFED. Final Report - Water Use Efficiency Comprehensive Evaluation. CALFED Bay-Delta Program Water Use Efficiency Element. Aug 2006.

from 2002 - 2007.[20] This is in contrast to PL 5 estimates that depend on "Locally Cost-Effective" projects as well as $40 million/year from 2005-2014. This level of investment has not materialized and is unlikely to happen in the near future.

Several other aspects involving the issue of water conserved versus investment include:

- The cost of water conservation versus savings of irrecoverable fractions (i.e., new water) is not a linear function. PL-5 indicates a total of $650 million required (beyond Prop 50 money) to save 190,000 AF/year. PL-150 indicates a total of $3,750 million, over 5.5 times the PL-5 funding level, to save 620,000 AF/year, which is just over 3.2 times as much as the PL-5 yield. The marginal costs of each acre-foot savings increases as the desired savings increases (the differences between PL-150 and PL-500 are even more striking).
- The CALFED Grant Funding Assumptions beyond Proposition 50 funding do not consider whether the measures implemented are cost-effective at the farm level. Thus, it could reasonably be assumed that without available funding many of the investments required at the different Projection Levels would not be made.
- The cost estimates for developing new water through agricultural water conservation need to be compared to cost estimates from other sources of new water. Several options are available in California that would result in new water (e.g., increased storage capacity, increased use of conjunctive management, desalinization, etc.). The benefits and costs (both tangible and intangible) of water conservation must be compared to all other options for developing new water (see Box I for a summary of this issue involving energy supplies in the state.)[21]

Box J – Regulated deficit irrigation (RDI)

It is seen IN Table 9 that the amount of new water available from implementation of **regulated deficit irrigation (RDI)** is constant at 142,000 AF/year. (Regulated deficit irrigation is a management practice whereby irrigation water required to fully replace crop water use is reduced at certain growth stages. The resulting stress reduces normal crop water use.) RDI is a viable management practice but its long-term impacts have limited research on certain crops, primarily almonds and wine grapes. Research on the concept continues. Thus, the assumption is made that the practice of RDI can be expanded on these crops; it is not assumed that it will be adapted to other crops.

Box K – Energy costs and efficiency programs – an analogy

California also has energy supply issues. The California Public Utilities Commission has identified Energy Efficiency (EE) as the cheapest form of new energy supplies – up to a point. During evaluations that decide which EE programs are funded, the CPUC calculates what they term the Total Resource Cost (TRC) of the energy produced by the different programs. If the TRC is less than 1.0, then this implies that it is cheaper to buy energy on the open market (or consider a new generation facility) then it is to fund that particular program.

Reference:
California Public Utilities Commission. Energy Efficiency Policy Manual - Version 4.0", R.06-04-010 DGX/avs. CPUC. San Francisco, CA: March, 2008

Another facet of Table 9 is the implication for potential water conservation versus the current level of water use by different user types. Referring to Table 1, the eight-year averages of DWR-estimated consumptive water use by different users, and comparing them to the estimates for savings at Projection Level 5 (which

[20] Volume 2, Chapter 2, "Agricultural Water Use Efficiency", California Water Plan Update 2009, Department of Water Resources, Resources Agency, State of California

[21] California Public Utilities Commission. Energy Efficiency Policy Manual - Version 4.0", R.06-04-010 DGX/avs. CPUC. San Francisco, CA: March, 2008

have been noted as requiring a level of financing that is probably not feasible) the following statistics can be calculated:

Compared to current consumptive use: The estimated potential new water (irrecoverable inefficiencies) is only 1.3 percent of current agricultural consumptive use – (0.190 MAF/year + 0.142 MAF/year)/ 25.80 MAF/year. This is only 0.5 percent of current total State consumptive use – (0.190 MAF/year + 0.142 MAF/year)/62.66 MAF/year

Compared to total diversions: The estimated reduction in total diversions (recoverable and irrecoverable inefficiencies as well as RDI savings) is 3.9 percent of current agricultural irrigation diversions – (0.947 MAF/year + 0.190 MAF/year + 0.142 MAF/year)/ 33.22 MAF/year. This is 1.5 percent of the total dedicated water in the system - (0.947 MAF/year + 0.190 MAF/year + 0.142 MAF/year)/ 83.33 MAF/year

To put this in further perspective, the Central Valley Project Improvement Act of 1992 reallocates approximately 1.21 MAF/year to the environment and the Trinity River Fishery Restoration settlements reallocate 0.647 MAF/year in a normal water year. These two mandated reallocations alone are 2.2 percent of the total dedicated water in the system. Assuming the majority of these reallocations came from agricultural users they represent 5.6 percent of total agricultural diversions.

However, even though the estimates of conservable volumes appear to be insignificant as a percentage, depending on the timing and place of conservation they could result in significant benefits. Thus, another aspect of the data in Table 9 is identifying exactly where and when the conserved water occurs. Table 9 speaks only to the costs of conservation; it does not identify the benefits.

In summary, the CWP indicates that there are various volumes of irrecoverable fractions that could be saved given different levels of investment.[22] However, these volumes are modest relative to California's overall long term needs and current use. The marginal cost of each saved fraction increases as the total recovered volume increases. The CWP also notes that in the recent past there has been nowhere near the funding made available as shown to be required by any option in Table 9. If the new water potential indicated by Table 9 is valued by the State then the corresponding investment must be made.

2.7 Summary

Section 2 re-introduces the concept of **recoverable** versus **irrecoverable fractions**. Two illustrated examples are presented to show how this concept affects different users within a use area/basin as well as the total agricultural water use. As discussed, many complex relationships form over time within an area and thus, any sudden and/or large changes to water use patterns must be carefully considered before being implemented.

Volumetric consumptive use is just one aspect of overall water stewardship within an area. Diversions for irrigation can create third-party impacts in themselves, regardless of subsequent impacts from return flows (surface runoff or deep percolation). Thus, a continual imperative in most situations is to strive for improved on-farm irrigation efficiency.

[22] Reference: Volume 2, Chapter 2, "Agricultural Water Use Efficiency", California Water Plan Update 2009, Department of Water Resources, Resources Agency, State of California

Three major options for reducing diversions were discussed. Changing the irrigation system type to improve on-farm efficiency involves many factors and no one type of irrigation system is always better than another. There are many factors to consider in choosing and designing an irrigation system. A key factor will be management of any particular irrigation system.

Section 2 ends with a discussion of DWR's latest estimates for the potential of agricultural water conservation to develop new water supplies in California. Their estimates acknowledge the difference between recoverable and irrecoverable flows but more importantly, tie the potential savings to different levels of investment. Agriculture will make investments in water conservation to the extent that they are profitable or as may be the case, in order to satisfy a mandate. However, there are options for increasing California's water supply (including new dams, re-operation of existing systems, closer cooperation among user-types in a basin through Integrated Regional Water Management Plans, desalinization, increased use of conjunctive water management) as well as for improving natural habitats, water quality, fisheries, and recreational opportunities. The benefits and costs, both tangible and intangible, of all options must be evaluated correctly.

3.0 Impacts of Irrigation Water Diversions

Similar to the discussion on recoverable and irrecoverable fractions, the DH report also framed the issue of the impacts from diverting water for agricultural use 30 years ago. Again, these issues remain the same including both a lack of understanding of how agriculture fits into local and regional complex relationships as well as the results of agricultural irrigation impacts that need considerably more effort to manage. Perhaps the largest difference over time is the more recent high level scrutiny of the issues and some of the responding regulatory and control mechanisms that are coalescing at the same time.

The examples illustrated in Figures 1 - 4 are representative of both the complexity of issues and true impacts. The diagrams show that while inefficiencies on one field can be captured and reused, thus increasing the total efficiency over a use area, there are potential impacts on other beneficial uses of the water. Focusing solely on the volume of water allocated to one reasonable use may not take into account that there are significant competing uses and impacts to others regarding that same water.

Additionally, even though a non-beneficial fraction may be considered recoverable, and in fact that very recoverability serves to increase the irrigation efficiency as spatial boundaries of irrigation are expanded (i.e., more fields and farms in the system are considered), each use generally degrades water quality. The range of potential uses may decrease and/or the cost of a particular use may increase. A prime example of the latter situation is the potential cost of treatment to remove contaminant residues in order to meet drinking water standards.

Section 3 is a summary discussion of some of the impacts that diversions and use of water for irrigation create. Information is also presented to indicate what actions California agriculture is involved in to alleviate the negative aspects of these impacts.

3.1 A Brief Summary of Third-Party Impacts from Irrigation Diversions and Use

Contemporary and at times competing beneficial uses and impacts include, but are not limited to:

- Recreational uses of lakes and rivers – dams can provide more stable flows in rivers creating recreational uses such as boating, camping, lake swimming and mixed fishing (cold and warm species) experiences can be improved as a result. However, this may preclude other recreational uses most notably whitewater rafting and kayaking and the aesthetic of natural streams.
- Fisheries – can be impacted either by taking water from natural rivers (reduced flows and/or increased water temperature) or by the quality of return flows. Such impacts led directly to the Owens Valley lawsuits, the San Joaquin River Restoration Program, and in part to the problems in the Sacramento-San Joaquin River Delta.
- Impacts on riverine and grassland habitats with subsequent effects on wildlife dependent on this habitat.
- Impacts on water quality and subsequent available uses from local irrigation inefficiencies (either deep percolation or surface runoff), regardless of the amount that is subsequently reused by others.
- Energy use and consequent impacts on air quality and contributions to greenhouse gas generation.

Agriculture has been compelled to address many of the impacts in a variety of ways, including, but not limited to: direct reallocation of supplies to other beneficial uses, regulatory actions and voluntary actions, especially water use efficiency. The question is how much can water supplies be reduced without doing significant damage to the economic contributions of the agricultural sector or the imbedded third-party beneficiaries in localized environments. The following describes some of the contributions and efforts to meet the needs of overall third-party impacts.

3.2 Agriculture Alleviating Third-Party Effects through Reallocations and Sale/Transfers

Agriculture, as a major user of water resources in California, must play a role in alleviating unavoidable impacts of reallocations and sale/transfers. The following are short discussions of actions that include agriculture, sometimes mandated, sometimes voluntary, that have occurred and are occurring.

3.2.1 Major Reallocations of Water to the Environment

In California, many water allocation decisions were made at a time when protecting the environment was not the major consideration it is today. As a result there were significant unintended impacts on natural habitats. Some of these earlier water supply decisions have been challenged and have resulted in major reallocations back to the environment – from both agricultural and M&I users. We do not pretend that agriculture or M&I users always acceded to these reallocations. Table 10 is presented to show that there has been an on-going and significant effort to rebalance water priorities in California and that agriculture has been impacted by this effort.

Table 10 – Examples of water reallocations from agricultural and M&I users to the environment (1994-2009)

EVENT	EFFECT	BASE ANNUAL TRANSFER (AF/YEAR)	FROM -> TO
Mono Lake Settlements - 9/1994	Reduced diversions from tributary streams of Owens River to Los Angeles in order to restore Mono Lake habitat	52,200 AF/yr at time of settlement (83,000 AF/yr average export 1974-89, estimated 30,800 AF/yr exportable after Mono Lake elevation stabilized)	Los Angeles to Environment [1]
Lower Owens River Settlement – 1997	Reduced diversions and groundwater pumping in Lower Owens Valley	Estimated that Mono Lake and Lower Owens River cut LA supplies from the Owens Valley system in the range of 50%	Los Angeles to Environment [2, 3]
Central Valley Project Improvement Act - 10/1992	Reallocated 800,000 AF of Central Valley Project yield to environment; Bureau of Reclamation notes another 410,000 AF allocated to State and Federal wildlife refuges	1,210,000 AF/year	Central Valley Project Contractors to Environment [4, 5]
Trinity River Restoration - 12/2000	Increased restoration flows to Trinity River from base 340,000 AF/yr to 647,000 AF/year	647,000 AF/yr - normal water year, varies with the type of water year from 369,000 (critically dry) - 815,000 AF/yr (extremely wet)	Central Valley Project Contractors to Environment [6, 7]
Biological Opinion Regarding Impact of Delta Pumping on Delta Smelt - 12/2008 but vacated by Courts and pending reissue by U.S. Fish and Wildlife by 12/2013 - pumping restrictions remain in place	Reduce pumping to CVP and SWP users in order to protect fishery habitat in the Delta	Unquantified but MWD notes "pumping restrictions now exist in the Delta for nine out of twelve months in the year. The result is a loss of [MWD's] supply of approximately 30 percent in an average year compared to delivery levels of 2005." [9]	CVP and SWP (including agriculture and urban users) to environment [8, 9]
Biological Opinion Regarding Impact of Delta Pumping on Salmon - 6/2009 (also under challenge) - pumping restrictions remain in place	Reduce pumping to CVP and SWP users in order to protect fishery habitat in the Delta and tributary rivers	330,000 AF/yr (as per the estimate by issuing agency, National Marine Fisheries) but actions of the two Opinions overlap	CVP and SWP (including ag and urban users) to Environment [10]
San Joaquin River Restoration Program – 2009	Restore flows from Friant Dam to re-water the San Joaquin River to the junction with the Merced River	Varies with type of water year but 247,826 AF/yr in a "Normal-Dry" year and 356,281 AF/yr in a "Normal-Wet" year	CVP Contractors to Environment [11, 12, 13]

1. SWRCB Order 1631, "Decision and Order Amending Water Right Licenses to Establish Fishery Protection Flows in Streams Tributary to Mono Lake and to Protect Public Trust Resources at Mono Lake and in the Mono Lake Basin", September 28, 1994.
2. Stipulation and Order, Sierra Club and Owens Valley Committee v City of Los Angeles, et al., Superior Court of State of California, County of Inyo, Lee Cooper assigned, cas S1CVCV01-29768, July 2007.
3. "Securing L.A.'s Water Supplies", Office of the Mayor, City of Los Angeles Department of Water and Power, May 2008.
4. Central Valley Project Improvement Act, Title 34, Public Law 102-535, October, 1992.
5. http://www.usbr.gov/projects/Project.jsp?proj_Name=Central+Valley+Project, home page for the Central Valley Project, Bureau of Reclamation, U.S. Department of Interior, as of April 21, 2011.
6. Record of Decision, Trinity River Mainstream Fishery Restoration, Final Environmental Impact Statement/Environmental Impact Report, U.S. Department of the Interior, December 2000
7. Westlands Water District vs. U.S. Department of Interior, case Nos. 03-15194, 03-15289, 03-15291 and 03-15737, Argued and Submitted Feb. 9, 2004. -- July 13, 2004, United States Court of Appeals, Ninth Circuit
8. " Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project (CVP) and State Water Project (SWP)", document 81420-2008-F-1481-5, Fish and Wildlife Service, California-Nevada Region, U.S. Department of Interior, December 2008.
9. Integrated Water Resources Plan- 2010 Update, Report 1373, Metropolitan Water District of Southern California, October 2010, page 1-11.
10. "2009 Biological Opinion on the California Central Valley Project", National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, June, 2009.
11. "Notice of Lodgment of Stipulation of Settlement" - document 1341, case CIV S-88-1685 LKK/GGH, filed 9/13/2006 in the Eastern District of California (Sacramento Division) of the U.S. District Court
12. Public Law 111-11, TITLE X—WATER SETTLEMENTS. Subtitle A—San Joaquin River Restoration Settlement. PART I—SAN JOAQUIN RIVER RESTORATION SETTLEMENT ACT, March 30, 2009 at 123 Stat. 991
13. "Friant Division facts", Friant Water User's Authority, available on line at http://friantwater.org/friantdivision.html

The cumulative effects of the actions shown in Table 10, and others (e.g. SWRCB Decision 1641 salinity goals to control water quality impacts from Westside San Joaquin Valley agriculture on the South Delta), in terms of an annual reduction in agricultural and M&I water supplies are difficult to accurately quantify due to overlapping impacts and the effects of the settlements from different types of water years. The uncertainty is

compounded by the legal challenges against the Delta fishery Biological Opinions (BiOps) and the San Joaquin River Restoration Program, which have potentially significant impacts on the distribution of California's water supplies. What can be said is that there have been, and will likely continue to be, reallocations of water from both agriculture and M&I users to the environment.

3.2.2 Agriculture Has Worked Cooperatively with M&I Users to Deal with Past and Potential Future Droughts

The example depicted in Figures 3 and 4 encompasses a conjunctive water management water district. Agriculture has practiced **conjunctive water management** (also called **water banking**) for many decades. Conjunctive water management is the practice of storing excess snowmelt and rainfall in groundwater aquifers during wet years (time of excess) for later use during dry years (time of shortage).

Kern County Water Agency lists twelve agricultural-based conjunctive water management systems in Kern County alone.[23] The water banking concept continues to expand including the development and expansion of several public and semi-private water banks (e.g., Kern Water Bank, City of Bakersfield Groundwater Recharge Facility, Arvin-Edison Water Storage District, Semitropic Water Storage District).

Table 11 – Cooperative groundwater banking programs for Metropolitan Water District

PROGRAM	CONTRACT MINIMUM ANNUAL QUANTITY DELIVERABLE (AF/YEAR)	CONTRACT MAXIMUM ANNUAL QUANTITY DELIVERABLE (AF/YEAR)
Semitropic Water District	32,000	133,000
Arvin-Edison WSD	40,000	75,000
San Bernardino Valley	20,000	50,000
Kern Delta WSD	50,000	50,000
TOTALS	**142,000**	**308,000**

Source: Kern County Water Agency Reflects on Importance of Groundwater Banking for Future Planning and Habitat Conservation, a press release by Kern County Water Agency, Bakersfield, CA, 6/7/2011

Contractual agreements between cities and agricultural interests with conjunctive water management programs are increasingly more common. These agreements provide city financing to improve agriculture's existing groundwater storage facilities in exchange for the city's right to use that stored groundwater during periods of drought. Metropolitan Water District (MWD) has developed several of these agreements as shown in Table 11.

Numerous temporary and permanent transfers from agriculture to M&I have also been made as shown in Table 12.

There have also been many transfers of water between agricultural users, especially in dry water years. In some cases these have been temporary (see examples in the Bureau of Reclamation's web page listing environmental assessments @http://www.usbr.gov/mp/nepa/nepa_base.cfm?location=sccao). In other cases, they have been permanent. For example, in 2004, the members of the Broadview Water District agreed to sell the entire district (lands and water contract) to the Westlands Water District including the transfer the 27,000 AF per year entitlement of CVP water.

[23] Kern County Water Agency Reflects on Importance of Groundwater Banking for Future Planning and Habitat Conservation, a press release by Kern County Water Agency, Bakersfield, CA, 6/7/2011

Table 12 – Example transfers of agricultural water to urban uses

FROM	TO	HOW	AMOUNT	LENGTH OF AGREEMENT
Dudley Ridge Water District	Irvine Water District and Mohave Water Agency	Permanent sale of entitlement	15,757 AF/yr	Permanent [1, 2]
Imperial Irrigation District	Metropolitan Water District	On-farm water conservation	106,000 AF/ yr	Contractual [3]
Imperial Irrigation District	San Diego County Water Authority	On-farm water conservation	Up to 200,000 AF/ yr	45 years with option for renewal of 30 years [4]
Imperial Irrigation District	San Diego County Water Authority	Lining of All-American Canal	67,700 AF/ yr	110 years [4]
SWP Agricultural Contractors	SWP Urban Contractors	Monterey Amendments to SWP contracts	Up to 130,000 AF/ yr (plus 45,000 AF/year in agricultural entitlements permanently retired)	Permanent as arranged between "willing buyer and seller" [5] [ref 21a]
Sacramento Valley Agricultural Users	Metropolitan Water District	Sale	125,000 AF	2003 [6]
Oakdale Irrigation District	Stockton East Water District	Unknown	15,000 AF/yr	10 years [7]
South San Joaquin Irrigation District	Stockton East Water District	Unknown	15,000 AF/yr	10 years [7]
Kern County Water Agency	Western Hills Water District	Unknown	8,000 AF/yr	35 years [7]
Devil's Den Water District	Castaic Lake Water Agency	Sale	12,700 AF/yr	Permanent [8]
South San Joaquin Irrigation District	Cities of Tracy, Escalon, Manteca, Lathrop	Unknown	75,000 AF/yr	25 years [7]
Sacramento Valley Agricultural Users	Metropolitan Water District	Sale	27,000 AF	2008 [6]

1. MOJAVE WATER AGENCY—DUDLEY RIDGE WATER DISTRICT WATER RIGHTS TRANSFER AGREEMENT: WHY MWA SOUGHT THIS STATE WATER PROJECT TABLE A AMOUNT PURCHASE AND HOW IT HELPS WATER USERS IN THE AGENCY'S SERVICE AREA, press release (as of August 16, 2011 - saved as MWA081611.mht) of the Mojave Water Agency at http://www.mojavewater.org/home/about/NewsArticles/Mojave%20Water%20Agency--Dudley%20Ridge%20Water%20District.aspx
2. IRWD / JACKSON RANCH WATER ALLOCATION PROJECT, Initial Study and Negative Declaration, Irvine Ranch Water District, January 2010.
3. Imperial Irrigation District and Metropolitan Water District of Southern California Water Conservation Program - Final Program Construction Report, Imperial Irrigation District, Water Resources Unit, April 2000.
4. Fact Sheet- Colorado River Water Transfer Agreements, San Diego County Water Authority @ http://www.sdcwa.org/sites/default/files/files/publications/watertransfer-fs.pdf
5. Chapter 4 - Proposed Project, Monterey Decision Plus Environmental Impact Report, California Department of Water Resources, October 2007 @ http://www.water.ca.gov/environmentalservices/monterey_plus.cfm
6. Integrated Water Resources Plan- 2010 Update, Report 1373, Metropolitan Water District of Southern California, October 2010, page 1-11.
7. Hanak, Ellen, "Who Should be Allowed to Sell Water in California? Third-Party Issues and the Water Market", Public Policy Institute of California, San Francisco, CA, 2003 ISBN 1-58213-075-2.
8. Amendment 16, Water Supply Contract between State of California and Upper Santa Clara Valley Water Agency, Department of Water Resources, Resources Agency, State of California, January 1, 1992. "

3.2.3 Consequences of Reallocations

The reallocations shown in Tables 10 and 12 are occurring partly due to a reassessment of prior decisions regarding the allocation of California's water resources and partly as a voluntary response to water scarcity. Some of these prior decisions, especially those involved in the water rights that the CVP and SWP rely on, are decades old. The existing natural environment was greatly altered by those decisions. However, new environments, both natural and human, have developed based on those decisions and the resulting water use patterns. It must be acknowledged that significant new reallocation, no matter what the intention or legal basis (whether to restore natural environments or supply growing cities), does not happen without impacts to the environments created by the original allocation or activity. For example:

- Land owners along the San Joaquin River are seeking legal recourse for alleged seepage of water into their crop land as a result of interim restoration flows of the San Joaquin River Restoration Program. The dynamics of the River system have obviously changed dramatically since the Friant diversions altered the operating conditions of the River for almost 60 years.

- The Imperial Irrigation District (IID)/San Diego County Water Authority transfer was delayed due to challenges by varying interests including:
  - environmental organizations protecting the Salton Sea as the transfer would divert large amounts of water away from the Sea, hastening its salinization
  - the Imperial County Board of Supervisors have found and memorialized that some of the diversions would come from fallowing farm land within IID, the result would impact the general economy of the County

To further demonstrate the potential of unintended consequences, Figures 1 and 2 depict a situation where the improvement in on-farm efficiency helped to improve the environment in the river (assuming the recharge from the river occurred at the end of the use area). However, it resulted in some degradation of habitat within the use area and possible loss of waterfowl habitat if part of the conservation included shifting cropping patterns away from rice. A major question to be answered is the benefit/costs ratio of the improved efficiency to agriculture.

Figures 3 and 4 illustrate how on-farm efficiency improvements could lead to unintended consequences such as the loss of the city's water supply and/or increased pumping costs. Other examples of unintended consequences of reallocations are:

- A common action for improving irrigation efficiency is to change from gravity irrigation to a pressurized system, either sprinkler or drip. Both of the pressurized systems, assuming a flexible water supply (i.e., timing and flow rate of water availability is not an issue), provide easier control over the total application of water. However, they also involve the need to pressurize the water, which requires energy. Whether by an electric motor or diesel or natural gas engine, there is the potential to increase the State's energy use as well as output of greenhouse gases. The net increase or decrease in energy use depends on the specific location (refer to the examples in Appendix D), primarily the **embedded energy** in the field's water supply (see Box L).

Box L – Embedded energy

Embedded energy refers to the energy required to deliver water to the field head. In the case of a field supplied by a water well, it would be the energy used to pump water to the surface. In the case of a canal it would involve the energy needed to deliver water through the canal. For areas like the Coalinga Valley or the Wheeler Ridge-Maricopa Water Storage District, the embedded energy can be substantial. For districts where the water supply is delivered by gravity it will be zero.

- Energy use can also increase as surface water supplies are shifted away from agriculture, either through market-driven or mandated reallocations or due to drought because the replacement supply is pumped groundwater.

- As noted previously, there has been an increase in conjunctive water management programs as California strives to find ways to save excess waters in wet years for use in dry years, without the need to build new water storage. However, conjunctive water management generally requires large areas of land that can be flooded for percolation. In certain cases, this need to flood land for groundwater banking could impact grassland and upland habitat. However, interim flooding could also create wetland habitat.

It should be noted that to take full advantage of dedicated recharge basins, water must be applied continuously. This usually necessitates some combination of surface storage, conveyance and recharge basins to recharge aquifers in dry years as well as wet years.

- Another type of third-party impact occurs if cropped acreages are reduced or a different crop is grown. These are the economic impacts that can affect suppliers to the farm such as the local farm labor force; implement, fertilizer, chemical, and seed dealers; and may affect packing sheds and transportation. These indirect impacts can ripple through whole communities as economic activity is reduced or modified (e.g., Imperial County as a result of the IID/San Diego County Water Authority transfer).

3.3 Water Quality

Degradation of water quality as a third-party impact is probably the most serious aspect of poor on-farm irrigation efficiency. Water quality can be impacted by **point sources** or **nonpoint sources**. Point sources are generally defined as any single identifiable source of pollutant discharge. Examples of point sources are industrial process discharges and M&I wastewater outfalls.

In contrast, irrigation return flows such as surface runoff or deep percolation are categorized as nonpoint source pollution (NPS). NPS sources have several defining characteristics:

- The source of the problem is diffuse. That is, there are multiple sources of the problem.
- Each individual source may be operating legally. That is, the activity is in compliance with all applicable California and Federal water quality requirements and is also being conducted to prevailing local governmental and business standards. Importantly, the activity may be or may have been agreed to and/or encouraged by society (e.g. use of fertilizer to increase crop yields).
- Few, if any, of the individual sources on their own are causing a problem as a legal or practical matter.
- The problem is caused by the cumulative effect of the diffuse sources.
- The effects of NPS are generally slow to appear with the activities causing the problem often **entrenched.** This means that they are the result of long-term investments to purchase and install the activity, and in terms of management education in how to actually conduct the activity with best practices. There may be strong cultural environment built up around the activity over time.

The characteristics of nonpoint source pollution add considerable political, economic, and engineering complexity to solving these types of problems. The result of the complexity has been a very complicated process of regulations and legal challenges that ultimately added significant controls to NPS discharges from agriculture. In certain cases, this has resulted in converting some NPS to point-source regulatory schemes. For example, one portion of agricultural activities that was shifted to point source controls was confined animal feeding operations (CAFO's).

The alternate approaches to water quality control, point source and non-point source regulation, also add significant more complexity to the interface with water supply management, conservation and stewardship.

The responses and tools to solve the water quality problems recently used are; additional required monitoring of the environment to evaluate the impacts of irrigated agriculture, and, either specified (point source) controls, broad collective controls and practices (because of the previously noted diffuse nature of NPS) or coordinated voluntary controls and best management practices. Additional applied research is needed to integrate water conservation and mandated or voluntary water quality management requirements. The issue of water quality has become critical and the evidence is clear that agricultural operations will need to add to the tools already in use for conservation and also include water quality in their approach. Water quality issues will be an ongoing source of management and protection needs.

3.4 Salinity, Drainage, and Nonpoint Source Pollution

Agriculture has been charged with curtailing nonpoint source pollution. To the extent that NPS from irrigation can be reduced through reducing surface runoff and excess deep percolation, the long-term productivity of soil will not be affected. However, you cannot practice irrigated agriculture without creating a certain amount of sub-surface drainage.

All irrigation water contains some level of salts. Thus, as irrigation proceeds, salts are continually being added to the soil. Most fertilizers contain salts and consequently salts are added through the use of commercial fertilizers or manure. Depending on the interactive chemistry of the water and the soil, soil salts may be dissolved or precipitated within the effective root zone. Excessive, or imbalanced, dissolved salts can cause four types of direct problems for irrigated agriculture:

1. General yield declines – dissolved salts create **osmotic forces** which act in the same manner as the water-holding forces that the soil structure creates (termed **matric forces)** – they tend to hold water back from the plant. Effectively, excessive dissolved salts increase moisture tension and reduce the amount of available water in the soil causing additional stress on the crop.

2. Soil structure problems – sometimes it is not the total amount of dissolved salts that is important, rather it is the relative amount of different types of salts. If the different types of salts are out of proportion, coincident with certain types of soils, soil structure problems can result, generally manifested as low permeability (low infiltration rates). It becomes difficult to get water to soak into the ground and root penetration and expansion is poor. The imbalance occurs if there is too much sodium in relation to magnesium and calcium in the soil water. However, the type and amount of clay in the soil texture also helps determine the extent of the problem. Note that the near absence of salts in the irrigation water can also cause infiltration problems.

3. Specific ion toxicities – some salts, while necessary for crop growth in proper amounts, can be toxic in excessive amounts. A prime example is boron. A benchmark of poor irrigation water quality for many growers is water that contains 1 part per million of boron or more.

4. Corrosion and other miscellaneous problems – salts can cause excessive corrosion of some irrigation system hardware. Depending on the specific chemistry, certain waters may require special handling or treatment to prevent clogging of drip irrigation systems.

There are also indirect problems. Salts in the soil must be kept under control and that means that some salts must be moved from the effective root zone to somewhere else. That “somewhere else” can cause both

environmental and political problems. The high concentration and/or specific types of salts in the drainage streams can cause serious detrimental impacts to fisheries, wildlife habitats, and downstream agriculture. However, not dealing with salinity and drainage can result (has resulted) in farmland going out of production, with resulting impacts to local businesses directly and indirectly dependent on agriculture.

Specific management techniques have developed for dealing with the direct effects of salt crop production. The two most common include maintenance leaching to maintain a proper salt balance in the soil and the addition of chemical amendments to the soil or irrigation water to maintain the correct balance of salts. Assuming there is an acceptable amount and balance of dissolved salts in the effective root zone, leaching is required to prevent excessive amounts of salt from accumulating. Leaching is the process of intentionally causing (or just coincidental as would be the case with a heavy rainfall) deep percolation in order to carry salts out of the root zone. A certain amount of leaching is required for all irrigated agriculture to prevent excessive salts from building up in the root zone. The key question is where does this deep percolation go?

There must be sufficient internal drainage in the soil so that the required deep percolation does not cause saturated conditions within the effective root zone. This drainage can be natural – that is, the soil profile is such that the deep percolation continues downward, or moves sideways, out of the effective root zone. The concern here is the effect of that deep percolation on any groundwater it reaches. Regardless of any nutrients or chemicals that may have leached out of the root zone, the deep percolation will always carry salts.

Another option for drainage occurs if there is insufficient internal drainage. This situation arises when an impermeable layer of rock or clay soil occurs relatively near the soil surface. With no other provision, deep percolation will create a saturated zone in the soil that can extend up into the root zone. In these situations, **tile drain systems** can be installed (so named because the first such systems used sections of clay pipe as the conduits). These are systems of perforated, polyethylene pipe buried at various depths and spacings. The perforations allow the deep percolation to enter the piping system. The percolation is then gathered up at collection points and pumped to the surface for disposal. The key question is where is the endpoint of disposal? The drainage pumped to the surface has the potential to contaminate surface waters depending on location and method of disposal.

One of the major farming areas in California that likely will continue to use artificial drainage is the Tulare Lake Basin north to the San Joaquin River on the west side of the San Joaquin Valley. Unfortunately, drainage flows originating from this area can contain naturally-occurring elements such as selenium and arsenic that are toxic to biological organisms at high concentrations. As the detrimental effects of this drainage became known, primarily through the experience at the Federal Kesterson reservoir in the mid-1980s, drainage outflows to the Delta from these areas were curtailed. (Pumped outflows from the Westlands Water District subsurface drainage system were stopped in the late 1980's.) They will become entirely prohibited under a timetable adopted by the State Water Quality Control Board.[24]

Many lawsuits have been filed as a result of the drainage issues in this area. Some have been concerned with the impacts of subsurface flows from upslope areas. Others have been concerned with lack of drainage facilities that were originally promised by the US Bureau of Reclamation.

[24] "Water Quality Control Plan for the Sacramento and San Joaquin River Basins", Central Valley Regional Water Quality Control Board, California Environmental Protection Agency, Fourth Edition, September, 1998.

Drainage challenges continue. Extensive research has been done to develop a sustainable farming model using integrated on-farm drainage management (IFDM). [25] [26] [27] There has also been land fallowing and there will likely be more:

- The U.S. District Court in 2002 ruled that the United States was responsible for providing drainage in the San Joaquin Valley although the final system/solution didn't have to consist of an interceptor drain and ocean outlet. Subsequently the Bureau of Reclamation issued their Final EIS for the "San Luis Feature Reevaluation" in March 2007. The Preferred Alternative for providing for drainage is retirement of some 200,000 acres in the drainage impacted area. This program has not started due to continuing negotiations among the various stakeholders.[28]

- Irrigated land has been fallowed due to lack of water supplies (either because of drought, original contract, or environmental requirements) while other land has been fallowed as a result of soil salinization or high water tables. The Westlands Water District 2003-2004 Annual Report notes that the district bought or intended to purchase about 100,000 acres to be fallowed, some permanently, by the end of 2004.[29] This effort was driven by lawsuits brought by landholders complaining that contractual drainage services were not provided.

- Salt management in the San Joaquin Valley is a larger issue than areas just lacking internal soil drainage. The entire Tulare Basin hydrologic area is essentially a “closed” basin that has only infrequent flood flows out into the San Joaquin River system. The combination of high evaporation and extremely slow groundwater movement results in long-term salt accumulation in the Basin.

Salinity and drainage management has also been addressed by high efficiency irrigation systems in terms of reducing the total amount of sub-surface drainage developed on an annual basis. Many existing tile drainage systems have gone dry or have substantially reduced volumes. Of particular note is the Grasslands sub-watershed that has used both irrigation efficiency and recycling to reduce the drainage volume by 85 percent. The recycling and reuse has involved using very salt tolerant plant species experimented with under the previously mentioned IFDM process. Nonetheless, many productive agricultural areas will continue to have the potential for drainage problems and additional strategies and technological advances will be needed to address long-term salt management issues.

[25] Salt Utilization Final Report, Salt Utilization Technical Subcommittee, San Joaquin Valley Drainage Implementation Program/University of California, Davis Salinity/Drainage Program, California Department of Water Resources, February 1999.
[26] Westside Resource Conservation District and The Center for Irrigation Technology, A Landowner’s Manual for Managing Agricultural Irrigation Drainage Water: A guide for developing Integrated On-Farm Drainage Management Systems. Fresno, CA: 2004.
[27] Westside Resource Conservation District and The Center for Irrigation Technology, A Technical Advisor’s Manual for Managing Agricultural Irrigation Drainage Water: A guide for developing Integrated On-Farm Drainage Management Systems. Fresno, CA: 2005.
[28] Final EIS, San Luis Feature Reevaluation, Mid-Pacific Region, Bureau of Reclamation, U.S. Department of Interior, March 2007. @ http://www.usbr.gov/mp/nepa/nepa_projdetails.cfm?Project_ID=61
[29] 2003-2004 Annual Report. Westlands Water District. Fresno, CA. page 2. 2004

4.0 Looking to the Future

4.1 Going beyond Irrigation Efficiency

Water conservation in agriculture is not a matter of farmers "just doing what they know they should." The decisions involved are extremely complicated and encompass operational, economic, and legal issues. It is time to go beyond the arguments surrounding irrigation efficiency on whatever spatial scale (field, farm, district, or basin). The authors believe that the concepts of recoverable versus irrecoverable fractions are well documented. Regardless of water use efficiency in terms of consumptive use alone, there are many other aspects to diverting and using water for irrigation.

At this point the discussion moves beyond one grounded in science (e.g., irrigation, environmental, water quality) to a more general discussion of agricultural water stewardship and becomes more socio-economic in nature. As with all public policy issues, the arguments can be objective (e.g., more economic benefit can be generated from an acre-foot of water delivered to Silicon Valley than to the San Joaquin Valley) or subjective (e.g., maintaining X miles of Wild and Scenic rivers is a moral imperative). Further, while there may be tangible benefits associated with any one argument, California voters may favor the intangible.

The movement towards this type of discussion is on-going. The authors point to a recent paper presented to the SWRCB by the Delta Watermaster calling for a re-evaluation and, possible expansion and/or more rigorous application, of California's constitutional imperative that water be reasonably and beneficially used.[30]

Another indicator can be found in California Senate Bill SBx7-7, The Water Conservation Act of 2009. One of the mandates of SBx7-7 is that DWR, in conjunction with all stakeholders, is to "…develop a methodology for quantifying the efficiency of agricultural water use."[31] As a starting point to stakeholder outreach, DWR staff distributed a Draft Discussion Paper. In it they wrote:

> *DWR staff defines the "quantification of the efficiency of agricultural water use" as a concept that can be applied at different scales with different indicators, to reflect a degree to which water diverted from surface or groundwater systems serves a desired effect. Ultimately the desired effect associated with agricultural water use is to produce agricultural goods.*
>
> *However, the concept of quantifying the efficiency of agricultural water use does not universally correlate to the concept of "water use efficiency', which is often considered to be an indicator of the ratio of (1) water consumed by a crop for evapotranspiration, or (2) water applied to a field to serve the crop's ET demand. Rather, DWR staff view the concept of the efficiency of agricultural water use to incorporate a range of information and indicators, requiring data collection and calculations for different locations, scales, and time periods in the water delivery system.* [32]

It is clear from the DWR comments that a priority topic for stakeholder discussions is to define (or what the developed methodology would define) what is meant by the term **water use efficiency (WUE)**. However,

[30] Wilson, Craig, "The Reasonable Use Doctrine and Agricultural Water Use Efficiency ", Report by Delta Watermaster presented to California State Water Resources Control Board, January 19, 2011.

[31] Water Conservation Act of 2009 at 10608.64, Senate Bill 7, Filed with Secretary of State November 10, 2009, State of California

[32] California Department of Water Resources, Resources Agency. 2002. Discussion Paper 1: Quantifying the Efficiency of Agricultural Water Use (Project A1). State of California. July 16, 2002.

WUE is a specific type of terminology in irrigation science that brings in the idea of how much economic good is achieved by irrigation. A common relationship to describe WUE, although there are many in use, would be:[33]

$$WUE = Yg / ETc \qquad [2]$$

where:

WUE = water use efficiency in tons of crop per acre-foot
Yg = tons of crop produced
ETc = evapotranspiration of the crop

Note that one might use gross applications of water or the net application of water after recoverable fractions are considered rather than ETc (the consumptive use of the crop). The latter might be important when considering supplemental irrigation systems – that is, systems that do not apply the majority of water (minus rainfall) needed for crop ETc.

The important aspect of using WUE is the denominator (the per unit water used component) can reference a specific type of water use. Some point to the use of WUE only as a crop-to-crop issue to identify the total economics of using one irrigation system or another. Thus, one might compare the WUE for cotton on furrow irrigation versus cotton using row crop drip irrigation. It is true that micro irrigation is typically seen as more efficient than flood irrigation, although to what degree will depend on the individual situation. It is also generally true that yields will be higher under micro irrigation.

However, switching to micro irrigation over flood usually involves substantial cost – not only direct costs to the user in terms of the cost for equipment and energy for system pressure, but also to society in terms of the effort involved in manufacturing, delivering, installing, and operating the system (operating in the sense that the energy use could contribute to green house gas emissions). The question becomes one of total economics and a WUE definition that considers all of these aspects to help identify the total impact of switching from flood to micro on cotton – that is, the numerator could become "net income per acre-foot."

The WUE can be used as a planning tool at a macro level. That is, those areas with higher WUEs than others should get more water. One might compare the WUE for cotton in a theoretical area A versus that for cotton in area B. However, differences in WUE from area to area might be due to any number of factors including total heat units, quality of available water supplies, soil types and fertility, and possibly different pest/disease complexes – regardless of the irrigation efficiency in either area.

It could be that the actual WUE measure should be "$ gross product to the State per unit water applied." If using WUE in terms of dollar income per unit water, one might compare the WUE of alfalfa versus cotton. Conceivably one might compare the WUE for water used by a computer chip manufacturer to the WUE of a cotton producer. Taking this approach could be seen as moving towards centralized government planning versus a) allowing the marketplace to determine which crops are grown and where and b) respecting the system of California water rights that became formalized with the 1914 Water Commissions Act.

[33] Howell, Terry. Irrigation Efficiency.2003. Published in Encyclopedia of Water Science DOI: 10.1081/E-EWS 120010252, Published by Marcel Dekker, Inc.

The SBx7-7 process established an important concept that whatever methodology is developed for WUE should be results-driven. The key issue is to define what needs to be accomplished with this effort before the methodology, which as noted by DWR could encompass any number of indicators, can be developed.

Stakeholder comments serve to show the divergence of views as to the proper definition for WUE to be used. Thoughts include:

- Defining a WUE using only a "hydraulic efficiency" component would seem to ignore the basic purpose of irrigated agriculture, which is to produce a profitable crop.[34]
- Including crop production aspects in defining WUE is not valid since there are many other factors besides water management that affect crop production.[35]

Box M – Production efficiency increases

Although water availability and costs are important factors, there are many other political and market-based forces that affect agriculture, including commodity prices, plant diseases, pest infestations, labor availability, and globalization of markets. This has resulted in major shifts in cropping patterns and irrigation methods shown in Tables 6 and 7.

Agriculture has also become more efficient in general. For example, note the improvement in the yield of Cotton Bales/Acre shown in Table 6 and the increase in Gross Sales and Net Income shown in Table 13. Increased efficiency can be a result of many factors including better plant varieties, improved fertilizer/pesticide management, and higher water use efficiency. In the case of cotton, it might also be a factor of production being moved to the highest yielding fields (soils).

Table 13 – Gross and net income from products sold as reported by USDA Census of Agriculture*

	1987	1997	2007	% CHANGE 87 - 07
Market Value of Products Sold	$13,922,234	$23,032,259	$33,885,063	143.3%
Net Farm Income from Products Sold	$3,004,641	$6,215,006	$6,922,423	130.4%

* Values are not corrected for inflation

SOURCES:

1. "Highlights of the State's Agriculture: 1992 and 1987", Table A, 1992 Census of Agriculture, Volume 1, Part 5 California State and County Data, AC92-A-5, Economics and Statistics Administration, Bureau of the Census, U.S. Department of Commerce, 1994
2. "Historical Highlights: 1997 and Earlier Census Years", Table 1, 1997 Census of Agriculture, California State and County Data, AC97-A-5, National Agricultural Statistics Service, U.S. Department of Agriculture, March 1999
3. "Historical Highlights: 2007 and Earlier Census Years", Table 1, 2007 Census of Agriculture, California State and County Data, AC97-A-5, National Agricultural Statistics Service, U.S. Department of Agriculture, December 2009

[34] Department of Water Resources, Resources Agency. California's Groundwater, Bulletin 118 Update 2003. State of California: October, 2003.

[35] Buis, Alan. 2009. NASA Data Reveal Major Groundwater Loss in California. press release of the Jet Propulsion Laboratory at the California Institute of Technology, Pasadena, CA, December 14, 2009 @http://www.jpl.nasa.gov/news/news.cfm?release=2009-194.

4.2 Continuing Challenges but Continuing Efforts

Water allocation and use in California continues to be as contentious and challenging as ever. An abbreviated list of issues includes:

- Fixing the Sacramento-San Joaquin River Delta - both of the Biological Opinions noted in Table 10 have been challenged and the Delta Smelt BiOp has been partially overturned and remanded to the FWS for further amendment.[36] This is in addition to current studies being carried out by the National Academy of Science regarding the recommended actions of the BiOps and also potential coordination of all actions aimed at protecting the Delta Smelt and salmon.[37] [38]

- Lawsuits claiming third-party impacts from the San Joaquin River Restoration decision have already been filed.[39] In addition, proposals are under consideration that would block the San Joaquin River Restoration Program (SJRRP).[40]

- There is continuing and serious groundwater overdraft south of the Delta.

- A recent report from DWR indicates that on average (depending on the type of water year) the SWP can only deliver about 65 percent of contracted water under current conditions. This falls to about 62 percent under future conditions, which includes accounting for the effects of climate change.[41]

- The current long-term drought in the Colorado River Basin and the Quantification Settlement Agreement between the Colorado River Basin States and the Federal Government has reduced California's base use of the Colorado River.[42]

The list of challenges would not be complete without mentioning the potential impacts of climate change, regardless of cause. Volume 1, Chapter 2 of the California Water Plan Update 2009 is titled "Imperative to Act." It details the important issues facing California water management and includes this statement regarding climate change:

> *California is already seeing the effects of climate change on hydrology (snowpack, river flows), storm intensity, temperature, winds, and sea levels. Planning for and adapting to these changes, particularly their impacts on public safety and long-term water supply reliability, will be among the most significant challenges facing water and flood managers this century.*[43]

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[36] Final Judgment, Delta Smelt Consolidated Cases, Case 1:09-cv-00407-OWW-DLB Document 851 Filed 03/29/11, United States District Court, Eastern District of California

[37] "Statement of Task", Committee on Sustainable Water and Environmental Management in the California Bay-Delta, Project DELS-WSTB-09-09, The National Academies, Washington DC, November 2009.

[38] "A Scientific Assessment of Alternatives for Reducing Water Management Effects on Threatened and Endangered Fishes in California's Bay Delta", Committee on Sustainable Water and Environmental Management in the California Bay-Delta; National Research Council of the National Academies, ISBN 978-0-309-12802-5, National Academies Press, Washington, D.C., 2010.

[39] Wolfsen Land & Cattle, et al v. United States, United States Federal Claims Court, case 1:2010cv00580, filed April 26, 2010.

[40] 112th Congress (2011-2012), H.R.1837.IH, San Joaquin Valley Water Reliability Act, Sponsor: Rep Nunes, Devin [CA-21] (introduced 5/11/2011)

[41] California Department of Water Resources, Resources Agency. 2010. Summary of Final State Water Project Delivery Reliability Report, 2009. State of California. September 27, 2010.

[42] Record of Decision, Colorado River Water Delivery Agreement, Bureau of Reclamation. U.S. Department of Interior, October 2003.

[43] California Department of Water Resources, Resources Agency. 2009. Imperative to Act, Chapter 2, Volume 1, California Water Plan Update 2009. State of California @ http://www.waterplan.water.ca.gov/technical/cwpu2009/

The key issue for flood and water management is the expected change in precipitation rates and patterns, especially as it relates to winter snowpack. The snowpack is California's largest surface reservoir, retaining precipitation and then (ideally) releasing this stored water gradually during the spring and summer. This reduces the number and size of man-made dams and levees needed for flood protection. It is also used to create the required flexibility in water delivery timing and place. The snowpack is expected to decrease, resulting in more precipitation falling as rain becoming immediate runoff rather than stored as snow. The immediate runoff would increase the pressure on the existing system of dams and levees. This change would also affect hydroelectric generation and could contribute to more frequent drought events. [44]

Efforts to address these challenges continue to evolve. One of the latest is the development of Integrated Water Management Plans (IRWM Plans) for various basins, sub-basins and/or areas of common interest. There are currently 48 regional groups in California. They cover the water management gaps between local independent water entities and the larger State, Federal and regional water management systems. Partners in most integrated regional plans have found that they are already connected and by sharing assets are exploring other ways of connecting synergistically – that is, the larger effort provides more benefits than the individual participants anticipated.

The largest connection in the San Joaquin Valley is the groundwater basin. The basin has no real local barriers or boundaries except the mountains on the periphery. Numerous examples exist where linking one agency's distribution and management system to others has had a substantial net benefit to all. In a previous section on delivery systems there was a discussion concerning water to wildlife areas that are interrupted partly by District efficiency investments. Yet, in the same general area an agricultural water district provides direct delivery to a federal wildlife area and in fact has made system improvements that assist both the District agricultural delivery capabilities and refuge water. In other areas, one agency can serve as a recharge agency for another (the Pixley Irrigation District case in Box D) and improve groundwater levels. Alternately, an agency that has invested in conservation techniques can sell the conserved water. Improving delivery infrastructure by one agency may reduce the shared reliance on groundwater, hence decreasing the pumping level and energy costs for both areas. It may seem that such coordination could have occurred previously but often entities did not explore these options because there were not sufficient incentives. It is important to communicate on an integrated level so that regional needs are considered (e.g., discussions occur between cities and irrigation districts overlying the same groundwater).

In several locations in this report the reader is introduced to the words "agricultural water stewardship."[45] It is useful to explain the concept surrounding the "stewardship" as it provides a more global framework to address agricultural water use and its attendant complexities. The concept embraces the notion that agriculture has become part of the fabric of many local watersheds and their associated ecosystems. Therefore, any plans to attain new efficiencies or alter the water landscape must understand the interdependence that the agricultural region has developed. The agricultural areas of watersheds have both pluses and minuses when it comes to managing or sustaining the natural environment and it remains an imperative to understand all the consequences of modifying the agricultural environment. Clearly, impacts such as the introduction of contaminants into groundwater must be corrected. It has taken time for many

[44] California Department of Water Resources, Resources Agency. 2008. Managing an Uncertain Future - Climate Change Adaptation Strategies for California's Water. State of California, October 2008.

[45] California Roundtable for Water and Food Security, California Agricultural Water Stewardship Initiative, Ag Innovation Network, Sebastopol, CA: June 2011

events to accumulate and it will take time to reverse such conditions. Furthermore, many such activities were the result of legal acts: it is through an understanding of the science of those acts that allow cooperative solutions by stakeholders. The "stewardship" concept covers all of these collective efforts with the overall goal of reaching economic, environmental and social sustainability.

5.0 Summary and Conclusions

5.1 Summary

The purpose of this paper is twofold: 1) to re-introduce the concept of recoverable and irrecoverable inefficiencies discussed in the DH Report that dispel the myth of gross irrigation inefficiency by California agriculture; and 2) to provide a summary discussion of the major contemporary issues and impacts regarding agricultural water use in California and in so doing, to provide a broader perspective of the role agriculture is playing to help solve the pressing water issues facing California.

In fulfilling these purposes this paper has discussed the following concepts and facts:

1. Deep percolation and surface runoff fractions resulting from irrigation events are either recoverable or irrecoverable. The importance of the concept is that much of the water in these fractions are recoverable and are reused by other farms, M&I users, and the environment.

2. Understanding recoverable versus irrecoverable fractions includes acknowledging the interrelationships of water users and that changing water use patterns, especially in a limited time frame, can create negative third-party impacts and unintended consequences.

3. Water diversions and use for irrigation can create impacts in itself, regardless of the irrigation efficiency (at whatever scale – field, farm, district, or basin). In most situations there is a continued imperative to reduce diversions.

4. The major options for reducing water diversions were identified and discussed: reducing cropped acreage (not really conservation but rather a transfer of water out of agriculture), reducing crop ETc, and improving seasonal irrigation efficiency. The role of water agencies in helping to improve on-farm efficiencies, as well as the need to improve district operations (reduce spill and seepage losses) was also identified.

5. The range of on-farm irrigation efficiencies for different irrigation system types was presented. The choice of a particular irrigation system is dependent on many factors. It cannot be said that any one type of irrigation system is always better than another. For example, in some situations a furrow irrigation system may provide close to, if not the same, irrigation efficiency as a micro system and may also prove to be the better business decision.

6. Within the discussion of reducing diversions it was identified that major shifts have occurred in both cropping patterns and irrigation system types (e.g., orchard acreage increased 150 percent from 1978-2007 while cotton acreage decreased by 69 percent, drip irrigated acreage increased by 150 percent from 1994-2008 while gravity system acreage decreased by 19 percent). It was pointed out

that these shifts were market-driven and occurred over time. Large-scale, short-term, mandated shifts would likely have unforeseen consequences.

7. The latest estimates for agricultural water conservation from the Department of Water Resources were presented and discussed. It was noted that these estimates recognize the difference between recoverable and irrecoverable fractions. It should be noted that any level of conservation depends on the level of investment. As conserved volumes increase, the marginal cost of each increment increases. The benefits and costs (tangible and intangible) of all options for satisfying the needs of water users in California need to be identified and compared.

8. Regardless of overall irrigation efficiencies, diversion and use of water for irrigation will create many types of impacts. These impacts were summarized and the role of agriculture in alleviating some of the impacts was discussed. Tables were presented showing the significant amounts of water reallocated back to the environment from both agriculture and M&I users starting with the Owens Valley decisions. Also noted was the cooperation between agriculture and M&I users in coping with and planning for droughts.

9. It was also pointed out that large-scale reallocations affect current environments and do not come without consequences. Third-party impacts from reallocations, no matter the purpose or basis, have been noticed by the courts.

10. Arguably the most important impact from irrigation return flows is the potential for nonpoint source pollution (NPS). The current Conditional Waiver for agriculture issued by the Central Valley Regional Water Quality Control Board is an example of efforts being implemented to reduce and curtail NPS from agriculture.[46] [47] It is important to note, that to maintain soil productivity and crop yields that some irrigation water is used for deep percolation to leach excessive salts from the root zone. The important question, and still unresolved, is the ultimate disposal (fate) of these accumulated salts.

11. Finally, the paper looks to the future and proposes that the controversies surrounding irrigation are moving from a discussion solely regarding irrigation efficiency to one of overall water stewardship. One result of this movement could be the development of some type of metric using the term "water use efficiency," that would include some measure of economic good produced as a result of using water for irrigating agricultural crops

[46] California Regional Water Quality Control Board. Order No. R5-2006-0053, Coalition Group Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigation Lands. Central Valley Region. June 22, 2006.
[47] California Regional Water Quality Control Board. Resolution No. R5-2011-0032, Short-term Renewal of the Coalition Group Conditional Waiver of Waste Discharge Requirements for Irrigated Lands. Central Valley Region. June 9, 2011.

5.2 Conclusions

A fundamental purpose of this paper was to point out the fallacy that agricultural water conservation can result in sufficient new water to solve the problems of water management or at least provide the volumes of water desired by all users in California. However, it seems clear that the likely focus going forward will be on efforts to reduce and reverse the impacts of agricultural water uses on water quality and the environment. Establishing sustainable groundwater supplies must also be a priority.

Agricultural water use is not an isolated activity. Rather, it is imbedded in local and regional environments that are often co-dependent and/or impacted by decisions and activities of the local agricultural water users. (These potential impacts were illustrated by the examples in Figures 1 - 4.) The most viable approach to improved agricultural water management is from the bottom up and any major changes must be vetted through a local impacts analysis.

It appears that our society is entering an age where the limits of both our natural and economic resources have been reached. California is dealing with several critical resource management issues at the same time – energy supply and costs, air quality, water quality, and the overall water supply, not to mention the unknown future effects of climate change. It is imperative that this be done in an integrated manner.

Regarding California's total water supply, there is not enough developed water now to serve all interests at their desired levels (considering enterprise economics as well as operational factors). There is also little political will (e.g., fears that voters will not support the $11 billion worth of water infrastructure and management improvement bonds in the midst of a serious recession[48]) and scarce economic resources available to build new infrastructure as both State and Federal budgets are currently impacted by large annual deficits and long-term debt.

The emerging questions then seem to be:

1. What allocation of available water resources leads to a sustainable situation?
2. On what basis is an allocation made?
3. What level of investment will be or can be made?
4. Which investments take priority?

Regarding the potential for agricultural water conservation to fix the water management problems in California, it is strongly evident that the major findings of the DH Report still stand (see Appendix E). A central tenet continues to be the need for a broad understanding of the concept of recoverable versus irrecoverable fractions when examining the potential for water conservation within agriculture. Claims of excessive irrigation inefficiencies, with resulting large volumes of new water available, are wrong for the same basic reason that the DH Report enumerated in 1982 – much of purported agricultural waste is recovered and reused by other agricultural interests, as well as by M&I or the environment.

[48] McGreevy, Pat, "California Water Bond Pushed Back to 2012", Los Angeles Times, Los Angeles, August 10, 2010

Regardless of what actual amount of net water savings would result, the authors emphasize that on-farm water conservation is a continual imperative, not just to create new water but to alleviate other, sometimes unavoidable, impacts such as impaired water quality and habitat degradation.

The authors want to make it clear that the issues facing California have gone beyond those that prompted the DH Report. The discussion needs to move to one of acceptable sustainability for all stakeholders, given that there are any number of steady-state solutions available. For example, one constant and critical issue that has continued over the past 30 years is groundwater overdraft. This issue alone, if not addressed in a timely manner, may ultimately seal the fate of much of San Joaquin Valley agriculture. An important goal for agriculture is to play a leading role in designing a plan that provides a sustainable groundwater supply, as well as targeting long-term improvements in both surface and groundwater quality.

A recent paper by the Public Policy Institute of California (PPIC) lists eight myths surrounding California water management that are seen to be impeding the development of real solutions. They are listed in Table 14.

Table 14 – Eight myths surrounding water use as identified by the Public Policy Institute of California

MYTH	REALITY
1. California is running out of water.	California has run out of abundant water and will need to adapt to increasing water scarcity.
2. [Insert villain here] is responsible for California's water problems.	There is no true villain in California water policy, but opportunities exist for all sectors to better use and manage water.
3. We can build our way out of California's water problems.	New infrastructure can contribute to California's water supply solutions, but it is not a cure-all.
4. We can conserve our way out of California's water problems.	Water conservation is important, but its effectiveness is often overstated.
5. Healthy aquatic ecosystems conflict with a healthy economy.	Healthy ecosystems provide significant value to the California economy, and many opportunities exist for mutually beneficial water management.
6. More water will lead to healthy fish populations.	Fish need more than water to thrive.
7. California's water rights laws impede reform and sustainable management.	The legal tools for reform are already present in California's water rights laws; we just need to start using them.
8. We can find a consensus that will keep all parties happy.	Tough tradeoffs mean that consensus is not achievable on all water issues; higher levels of government will need to assert leadership.

Source: Hanak, Ellen, J. Lund, A. Dinar, B. Gray, R. Howitt, J. Mount, P. Moyle, B. Thompson, "California Water Myths." Public Policy Institute of California, San Francisco, CA, 2011.

The authors would point out two things. First, PPIC agrees that the potential for water conservation (agricultural or M&I) to fix the situation is widely overstated. But most importantly, the PPIC paper points to the involvement of all stakeholders in creating the problems California is facing and the absolute need for cooperation among all stakeholders to solve these problems. PPIC stated it very well in the introduction of their paper:

> *Often, myths serve the rhetorical purposes of particular stakeholders. And they persist because our public policy debates are not sufficiently grounded in solid technical and scientific information about how we use and manage water. In combating these myths, we hope to set the stage for a more rational and informed approach to water policy and management in the state.*[49]

[49] Hanak, Ellen, J. Lund, A. Dinar, B. Gray, R. Howitt, J. Mount, P. Moyle, B. Thompson. 2011. California Water Myths. Public Policy Institute of California, San Francisco, CA, 2011.

It is the intention of the author's that the paper serve as an important addition to the ongoing discussions about California water and specifically what decisions must be made to assure adequate supplies for the future. The scientific and technical information presented in this paper should provide a valuable tool in moving the discussions forward.

Among the study's key findings are:

- The estimated potential new water from agricultural water use efficiency is 1.3 percent of the current amount used by the state's farmers – about 330,000 acre-feet per year (at funding level PL-5 of the Department of Water Resources latest California Water Plan Update 2009). That represents about 0.5 percent of California's total water use of 62.66 million acre-feet.
- Groundwater overdraft of about 2 million acre-feet per year continues to be a serious problem in certain regions of California because of inconsistent and uncertain surface water supplies.
- Changes in irrigation practices, such as switching from flood irrigation to drip, have the effect of rerouting flows within a region (or basin) but generally do not create new water outside of the basin.
- Previous reallocations of agricultural water supplies for environmental purposes represent at least 5 percent of farm water diversions depending on water year.
- On-farm water conservation efforts can affect downstream water distribution patterns, with potential impacts on plants and animals, recreation, as well as human and industrial consumptive uses. The effects can be positive or negative and also inconsistent (e.g., on-farm conservation could reduce a city's water supply but improve the nonpoint source situation).

Appendices:

A. List of Acronyms, Boxes, Figures and Tables
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APPENDIX
Agricultural Water Use in California:
A 2011 Update

Appendix A
List of Acronyms, Boxes, Figures and Tables

AAC	All American Canal
AB	Assembly Bill, legislation originating in the California State Assembly
ACWA	Association of California Water Agencies
AF	acre-foot (1 AF/ac = 1-ft depth of water) = 325,853 gallons
AF/yr	acre-foot/year
AC	acres
BiOp1	a Biological Opinion issued by the U.S. Fish and Wildlife Service regarding the impact of SWP and CVP operations in the Delta on the Delta Smelt and other listed fish species
BiOp2	a Biological Opinion issued by the National Marine Fisheries Service regarding the impact of the SWP and CVP operations in the Delta on salmonoid species
CALFED	a consortium of state and federal agencies with jurisdiction over various aspects of water management in the Sacramento-San Joaquin River Delta charged with developing a plan to alleviate the long term problems of the Delta. Their Record of Decision (ROD) was published in August, 2000.
CDFA	California Department of Food and Agriculture
cfs	cubic feet per second
CR	required leaching ratio
CWA	Federal Clean Water Act of 1972
CWP	California Department of Water Resources Bulletin 160 - 2009 Update to California Water Plan
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act of 1992
CSU	California State University
Delta	Sacramento-San Joaquin River Delta
DFG	California Department of Fish and Game
DH Report	Agricultural Water Conservation in California with Emphasis on the San Joaquin Valley by David C. Davenport and Robert M. Hagan was published by the Department of Land, Air, and Water Resources at the University of California at Davis - October, 1982.
DU	distribution uniformity
DWR	California Department of Water Resources
EPA	Environmental Protection Agency
ET	evapotranspiration
ETc	net crop water use

IE	irrigation efficiency
FWS	U.S. Fish and Wildlife Service
gpm	gallons per minute
IID	Imperial Irrigation District
IRWM Plan	Integrated Regional Water Management Plan
K_C	crop coefficient
LAA	Los Angeles Aqueduct
LADWP	Los Angeles Department of Water and Power
LR	required leaching ratio for salt control
M&I	municipal and industrial water users
MAF	million acre-feet; also million acre-feet per year depending on context
MWD	Metropolitan Water District of Southern California
NMFA	National Marine Fisheries Service
NPS	nonpoint source pollution
PPIC	Public Policy Institute of California
ppm	parts per million
psi	pounds per square inch (pressure)
RAINeff	rainfall effective in supplying crop ETc needs
RWQCB	Regional Water Quality Control Board
SB	Senate Bill, legislation originating in the California State Senate
SDCWA	San Diego County Water Authority
SJRRP	San Joaquin River Restoration Program
SJV	San Joaquin Valley
SWP	State Water Project
SWRCB	State Water Resources Control Board
TLDD	Tulare Lake Drainage District
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
WUE	water use efficiency
WWD	Westlands Water District
Yg	tons of crop produced

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Appendix B References

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Appendix C Irrigation Systems Table

	FURROW	BORDER CHECK	HANDMOVE SPRINKLER	CENTER PIVOT SPRINKLER	LINEAR MOVE SPRINKLER	MICRO IRRIGATION
PHYSICAL CHARACTERISTICS	Formed or dug channels running downslope; could be in a uniformly-graded field (with more than one rate of fall downslope) or along the contours of a slope. Furrow and field dimensions can vary widely depending on the crop, soil, and slopes.	The field is arranged with wide strips running downslope, with raised borders to contain the water within the strips during irrigation. The strips have a smooth grade downslope, which may have two or more rates of fall. Border checks must have close to a level grade perpendicular to the flow direction so that water spreads evenly across the check during irrigation. Limited to relatively flat fields.	Handmove – System of portable aluminum or PVC piping that includes "mainlines" running in one direction and connected "laterals" that take off perpendicularly from them. Each lateral has a number of sprinkler heads. In these systems the mainline pipes are usually 30-45 feet in length and 6-12 inches in diameter. Lateral pipes are generally 30 feet long and 3-4 inches in diameter. There will not be enough laterals laid out to cover the field at one time. Rather these systems are operated so that irrigating the entire field will require several "sets." The laterals are moved to a different position along the mainline after each set. Solid Set – same as handmove except enough pipe is laid in the field to irrigate the entire field in one set.	A pipeline supported by a series of motor-driven towers. One end of the pipe is anchored in the center of the field and the pipe rotates around this anchor (hence the name "center pivot"). Water emission devices are attached to the pipe. They may be standard sprinkler heads or "drops" with sprayers or bubblers attached.	A pipeline supported by a series of motor-driven towers. However, this system moves linearly across the field. Water is introduced to the pipe 1) through an open ditch, in which case the "pickup" tower also includes a booster pump, or 2) through a flexible hose that moves with the system, in which case the pressure may be supplied by a stationary booster at one end of the field or located on the end tower. Water emission devices are attached to the pipe. They may be standard sprinkler heads or "drops" with sprayers or bubblers attached. Some adaptations have utilized a boom system suspended underneath the moving pipe to increase the area being wetted at any one time.	A system of buried and aboveground pipelines using various forms of emission devices. Point-source emitters, which are the classic dripper type. Foggers, sprayers, micro sprinklers, which cover much more wetted surface per device. Drip tape, which is a very thin-wall hose that has point source emitters molded or glued to it at a consistent spacing. Tapes can be installed on the field surface or buried.

Appendix C Irrigation Systems Table

	FURROW	BORDER CHECK	HANDMOVE SPRINKLER	CENTER PIVOT SPRINKLER	LINEAR MOVE SPRINKLER	MICRO IRRIGATION
HOW WATER IS APPLIED	Water is delivered to the top of the field via open channels (which sometimes entails transitional "head ditches") or buried pipe and then to the individual furrows through siphons, spiles, gated pipes, or cuts in the ditch bank.	Water is delivered to the field head via open channels or buried pipe and then to each border strip through siphons, spiles, gated pipes, "alfalfa valves," or cuts in the ditch bank.	Water is delivered through the piping system to individual sprinklers where water is sprayed through the air to cover a certain amount of soil. The wetting patterns from adjacent sprinklers are intended to overlap to produce a uniform application.	Standard sprinklers attached on top of the pipe may be used in which case the patterns from adjacent sprinklers are meant to overlap. In some systems, "drops" and sprayers are incorporated so that patterns do not overlap. There are adaptations where the drop incorporates a "bubbler" and basically irrigates one furrow.	Standard sprinklers attached on top of the pipe may be used in which case the patterns from adjacent sprinklers are meant to overlap. In some systems "drops" and sprayers are incorporated so that patterns do not overlap. There have been adaptations where the drop incorporates a "bubbler" and basically irrigates one furrow.	Point source emitters and drip tape apply water through droplets from the emitter. The emitters may be externally punched into a blank hose or come pre-installed at specified intervals. The emitters/hose may be installed above ground, at ground surface, or installed below ground. On widely spaced trees (18+ ft) there may be two lines of emitters and hose per tree row. Common emitter flow rates are between 0.2 and 2.0 gph. One adaptation of point source irrigation is to attach smaller diameter PE hose to the main drip hose and install two or more emitters to this "pigtail." This is most often used with orchards where four or more emitters may be needed per tree to deliver the required volume of water as well as create enough wetted volume of soil. Foggers and misters produce a fine spray of water droplets and wet a larger area than point source. With typical flow rates between 2.0 and 5.0 gph, these are most often used for low application rate situations or tight in-row plantings. Micro sprinkler and jets are typically used for orchard irrigation/frost control and apply 6 to 20 gph with 40 percent or more of the soil surface covered. Various patterns (e.g., full circle, half circle, split circle) are available to suit particular needs and soil types.

Appendix C Irrigation Systems Table

	FURROW	BORDER CHECK	HANDMOVE SPRINKLER	CENTER PIVOT SPRINKLER	LINEAR MOVE SPRINKLER	MICRO IRRIGATION
ASPECTS GOVERNING DISTRIBUTION UNIFORMITY (DU)	Down row – water takes time to advance to the end of the furrow but infiltrates or runs off relatively quickly when water is shut off. Thus, the opportunity times are different. The actual impact on DU from different opportunity times depends on the soil type with coarser soils being more sensitive to differences. (Some managers will dam the furrow end or grade to a flatter slope near the end in order to pond the water to even out opportunity times as well as prevent or minimize runoff.) Cross row – infiltration rates in adjacent furrows may be different due to compaction by tractor tires that will run in the same rows for each tillage operation. Soils variability – infiltration rates will be different across the field depending on the level of different soil types present. Grade uniformity – fields may develop high or low spots due to different soil types in the field and/or tillage operations and thus, must be re-graded periodically. Set duration – in some cases, set duration will differ due to day versus night operations, weekend versus normal weekday operations, and/or irrigation district water delivery schedules.	Down strip – water takes time to advance to the end of the strip but at a slower rate than with furrows due to the flow hydraulics. Water generally runs off of a strip at a slower rate as well resulting in essentially a moving sheet of water (especially when a cover crop is present). Depending on the design and management and opportunity times, infiltrated water will be variable at different locations in the strip. Soils variability – infiltration rates will be different across the field depending on the level of different soil types present. (Cross row uniformity is not generally a problem with border strips since the compaction patterns are similar in all strips due to their width.) Grade uniformity – fields may develop high or low spots due to different soil types in the field and/or tillage operations and thus, must be re-graded periodically. Set duration – in some cases, set duration will differ due to day versus night operations, weekend versus normal weekday operations, and/or irrigation district water delivery schedules.	Pressure uniformity – to the extent that pressure varies within the piping system then water flow from the different sprinklers may vary (pressure-regulating devices are available). Device uniformity – to the extent that one or more sprinklers are of different types, use different nozzle sizes or types, or have worn nozzles then the water flow from the different sprinklers will vary. Overlap uniformity – wetting patterns from adjacent sprinklers are meant to overlap so as to result in a uniform application. To the extent that the design is incorrect (too close or too wide a spacing) or wind is a factor (distorting the patterns) the overlap uniformity will decrease.	Device condition – because each section of pipe will cover a different area per revolution there will be different sprinkler heads and nozzles along the pipe, or different spacings. The only issue is to maintain all devices in good condition. Overlap uniformity – if using sprinklers or mid-height drops with sprayers the wetting patterns from adjacent sprinklers are meant to overlap so as to result in a uniform application, although because of the movement of the pipe there is only one dimension to the overlap. If using low height drops with bubblers then overlap uniformity is not a factor.	Pressure uniformity – to the extent that pressure varies within the pipe then water flow from the different sprinklers/drops may vary (pressure compensating devices are available). Device uniformity – all emission devices should be similar and in good working conditions. Overlap uniformity – if using sprinklers or mid-height drops with sprayers the wetting patterns from adjacent sprinklers are meant to overlap so as to result in a uniform application, although because of the movement of the pipe there is only one dimension to the overlap. If using low height drops with bubblers then overlap uniformity is not a factor.	Pressure uniformity – to the extent that pressure varies within the piping system then water flow from the different emitters may vary. However, the variance depends on the emitter hydraulic design – laminar flow, turbulent flow, or pressure compensating. Device uniformity – to the extent that one or more emitters in the field are of different types or flows, or emitters become worn or clogged then the water flow from the different emitters will vary. Manufacturing variance – these devices have very small flow paths and even slight variations that occur during the manufacturing process can result in varying flows.

Appendix C Irrigation Systems Table

	FURROW	BORDER CHECK	HANDMOVE SPRINKLER	CENTER PIVOT SPRINKLER	LINEAR MOVE SPRINKLER	MICRO IRRIGATION
CONTROL OF TOTAL APPLICATION	Depth infiltrated depends on the soil type, soil moisture content at the start of irrigation, and opportunity time. Experience is required to judge when to turn off water.	Depth infiltrated depends on the soil type, soil moisture content at start of irrigation, and opportunity time. Experience is required to judge when to turn off water but generally occurs as water advances in the range of 2/3 to 7/8 of check length.	Control of applications is a matter of turning the system on and off at the correct times.	Control of applications is a matter of turning the system on and off at the correct times and choosing the system travel speed.	Control of applications is a matter of turning the system on and off at the correct times and choosing the system travel speed.	Control of applications is a matter of turning the system on and off at the correct times.

Appendix C Irrigation Systems Table

	FURROW	BORDER CHECK	HANDMOVE SPRINKLER	CENTER PIVOT SPRINKLER	LINEAR MOVE SPRINKLER	MICRO IRRIGATION
ADVANTAGES	Keeps crop from being wetted (this is essential with some crops). Low-energy use for distribution of water onto the field (but keep in mind energy required to produce and move the water to the field). Low labor skills required but the truly required “skill” may be experience with a particular field, leading to the ability to apply water efficiently with furrows. Low capital requirements, depending on land grading requirements. Can have high on-field efficiencies, especially when a tailwater reuse system is in place. Wide adaptability to water supply flow rate – number of furrows operating can vary easily. Generally low maintenance requirements, mainly periodic grading to prevent low and high spots from forming.	Low energy use for distribution of water onto the field (but keep in mind energy required to produce and move the water to the field). Low labor skills required, but the truly required "skill" may be experience with a particular field, leading to the ability to apply water efficiently with border strips. Low capital requirements, depending on land grading requirements. Can have high on-field efficiencies, especially when a tailwater reuse system is in place. Wide adaptability to water supply flow rate – number of strips operating can vary easily. Generally low maintenance requirements, mainly periodic grading to prevent low and high spots from forming.	Good on streaked soils (as long as the system application rate is less than the soil infiltration rate, the infiltration rate of the soil doesn't matter. The total application is governed by the application rate of the system and the set time). Well adapted to rolling terrain (where it would be impossible to use a flood method). Good for wide range of application depths, except runoff must be watched for large applications when the infiltration rate of the soil might decrease to below the application rate of the system. The irrigator has good control of the total application, if the water supply, and in some cases labor, are flexible. Labor costs can be higher or lower than flood systems depending on whether the system is a handmove, solid set, or mechanical move. But solid set systems require labor to set up and both solid set and mechanical move systems generally have higher capital costs. Solid set systems are used for frost control or crop cooling and have been used to delay bud and bloom crop stages to protect against frost damage. Can result in little or no erosion of soil since there should be little, if any, surface runoff. Irrigators really don't need experience with any particular	Good on streaked soils (the infiltration rate of the soil doesn't matter as long as the system application rate is less than the soil infiltration rate, the total application is governed by the application rate of the system and the set time). Can be used in rolling terrain (where it would be impossible to use a flood method). The irrigator has good control of the total application, if the water supply is flexible. Theoretically higher DU than field sprinklers because one dimension of sprinkler spacing/overlap is taken away. Generally a high frequency system (with low application depths per irrigation) so that soil moisture is kept nearer optimum throughout the season. Variety of emission devices available including the Low Energy, Precision Application (LEPA) concept devices. Crop doesn’t have to get wet (use drops with bubblers in furrows). System can be designed to operate during “off-peak” energy usage to reduce utility load requirements and take advantage of reduced electrical energy rates. Adaptable to automatic operation. Low maintenance costs.	Good on streaked soils (the infiltration rate of the soil doesn't matter as long as the system application rate is less than the soil infiltration rate, the total application is governed by the application rate of the system and the set time). The irrigator has good control of the total application, if the water supply availability is flexible. Theoretically higher DU because one dimension of sprinkler spacing/overlap taken away. Generally a high frequency system (with low application depths per irrigation) so that soil moisture is kept nearer optimum throughout the season. Covers rectangular/square fields (no wasted field in corners). Variety of emission devices available including Low Energy, Precision Application (LEPA) concept devices. Crop doesn’t have to get wet (use drops with bubblers in furrows). System can be designed to operate during “off-peak” energy usage to reduce utility load requirements and take advantage of reduced electrical energy rates.	Easy to maintain a highly uniform and consistent moisture/nutrient regime. Yield expectations are generally higher than with other methods due to the maintenance of optimum soil moisture levels. Variability of soil and/or elevation problems is easier to overcome. Salinity and humidity issues affecting disease are often easier to manage. System can be designed to operate during “off-peak” energy usage to reduce utility load requirements and take advantage of reduced electrical energy rates.

Appendix C Irrigation Systems Table

	FURROW	BORDER CHECK	HANDMOVE SPRINKLER	CENTER PIVOT SPRINKLER	LINEAR MOVE SPRINKLER	MICRO IRRIGATION
			field, as with furrow or border check systems. More efficient for leaching salts. System can be designed to operate during “off-peak” energy usage to reduce utility load requirements and take advantage of reduced electrical energy rates.			

Appendix C Irrigation Systems Table

	FURROW	BORDER CHECK	HANDMOVE SPRINKLER	CENTER PIVOT SPRINKLER	LINEAR MOVE SPRINKLER	MICRO IRRIGATION
DISADVANTAGES	They are usually not good at putting on small amounts of water due to the time it takes for water to move down the furrow. (Note that furrow lengths are often times governed by parcel dimensions and generally conform to 1/8, 1/3, 1/4, or 1/2 mile runs.) Fields with variable soil types are hard to irrigate uniformly. Fields with extremely high infiltration rates are hard to irrigate uniformly without utilizing relatively short furrows. Salts tend to migrate up into the seed row which can be a problem during germination. They generally require periodic land grading. Need to deal with tailwater - options include pick-up and reuse on the field being irrigated or on an adjacent field, put in storage for later use on the farm, intend to be picked up by another farmer, and sent to recharge basins.	They are usually not good at putting on small amounts of water due to the time it takes for water to move down the furrow. (Note that check lengths are often times governed by parcel dimensions and generally conform to 1/8, 1/3, 1/4, or 1/2 mile runs.) Fields with variable soil types are hard to irrigate uniformly. Fields with extremely high infiltration rates are hard to irrigate uniformly without utilizing relatively short check lengths They generally require periodic land grading. Need to deal with some amount of tailwater - options include pick-up and reuse on the field being irrigated or on an adjacent field, put in storage for later use on the farm, intend to be picked up by another farmer, and sent to recharge basins. Generally suitable for use on relatively flat fields only.	Energy requirements for system pressure. Generally higher capital costs. Requires good engineering in order to produce good pressure and overlap DU. May be some restrictions with high salt water (sodium and chlorides) since the sprayed water could contact a crop. Needs a very flexible water supply in terms of ability to start and stop for best efficiency. Needs crop that can be wetted. May be very inefficient in windy areas (see the discussion of DU).	Energy requirement to pressurize system. High capital costs. Requires good engineering in order to produce good pressure and overlap DU. May be some restrictions with high salt water (sodium and chlorides) since the sprayed water could contact a crop. Needs a very stable water supply in terms of flow rate. Needs a very flexible water supply in terms of ability to start and stop for best efficiency. DU and efficiency can be severely impacted by windy conditions. They are not well-adapted to very tight soils as it is difficult to design a system with the required low application rate at the outer regions of the pivot.	Energy requirement to pressurize system High capital costs. Requires good engineering in order to produce good pressure and overlap DU. May be some restrictions with high salt water (sodium and chlorides) since the sprayed water could contact a crop. Needs a very stable water supply in terms of flow rate. Needs a very flexible water supply in terms of ability to start and stop for best efficiency. DU and efficiency can be severely impacted by windy conditions. If being run end-to-end on a field, at the end of an irrigation cycle the system is at the wettest part of the field and must be run "dead-head" back to the other (drier) side (versus a center pivot where the system ends an irrigation cycle at the start of the driest part of the field). Require relatively flat fields due to alignment problems with the moving towers.	Energy requirements for system pressure High capital costs. Maintenance issues are critical. Requires good engineering in order to produce good emission uniformity. Needs a very stable water supply in terms of flow rate. Needs a very flexible water supply in terms of ability to start and stop for best efficiency Can have high maintenance costs associated with damage to drip lines by equipment, insects and rodents.

Appendix C Irrigation Systems Table

	FURROW	BORDER CHECK	HANDMOVE SPRINKLER	CENTER PIVOT SPRINKLER	LINEAR MOVE SPRINKLER	MICRO IRRIGATION
MAINTENANCE ISSUES	Assuming that the water supply system (pumps, piping, and/or ditches) is maintained, the main infield maintenance functions would be periodic field grading and dredging of the tailwater system, if present and sedimentation is a problem.	Assuming that the water supply system (pumps, piping, and/or ditches) is maintained, the main infield maintenance functions would be periodic grading and dredging of the tailwater system, if present and sedimentation is a problem. Burrowing rodents can cause "leaks" between adjacent strips. Periodic reshaping berms may also be needed.	Replacing worn nozzles; maintaining the same head and nozzle size in a system; replacing broken risers from movement, pumping plant repair and maintenance.	Relatively few sprinkler heads/nozzles/etc. to deal with, repair and maintenance on a guidance system, motors, gear drives, and tires.	Relatively few sprinkler heads/nozzles/etc. to deal with, repair and maintenance on a guidance system, motors, gear drives, and tires. With linear move systems fed by an open ditch and moving pick-up keeping the supply ditch clean and free of algae may be an issue.	System must be periodically flushed and (generally) treated with chemicals to prevent plugging. Repair and maintenance on headworks (pumps, valves, filters, etc. Hoses and emitters must be regularly inspected for leaks or damage. Subsurface emitters have special plugging considerations due to root intrusion.
CRITICAL ISSUES	Can be as efficient as any other system, but requires experienced irrigators, furrow dimensions and grades matched to the field conditions, uniform soil, and a tailwater return system for highest field efficiency.	Usually good at putting a narrow range of application depths on very efficiently. Best operation requires an irrigator with experience with the system type and preferably with the field.	High winds can distort sprinkler patterns and result in excessive evaporation losses. Application depths per irrigation may be constrained by the availability of labor to make pipe moves between sets – e.g., set lengths may be constrained to 12 or 24 hours.	The water supply must be flexible so that full advantage of the potential efficiency of the system is achieved, primarily due to the need to turn on and off on demand. This is a high frequency irrigation system and managers cannot "get behind" in their irrigation schedule as there is not enough excess capacity in the system to "catch-up." High winds can distort sprinkler patterns and result in excessive evaporation losses.	The water supply must be flexible so that full advantage of the potential efficiency of the system is achieved, primarily due to the need to turn on and off on demand. This is a high frequency irrigation system and managers cannot "get behind" in their irrigation schedule as there is not enough excess capacity in the system to "catch-up." High winds can distort sprinkler patterns and result in excessive immediate evaporation losses.	The water supply must be flexible so that full advantage of the potential efficiency of the system is achieved, primarily due to the need to turn on and off on demand. This is a high frequency irrigation system and managers cannot "get behind" in their irrigation schedule as there is not enough excess capacity in the system to "catch-up".
RELATIVE CAPITAL COSTS	Low – initial grading requirements; cost of water delivery system.	Low – initial grading requirements; cost of water delivery system.	Medium to high – depending on whether a handmove or solid set system (amount of pipe and sprinklers to be bought).	High – substitutes engineered system for hand labor.	High – substitutes engineered system for hand labor.	High – underground and above ground piping, emitters, filters, valves, and booster pump.
RELATIVE MAINTENANCE COSTS	Low – periodic touch-up grading; dredging/cleaning the tailwater system if present.	Low – periodic touch-up grading; dredging/cleaning the tailwater system if present.	Medium – changing worn nozzles; worn/broken sprinkler heads; broken risers.	Low – changing worn nozzles; worn/broken sprinkler heads; periodic maintenance of motors, gear drives, tires.	Medium – changing worn nozzles; worn/broken sprinkler heads; periodic maintenance of motors, gear drives, tires.	High – constant inspection for leaks, plugged emitters/filters.
RELATIVE OPERATING COSTS	Low – but requires an irrigator with experience.	Low – but requires an irrigator with experience.	Medium to high – labor to move pipe to field and within field; energy required to pressurize the system.	Low to medium – turn the system on and off, can be set up for remote control; energy required to pressurize the system.	Low to medium – turn the system on and off; may require periodic effort to change supply hose location; energy required to pressurize the system.	Low to medium – turn system on and off, many times adapted to automation and/or remote control; energy required to pressurize the system.

Appendix D Energy Considerations

Equations D-1 and D-2 represent a simplified method for estimating energy use to supply irrigation water to a field.

kWh/yr = kWh/AF * AF/yr **[D-1]**

where:

kWh/yr = kiloWatt-hours of electricity used annually

kWh/AF = kiloWatt-hours required to pump an acre-foot of water through the pumping plant

AF/year = acre-feet of water pumped per year

kWh/AF = 1.0241 * TDH / OPE **[D-2]**

where:

kWh/AF = kiloWatt-hours required to pump an acre-foot of water through the pumping plant

TDH = total dynamic head developed by the pumping plant in feet

OPE = overall pumping plant efficiency as a decimal (0 - 1.0)

1.0241 = is the conversion constant for water at standard conditions

Equation D-1 illustrates that reducing energy use in agriculture will involve either reducing the amount of water pumped or reducing the kWh needed to pump an acre-foot of water. Equation D-2 illustrates that reducing the number of kWh required per acre-foot will involve either reducing the total dynamic head in the system or improving the pumping efficiency.

Equations D-1 and D-2 are presented primarily to identify the main variables involved in energy use for irrigation. In practice there are many ways that these equations are used. Three example scenarios are:

1. Water is pumped from a well and applied by a furrow system with a tailwater return system that reuses the tailwater on the field immediately. In this situation the total energy use is derived by adding the kWh/AF for the water well multiplied by the total amount of water pumped plus the kWh/AF for the tailwater pumped multiplied by the total amount of tailwater pumped.

2. Water is pumped from a river to a reservoir on the farm then pumped through a drip irrigation system with no tailwater or runoff generated. In this situation the energy use is the kWh/AF from the river pump multiplied by the water volume extracted from the river plus the kWh/AF required by the drip irrigation system pump multiplied by the water volume pumped through the irrigation system.

3. Consider a situation similar to the first example, but now the water is pumped from a canal instead of a well. At first glance one would simply substitute the energy difference between the canal pump and the well pump. However, one must consider the energy required to get the water into the canal and to the pumping plant. Scenarios include:

   Water is pumped from a river into the canal and then flows by gravity.

A river is dammed and water flows by gravity into the canal.

The canal is part of the State Water Project and water was lifted two or three times as it flowed south down the San Joaquin Valley.

Example 3 introduces the concept of **embedded energy**. Assuming the cutoff point to identify embedded energy is at the start of the field irrigation system, the embedded energy is the energy required to deliver the required water to the field.

When talking about agricultural water conservation, theoretically one would always be reducing AF/yr in Equation D-1, thus implying a savings in energy. Generally the embedded energy would always be saved. However, reducing AF/yr may require a change in the irrigation system, possibly from a furrow system to a drip method. In this case, while reducing the embedded energy, the energy required to irrigate the field is increased. Whether the net result is energy savings or not depends on the amount of water savings, the level of embedded energy, and the energy required to pressurize the system.

In some areas, switching from a gravity to a pressurized irrigation system increases on-farm energy consumption but may reduce total (embedded energy plus on-farm energy) energy consumption. Consider a farmer who is irrigating almonds that are entirely irrigated by surface water from the Central Valley Project's Coalinga Canal, which has an embedded energy of 718 kWh/AF. Table D-1 is a summary of the effects of switching from border strip irrigation with a 78-percent field efficiency (using a tailwater return system) to drip irrigation with 85-percent efficiency. There is a net energy cost increase of $1,135.

TABLE D-1

	CURRENT SYSTEM Surface	PROPOSED SYSTEM Drip	SAVINGS
Crop	Almonds	Almonds	
Acres	100.00	100.00	
Net Annual Water Use (acre-inch/acre)	45.47	47.56	
Net Effective Rainfall (acre-inch/acre)	1.40	1.40	
Required Leaching Ratio	0.06	0.06	
Irrigation:			
System Type	Border Strip w/ tailwater	Drip	
Efficiency (%)	78.0%	85.0%	
Annual Applied Water (AF)	**522.6**	**488.4**	**34.2**
Unit Cost of Water ($/AF)	**$0.00**	**$0.00**	**$0.00**
Annual Water Cost	**$0**	**$0**	**$0**
Unit Energy Requirement: (kWh/AF)			
Well/Water Supply	718	718	
Booster	17	99	
Tailwater	55	0	
Total kWh/AF for Irrigation System (not counting tailwater kWh/AF)	735	817	- 83
Annual Energy Use (kWh/year)	**389,616**	**399,079**	**- 9,462**
Melded Unit Cost of Energy ($/kWh)	**$0.1200**	**$0.1200**	
Annual Energy Cost	**$46,754**	**$47,889**	**- $1,135**
Total Annual Cost	**$46,754**	**$47,889**	**- $1,135**

As shown in Table D-1 there is actually about a 2 percent increase in energy use due to the need for the drip system's pressure. Now, if it is assumed that the irrigation efficiency (IE) of the drip system is 90 percent then there is about a 3 percent decrease in energy use. The key to this example is that there was little impact to energy use, even considering the embedded energy.

The example shown in Table D-2 assumes the almonds are irrigated by a water well pumping from 200 feet and using surface irrigation. The pumping depth will decrease to 190 feet when converting to a drip system since the drip system will require a somewhat lower flow rate. This example again shows a small increase in energy costs ($428) even with an assumed 90 percent irrigation efficiency.

TABLE D-2

	CURRENT SYSTEM Surface	PROPOSED SYSTEM Drip	SAVINGS
Crop	Almonds	Almonds	
Acres	100.00	100.00	
Net Annual Water Use (acre-inch/acre)	45.47	47.56	
Net Effective Rainfall (acre-inch/acre)	1.40	1.40	
Required Leaching Ratio	0.06	0.06	
Irrigation:			
System Type	Border Strip w/ tailwater	Drip	
Efficiency (%)	78.0%	90.0%	
Annual Applied Water (AF)	**522.6**	**461.5**	**61.1**
Unit Cost of Water ($/AF)	**$0.00**	**$0.00**	**$0.00**
Annual Water Cost	**$0**	**$0**	**$0**
Unit Energy Requirement: (kWh/AF)			
Well/Water Supply	330	314	
Booster	17	99	
Tailwater	55	0	
Total kWh/AF for Irrigation System (not counting tailwater kWh/AF)	347	413	- 66
Annual Energy Use (kWh/year)	**187,028**	**190,594**	**- 3,565**
Melded Unit Cost of Energy ($/kWh)	**$0.1200**	**$0.1200**	
Annual Energy Cost	**$22,443**	**$22,871**	**- $428**
Total Annual Cost	**$22,443**	**$22,871**	**- $428**

The example shown in Table D-3 shows almonds with a water supply from a well, but operating at 65 percent IE (considered poor) with the border strip system. This scenario represents a significant potential savings in energy – almost $4000 annually.

TABLE D-3

	CURRENT SYSTEM Surface	PROPOSED SYSTEM Drip	SAVINGS
Crop	Almonds	Almonds	
Acres	100.00	100.00	
Net Annual Water Use (acre-inch/acre)	45.47	47.56	
Net Effective Rainfall (acre-inch/acre)	1.40	1.40	
Required Leaching Ratio	0.06	0.06	
Irrigation:			
System Type	Border Strip w/ tailwater	Drip	
Efficiency (%)	65.0%	90.0%	
Annual Applied Water (AF)	**623.1**	**461.5**	**161.6**
Unit Cost of Water ($/AF)	**$0.00**	**$0.00**	**$0.00**
Annual Water Cost	**$0**	**$0**	**$0**
Unit Energy Requirement: (kWh/AF)			
Well/Water Supply	330	314	
Booster	17	99	
Tailwater	55	0	
Total kWh/AF for Irrigation System (not counting tailwater kWh/AF)	347	413	- 66
Annual Energy Use (kWh/year)	**223,003**	**190,594**	**32,409**
Melded Unit Cost of Energy ($/kWh)	**$0.1200**	**$0.1200**	
Annual Energy Cost	**$26,760**	**$22,871**	**$3,889**
Total Annual Cost	**$26,760**	**$22,871**	**$3,889**

Obviously any number of scenarios could be developed, some showing energy savings, some not. A key concept identified by these examples is that generalizations cannot be drawn regarding field irrigation efficiencies and corresponding energy use.

Appendix E
Davenport-Hagen Conclusions[1]

Because California's water issues, including conservation of agricultural water, are multifaceted, this report necessarily covers numerous aspects, some in detail and some superficially. However, the following principal conclusions can be distilled from the volume of material presented:

1. Within a crop season, water used in irrigation is either recoverable or is irrecoverably lost. It is important that recoverable water be recovered and reused as efficiently as possible. However, it should not be permitted to accumulate under conditions where it is subject to evaporation or to transpiration losses by nonproductive vegetation. Furthermore, if seepage, surface runoff, and deep percolation make contributions to soil moisture available to crops, groundwater, or wildlife habitat and recreation, that water cannot be regarded as lost. High priority should be given to preventing water flow to highly saline sinks both inland and to the ocean because such losses are irrecoverable. However, conservation decisions must take into account environmental and instream needs as well as the appropriate balance of potential water savings against net farm income, possible reductions in food and fiber production, infrastructural viability, and the ability of farmers to retain flexibility in their operations and remain competitive in the market.

2. Much of California's irrigation water is distributed through water agencies such as irrigation districts. Each district is unique in its historic, geologic, geographic, water-source, political, and other characteristics. Therefore, water pricing, management, and distribution policies vary considerably from district to district. Because of these unique characteristics, universal recommendations on agricultural water conservation actions cannot be made.

3. There is a large array of water conservation actions, but while these are workable in theory many are not always justified in practice because of technical, economic, and environmental reasons. These conservation actions might be taken during water storage, conveyance, and application; by use of cultural and crop management practices; by reusing and reclaiming water; and through institutional mechanisms.

4. In much of the San Joaquin Valley, water conservation has been practiced by water agencies and growers for many decades. This has been done out of necessity because of poor natural distribution of water and scarcity of water supplies relative to irrigation demands. Irrigation is essential because available water is the major resource lacking in an otherwise bountiful valley blessed with fertile soil and plentiful solar radiation. The findings of this report are in general agreement with the principal conclusions in the "summary of Proceedings of the Workshop on Agricultural Water Conservation, An Update with Emphasis on Conditions in the San Joaquin Valley," sponsored by the California Water Commission, DWR, and the SJV Agricultural Water Committee.

[1] Davenport, David C. and Robert M. Hagan. Agricultural Water Conservation in California, With Emphasis on the San Joaquin Valley. Department of Land, Air, and Water Resources. University of California at Davis. Davis, CA. October 1982.

5. If water saving is looked at solely from an on-farm viewpoint (without regard to associated affects) the decision to use water conservation measures depends on whether the motive is 1) just to reduce on-farm water demand, or 2) to reduce the state's net water deficit. Reducing field runoff (RO) and deep percolation (DP) by improving irrigation application efficiency, will reduce on-farm water demand but will not affect the state's water deficit because RO and DP are recoverable for reuse. The state's water deficit can only be reduced by curtailing irrecoverable losses to the air and to saline sinks, mainly to the ocean. This will not create new water, but it will make more of the existing water supplies available for agricultural, M&I, and instream uses.

6. On-farm water savings can best be achieved by proper management of existing and new irrigation systems and through good irrigation programs which determine the correct timing and quantity of water application. These savings will mainly occur as a reduction in recoverable water and as reuse of recovered water. On-farm reduction of irrecoverable water loss can be achieved without curtailing economic crop production, mainly by reducing soil surface evaporation (E), but the magnitude of the state-wide savings that can be practically achieved through reduced E is not expected to be substantial.

7. The largest true loss of water from agricultural areas occurs as crop transpiration (T) which can theoretically be curtailed only by reducing the area, the rate and/or the time duration of the transpiring surface. Because of the strong relationship of crop growth to T, reductions in T by restricting irrigation, if considerable, would clearly reduce crop production, and if small, may cause only a small reduction in crop yield but would increase the risk of substantial reductions in yield. Neither prospect is likely to be acceptable to growers. They are more likely to take water conservation actions, however, if their net farm profits increase through savings in production costs associated with water management. This could mean replacing the goal of yield maximization with a goal of profit maximization, but the quantity of water saved may be small at present water and production costs and crop values.

8. Apart from crop yield loss, likely to occur by reducing irrecoverable transpiration losses, there are many other effects associated with agricultural water conservation actions. These may be good (e.g., energy savings) or bad (e.g., less water contributed to groundwater recharge and to wildlife habitat), and may occur on-farm (e.g., less leaching of fertilizers) or off-farm (e.g., less pollution of waters receiving agricultural return flows).

9. In the San Joaquin Valley, the present annual net water deficit is represented by a 1.7 MAF overdraft. There are only three ways to overcome this deficit:

    a. Reduce net water demand, i.e., reduce irrecoverable losses, mainly ET to the air. Because ET reduction will usually curtail agricultural production, this generally is not a practical solution.

    b. Bring more water into the SJV through water development and/or water transfers from Northern California through public-developed systems or through private water sales in an open water market system.

    c. A combination of a) and b) above.

10. To be practical, these solutions should result in little loss in farm profit, and water transfers should be of mutual benefit to the water sellers and the water buyers. The storage and transfer of surplus flood water (over and above that needed to maintain instream needs) that would otherwise be irrecoverably lost to the ocean would contribute considerably toward reducing California's total projected net water deficit. Also, increased storage, both as surface and groundwater, would reduce the state's vulnerability to future droughts.

11. Although several estimates of potential "water savings" in California have been publicized, this report does not provide a precise numerical value for conservation because: a) a distinction must be made between water savings that occur only on-farm and those that help alleviate the state's water deficit; and b) that deficit can only be met by reducing irrecoverable water outflow, but there is insufficient information on the economic and environmental impacts of reducing those irrecoverable water losses from the state.

12. lt is erroneous to conclude that a particular irrigation system such as sprinkler or drip requires only a fraction of the water applied by systems such as furrow or border-strip. (With good design and management, most irrigation systems have a similar potential for efficient water application.) Because of the recoverability and reusability of field runoff and deep percolation, it is even more erroneous to conclude that decreasing runoff and deep percolation will proportionately reduce the state's net water deficit. Therefore, statements suggesting a 10-50% potential savings in agricultural water conservation by improving irrigation application systems are a disservice to the people of California because water policy and action programs based on such statements will substantially underestimate the state's needs for future water supplies.

13. Because only reductions in irrecoverable (rather than recoverable) water losses have an impact on the state's net water balance, and because crop transpiration (T) cannot be greatly reduced if agricultural production is to be maintained, the state's net water deficit can be reduced only by agricultural water conservation actions that curtail a) soil surface evaporation (the E component of ET) and b) flows to highly saline sinks. Therefore, the realistic potential for agricultural water conservation, without loss in crop production, is not likely to be in the range of 10-5O%, but is more likely to be approximately 2-3% of the water applied in California's irrigated agriculture. This estimated percentage saving is similar to the percentage saving calculated from figures published in the State Department of Water Resources Bulletin 198 (197 6) on Water Conservation in California.

14. A savings of about 2% of the state's water applied to agriculture conserves only approximately 0.65 MAF, an amount that alone is insufficient to meet California's current net deficit of 2.3 MAF, now reflected as groundwater overdraft.

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