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MORE WITH LESS: AGRICULTURAL WATER CONSERVATION AND EFFICIENCY IN CALIFORNIA

A Special Focus on the Delta

Heather Cooley, Juliet Christian-Smith, Peter H. Gleick

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California's agricultural sector faces a number of major challenges, including uncontrolled urbanization, global market pressures, and threats to the reliability and availability of fresh water. This study offers an assessment of the potential to improve agricultural water-use efficiency, with a focus on the Sacramento-San Joaquin Delta, and provides explicit recommendations for the public, growers, and policy makers working to improve that water use.

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Acronyms and Abbreviations

AF – acre-feet
AUM – animal unit months
AWMC – Agricultural Water Management Council
C2VSIM – California Central Valley Groundwater – Surface Water Simulation Model
CCC – Contra Costa Canal
CDFA – California Department of Food and Agriculture
CEDD – California Employment Development Department
CEC – California Energy Commission
CIMIS – California Irrigation Management Information System
CVP – Central Valley Project
CVPIA – Central Valley Project Improvement Act
DWR – California Department of Water Resources
ET – evapotranspiration
EWG – Environmental Working Group
EWMPs – efficient water management practices
EQIP – Environmental Quality Incentives Protocol
FAO – Food and Agriculture Organization
LAEDC – Los Angeles County Economic Development Council
LEPA – Low-energy precision application
LESA – Low elevation spray application
MAF – million acre-feet
NBAQ – North Bay Aqueduct
NRCS – Natural Resources Conservation Service
PPIC – Public Policy Institute of California
RDI – regulated deficit irrigation
SWP – State Water Project
USBR – United States Bureau of Reclamation
USDA – United States Department of Agriculture
USGS – United States Geological Survey

Conversions

1 cubic meter (m^3) = 264 gallons = 0.0008 AF
1,000 gallons (kgal) = 3.79 cubic meters (m^3) = 0.003 acre-feet (AF)
1 million gallons = 3,785 cubic meters (m^3) = 3.1 acre-feet (AF)
1 acre-foot (AF) = 325,853 gallons = 1,233 cubic meters (m^3)

Executive Summary

The Sacramento-San Joaquin Delta is a critical resource. Almost half of the water used for California's agriculture comes from rivers that once flowed to the Delta and more than half of Californians rely on water conveyed through the Delta for at least some of their water supply.[1] The Delta also provides habitat for 700 native plant and animal species. This important region is now in a serious, long-term crisis. Major threats include rapidly declining populations of threatened and endangered fish; increasing risk of levee failure due to earthquakes and decades of neglect; rising seas and changes in frequency and intensity of floods and droughts due to climate changes; and worsening water quality.

A key finding of recent court decisions, scientific assessments, and the Delta Vision Blue Ribbon Task Force is that the absolute volume of water exported from the Delta is too high, or is so at critical times.[2] Given that agriculture accounts for about 80% of Delta water consumption,[3] no economic, environmental, or policy assessment can be complete without a serious examination of agricultural water withdrawals from the Delta.

This report looks at four scenarios for increasing agricultural water-use efficiency. Our central findings show that improving agricultural water-use efficiency through careful planning; adopting existing, cost-effective technologies and management practices; and implementing feasible policy changes can maintain a strong agricultural sector in California while reducing pressures on the Delta. Reducing water use can also create a more resilient agricultural sector by increasing the quantity of water in storage, reducing the risk of drought, and improving the reliability of the available water. In addition, certain water conservation and efficiency improvements actually increase farm productivity and profitability, further bolstering the agricultural sector.

Reductions in the amount of Delta water available to the agricultural sector are already occurring. Despite record production in counties throughout the Central Valley in 2007,[4] recent water shortages resulting from the drought and legally-mandated Delta pumping restrictions have resulted in total farm losses that some estimate to be as high as $245 million as of mid-summer 2008.[5] The consequences of future sudden shortages or disruptions in water supplies from the Delta on local economies and the state can be far less severe if focused efforts to improve efficiency are implemented early and intentionally.

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[1] Isenberg, P., M. Florian, R.M. Frank, T. McKernan, S.W. McPeak, W.K. Reilly, and R. Seed. (2008). Blue Ribbon Task Force Delta Vision: Our Vision for the California Delta. State of California Resources Agency, Sacramento, California.
[2] Isenberg, P., M. Florian, R.M. Frank, T. McKernan, S.W. McPeak, W.K. Reilly, and R. Seed. (2008). Blue Ribbon Task Force Delta Vision: Our Vision for the California Delta. State of California Resources Agency, Sacramento, California.; Natural Resources Defense Council v. Kempthorne, E.D.Cal, (2007); Pacific Coast Federation of Fisherman's Associations, Institute for Fishery Resources v. Gutierrez, E.D.Cal., (2007).
[3] Lund, J., E. Hanak, W. Fleenor, R. Howitt, J. Mount, P. Moyle. (2007). Envisioning Futures for the Sacramento-San Joaquin Delta. Public Policy Institute of California. San Francisco, California.
[4] Kern County. (2008). 2007 Kern County Agricultural Crop Report. Department of Agriculture and Measurement Standards, Bakersfield, California.; Fresno County 2008. 2007 Annual Crop Report. Fresno, California.
[5] Schultz, E.J. (2008, July 24). Rally Demands State Face Up to Water Crisis. *Sacramento Bee*.

Scenarios

Previous research from the Pacific Institute evaluated the potential for urban water-use efficiency improvements[6] and developed a high-efficiency scenario for the year 2030 that explores how to reduce water use while maintaining a healthy economy and strong agricultural sector.[7] This analysis expands on that work by evaluating scenarios for improving agricultural water-use efficiency, with a focus on the Delta.

Four scenarios for improving the water-use efficiency of the agricultural sector are evaluated:

- **Modest Crop Shifting –** shifting a small percentage of lower-value, water-intensive crops to higher-value, water-efficient crops
- **Smart Irrigation Scheduling –** using irrigation scheduling information that helps farmers more precisely irrigate to meet crop water needs and boost production
- **Advanced Irrigation Management –** applying advanced management methods that save water, such as regulated deficit irrigation
- **Efficient Irrigation Technology –** shifting a fraction of the crops irrigated using flood irrigation to sprinkler and drip systems

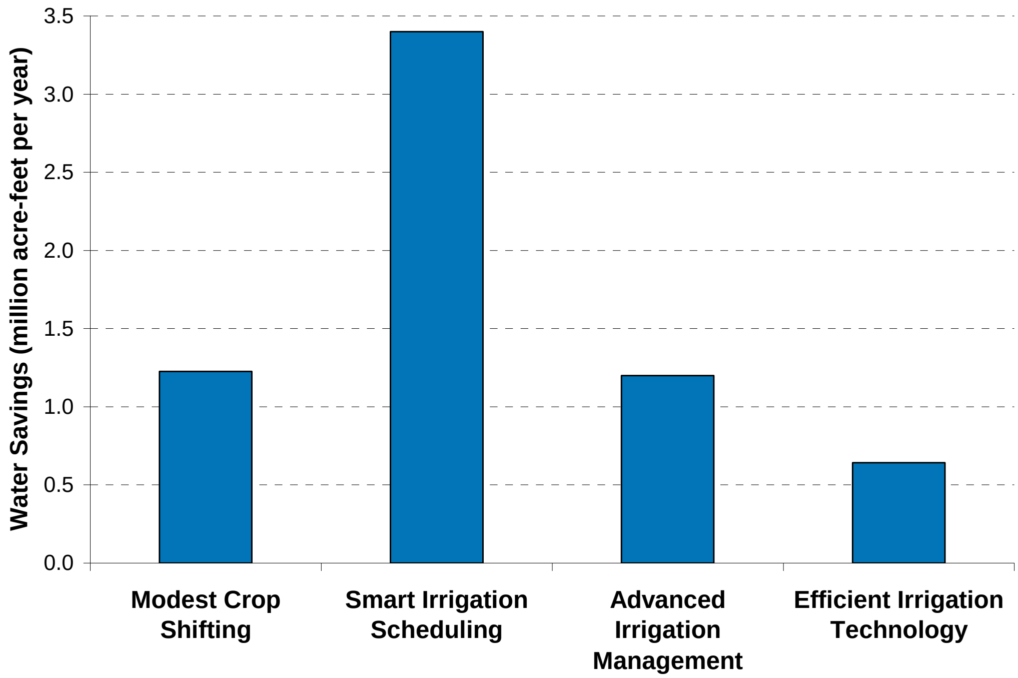
Results

Each scenario identifies substantial potential to improve the efficiency of agricultural water use in regions supplied by the Sacramento-San Joaquin Delta. Annual water savings from the four scenarios ranged from 0.6 to 3.4 million acre-feet (Figure ES-1). These scenarios, by themselves and in combination with one another, can help satisfy the legal restrictions on Delta withdrawals, reduce groundwater overdraft in the region, and help restore the health of the ecosystems, while still maintaining a strong agricultural economy.

Water savings achieved through conservation and efficiency improvements are just as effective as new, centralized water storage and are often far less expensive.[8] For example, the savings we find in these scenarios can be compared using "dam equivalents." Assuming that a dam yields 174,000 acre-feet of "new" water,[9] our efficiency scenarios save as much water as provided by 3 to 20 dams of this size. Furthermore, these savings could be achieved without adversely affecting the economic productivity of the agricultural sector.

[6] Gleick, P.H. (2003). Water Use. *Annual Review of Environment and Resources*, 28: 275-314.
[7] Gleick, P.H., H. Cooley, and D. Groves. (2005). California Water 2030: An Efficient Future. Pacific Institute. Oakland, California.
[8] According to LACEDC 2008, conservation would be the least costly water supply alternative for Southern California at $210 per acre-foot of treated water as compared to water recycling at about $1,000 per acre-foot, ocean desalination at more than $1,000 per acre-foot (depending on energy prices), and surface storage options – including proposals such as the Sites Reservoir in Northern California and the Temperance Flat dam near Fresno – that would cost $760 to $1,400 per acre-foot.
[9] This is the average estimated yield of water from recent proposals to build Temperance Flat Dam (Department of Water Resources. 2007. Temperance Flat: Frequently Asked Questions. Retrieved on July 28, 2008 from http://www.storage.water.ca.gov/docs/Temperance_FAQ.pdf).

Figure ES-1. Water Savings by Scenario



While we do not consider land fallowing to be a water-efficiency measure, planned short-term fallowing could produce significant water savings during a drought or supply disruption. Planned short-term fallowing of 10% of the field crop acreage would save 1.7 million acre-feet of water and provide revenue for capital and other needed improvements. Furthermore, permanently retiring 1.3 million acres of drainage-impaired lands in the San Joaquin Valley would save 3.9 million acre-feet of water per year, while also reducing clean-up costs and minimizing the social and environmental impacts associated with polluted surface and groundwater.[10,11] However, impacts on agricultural workers and the local community, referred to as third party impacts, should be mitigated in any land fallowing or retirement agreement.

Our report provides a new vision of the Delta's future—one in which a profitable and sustainable agricultural sector thrives, while water withdrawals from the Delta are significantly reduced. Each scenario has risks and tradeoffs, and implementation details will be critical to the success of these measures. We do not address the question of how water is withdrawn from the Delta, i.e., whether a peripheral canal, "dual conveyance system," continued pumping, or no pumping from the south Delta is best. Independent of a decision to change how water is taken from the Delta, we show that it is possible, indeed preferable, to take *less* water and improve the Delta's environmental and economic conditions. Certainly, no decision about new or modified infrastructure should be made without evaluating the ability to reduce its size and cost through water-use efficiency improvements.

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[10] Department of Water Resources (DWR). (2007). San Joaquin Valley Drainage Monitoring Program: 2002. Sacramento, California.

[11] Drainage-impaired lands are those areas where the water table is within 20 feet of the ground surface. To estimate the water savings, we multiplied estimates of the drainage-impaired land by the weighted average of applied water in the San Joaquin and Tulare Lake hydrologic regions from 1998 to 2003, which was 3.11 acre-feet per acre (DWR 2008b).

We conclude that with existing technologies, improved management practices, and changes in educational and institutional policies, agricultural withdrawals from the Delta can be reduced substantially, lessening pressure on endangered fish, mitigating groundwater overdraft, and easing political tensions over water allocations. By significantly reducing water withdrawals, and by encouraging a more drought-tolerant and resilient agricultural sector, our vision for the future of the Delta moves us toward more sustainable water management while maintaining a healthy and profitable agricultural sector. We recommend several key political, legal, and economic initiatives below that would support such a vision and move toward capturing these potential savings.

Conclusions and Recommendations

Agriculture is important to our economy, culture, and environment but is subject to mounting pressure from uncontrolled urbanization, global market pressures, and threats to the reliability and availability of fresh water. Actions are needed to both ensure a sustainable agricultural sector and to reduce the amount of water required for it.

- Better combined land and water planning is needed. For example, strengthen recent legislation, such as the Costa and Kuehl Acts (SB 610 and SB 221) to ensure all new developments have an adequate water supply for at least 100 years. In addition, the number of new housing units required to trigger implementation of these acts should be reduced.

- Modify and expand the Williamson Act to encourage protection of prime agricultural land from urban and suburban development.

Water conservation and efficiency improvements can reduce water use and improve water quality while maintaining or increasing crop yield. Yet these improvements often entail significant investment which can be a barrier to implementation. Smart policies can reduce this barrier.

- Provide sales tax exemptions or rebates on efficient irrigation equipment to help offset capital investments for these systems.

- Provide property tax exemptions for farmers who upgrade to more water-efficient irrigation systems. Exemptions should apply to the value added to a property by the irrigation system and be valid for 5 to 10 years.

- Develop new legal mechanisms by which municipal water or state or local wildlife agencies could invest in farmers’ irrigation systems in exchange for some portion of the water conserved.

- The state, federal government, and/or energy providers should offer rebates or incentives to farmers who implement on-farm conservation measures that may increase on-farm energy use but result in a net energy savings.

- The state and/or federal government should investigate and establish other mechanisms that encourage water-use efficiency if they achieve broader social or environmental benefits.

Agricultural commodity-support programs typically subsidize field crops, inadvertently encouraging the production of low-value, water-intensive crops. These programs should be refocused on the potential to save water.

- Reduce or realign subsidies from low-value, water-intensive crops to higher-value, less water-intensive crops.

- Provide greater emphasis on water conservation and efficiency improvements within the federal Environmental Quality Incentives Program and expand funding for these initiatives.

- Implement new water rate structures that encourage efficient use of water.

Federal and state government has invested substantially in the construction of irrigation systems, without full repayment. By creating an artificially inexpensive supply of water, these indirect water subsidies provide a disincentive for water conservation and efficiency improvements. Eliminate programs that encourage inefficient use.

- Ensure federal contracts for the Central Valley Project achieve full repayment by 2030 or sooner.

- Avoid inappropriate public subsidies for new water-supply options that are more expensive than efficiency improvements.

The existing water rights system in California provides disincentives for water conservation and efficiency improvements. More aggressive efforts are needed to apply the constitutionally mandated concepts of reasonable and beneficial use in ways that encourage improvements in water-use efficiency.

- Give legislative, regulatory, and administrative support to developing a more rational water rights system. In particular, the State Water Resources Control Board's authority and funding should be expanded to include groundwater and to challenge inefficient use as neither reasonable nor beneficial.

- Establish groundwater management areas in regions where overdraft is most severe as an immediate stop-gap measure.

- Define instream flow as a beneficial use in California.

Many proven technologies and practices can improve water-use efficiency. Strengthen and expand efforts to promote the use of these technologies and practices.

- Revise and expand "Efficient Water Management Practices" for agricultural water agencies.

- Make agricultural "Efficient Water Management Practices" mandatory and enforceable by the State Water Resources Control Board.

- Develop institutional mechanisms to increase the reliability of agricultural water deliveries to users meeting high standards of water-use efficiency.

One of the many challenges to studying water issues in California is the lack of a consistent, comprehensive, and accurate estimate of actual water use. The failure to accurately account for water use contributes directly to the failure to manage it sustainably. Efforts should be implemented immediately to improve our understanding of actual water use in the agricultural sector.

- Create a statewide system of data monitoring and data exchange available to all users, especially for water use.

- Use satellite and other technology to improve data collection and analysis, particularly for annual assessments of crop area.

- Design and implement comprehensive local groundwater monitoring and management programs statewide.

Education and technical assistance programs are important to encourage the widespread adoption of these technologies. Existing programs should be expanded and new ones implemented.

- Expand water-efficiency information, evaluation programs, and on-site technical assistance provided through Agricultural Extension Services and other agricultural outreach efforts.

- Improve online data collection and dissemination networks to provide farmers with immediate meteorological and hydrological information on climate, soil conditions, and crop water needs.

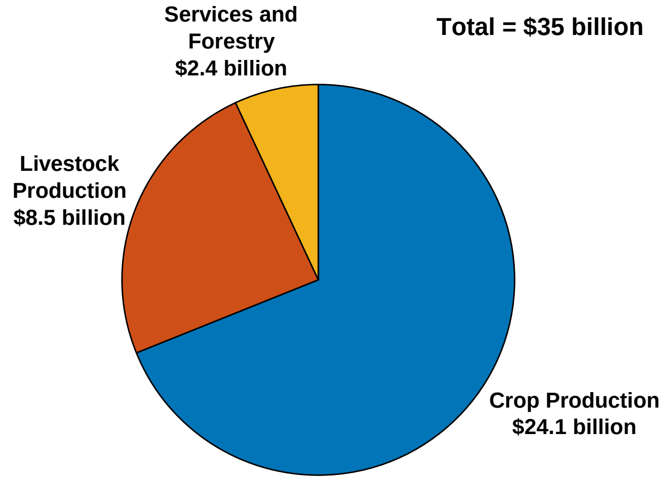
Agriculture in California

California is one of the most productive agricultural regions in the world. Agriculture is important to our economy, culture, and environment but is subject to mounting pressure from uncontrolled urbanization, global market pressures, and threats to the reliability and availability of fresh water. Actions are needed to both ensure a sustainable agricultural sector and to reduce the water required for it. Our report provides a new vision for California's future—one in which a profitable and sustainable agricultural sector thrives, while water withdrawals are significantly reduced.

Economics

The state produces approximately 400 different agricultural commodities, supplying about half of the fresh fruits, vegetables, and nuts consumed by Americans (CDFA 2007). California also provides food for the international market, accounting for 15% of the nation's total agricultural export (Trott 2007). In 2005, California's agricultural sector produced $35 billion in goods and services (Figure 1). Because agriculture requires inputs, such as fertilizer and seeds, the total net value added (gross production minus costs) for the agricultural sector in 2005 was $17.5 billion (USDA 2007a), or about 2% of California's estimated $1.6 trillion economic output (U.S. Dept. of Commerce 2008).[12, 13]

Figure 1. Gross Production Value for California's Agricultural Sector, 2005



Note: Revenue from services and forestry includes forest product sales, recreational income, rental value of farm dwellings, machine hire and custom work, and other farm income.
Source: USDA 2007a

Agriculture also provides jobs. The agricultural sector accounts for an estimated 2% of all jobs in the state. If unauthorized workers are included, that number may be exceed to 4 percent.[14] These statewide estimates, however, hide the regional importance of agriculture. In the San Joaquin Valley, for example, agricultural production accounts for about

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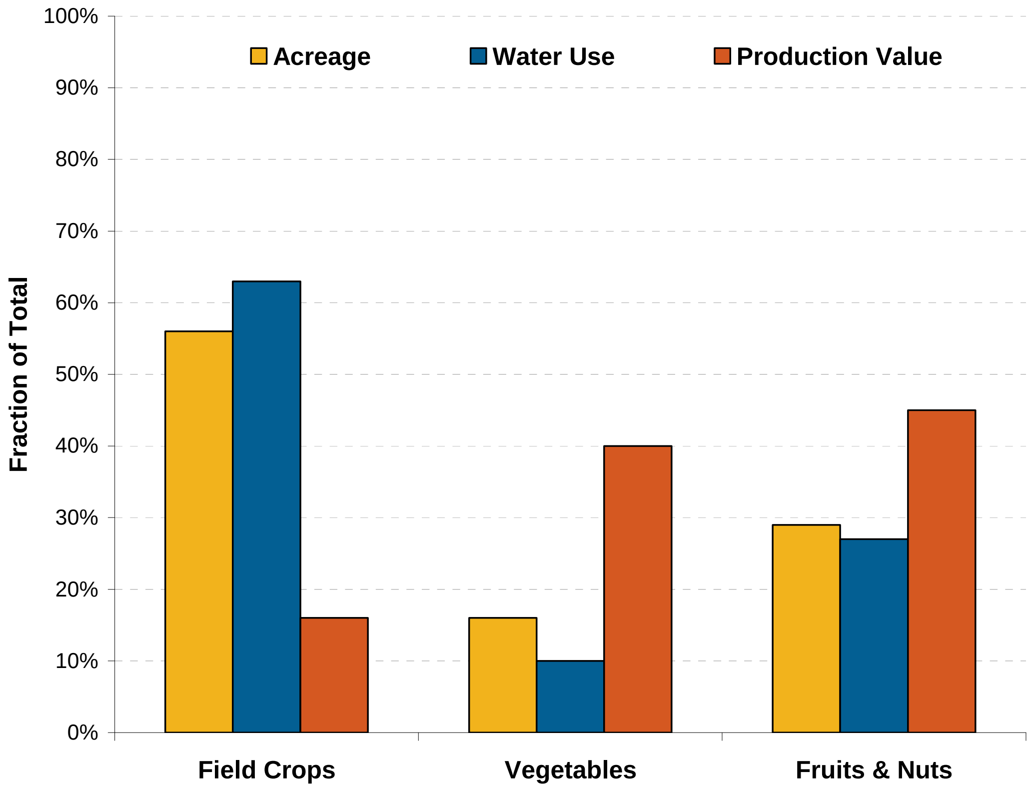
[12] We use Gross State Product as an estimate of California's economic output.
[13] Some argue, however, that agricultural products are important inputs for the production of others goods and services, and consequently agriculture's contribution to California's economy is actually higher, perhaps as high as 6.5% (UC Davis 2006).
[14] This figure does not include unauthorized immigrants, which according to 2005 U.S. Department of Labor statistics comprise just over 50% of agricultural employment. The status of these workers has changed considerably over the last two decades. In 1989, only 8% of U.S. crop workers were unauthorized (37% of US crop workers were Special Agricultural Workers whose status had been legalized under the Immigration Reform and Control Act of 1986).

10% of the regional economy and some communities are almost fully dependent on farm activity (UC Davis 2006).

Crops Grown in California

California produces a diverse array of agricultural commodities that can be grouped into four major crop types: field crops (including hay and pastureland); vegetables; orchards; and vineyards.[15] There is significant variation among each in terms of resource use and economic value (Figure 2). Field crops, for example, currently account for 56% of total irrigated acreage. Field crops use 63% of the applied water but generate only 17% of California's crop revenue. Vegetables, however, produce substantially more revenue per unit land or water: vegetables account for only 16% of the irrigated acreage but use 10% of the applied water and generate 39% of California's crop revenue.

Figure 2. Percent of Irrigated acreage, Gross Production Value, and Applied Water for Each Major Crop Type, 2003



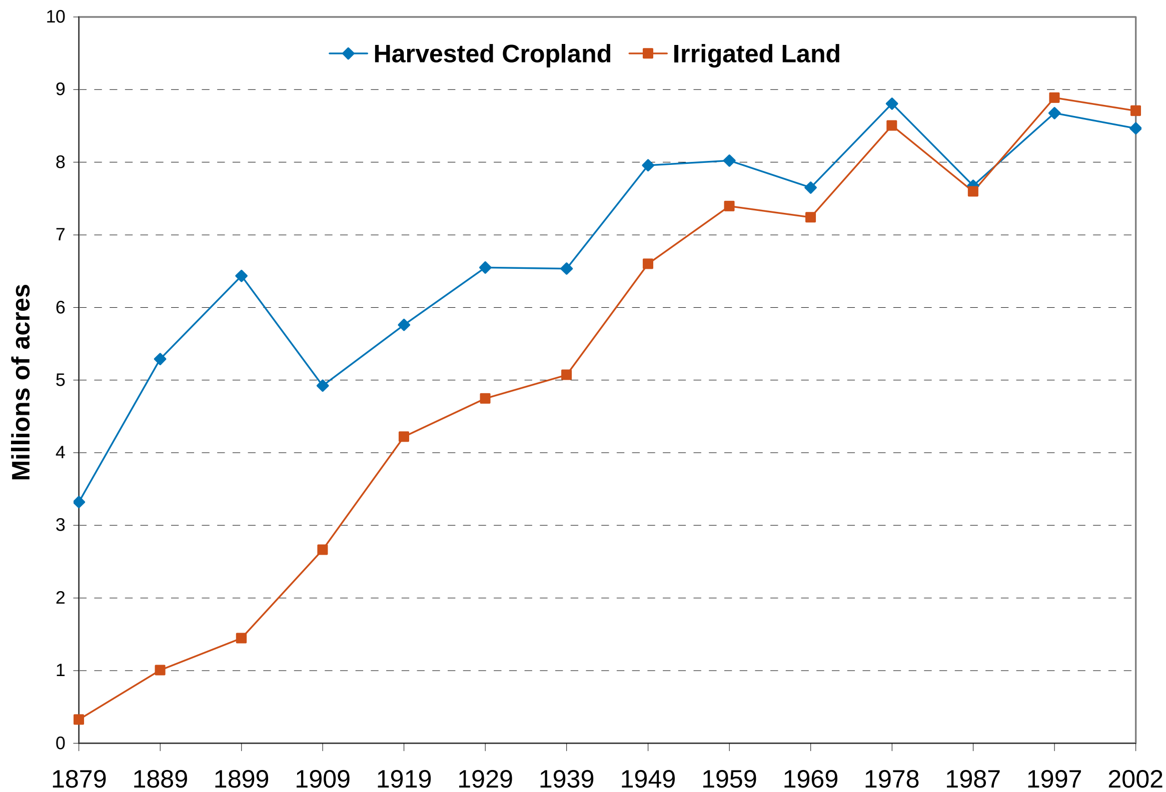
Note: Nursery products account for a large proportion of agricultural revenue but are excluded here because of insufficient data on irrigated acreage and water use.
Source: Gross production value is based on crop production values for 2003 (USDA 2007a). The applied water and irrigated acreage values were based on 2003 estimates from the DWR 2008c.

[15] Field crops include: alfalfa, pasture, grain, rice, cotton, sugar beets, corn, beans, and safflower. Vegetable crops include: tomatoes, melons, cucurbits, onions, garlic, potatoes, and other truck crops. Orchards include almonds, pistachios, citrus, sub-tropical and other deciduous trees. Vineyards are grapevines.

Water Use

California's rich agricultural production has been made possible by irrigation supplied by a vast and integrated water infrastructure. The Central Valley Project (CVP), for example, was undertaken by the Bureau of Reclamation in 1935 to move water from the northern end of the Sierra Nevada and the Central Valley to drier southern croplands. Similarly, the State began construction of the State Water Project (SWP) in the 1950s to transport water from Northern to Southern California for urban and agricultural uses. The CVP, SWP, and other water supply projects permitted the dramatic expansion of California's irrigated acreage. In 1929, prior to the authorization of the CVP, irrigated acreage was approximately 4.7 million acres (Figure 3). Following the completion of the CVP and the SWP in the late 1950s, California's irrigated acreage totaled 7.4 million acres. In 1997 irrigated acreage peaked at 8.9 million acres.[16]

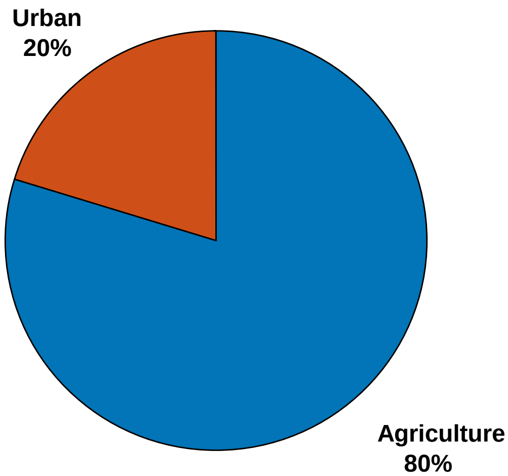
Figure 3. Harvested Cropland and Irrigated Land in California, 1879-2002



Source: Johnston and McCalla 2004 (1869–1987 from Olmstead and Rhode 1997; 1997–2002 from U.S. Department of Agriculture, National Agricultural Statistical Service 2008).

[16] Some land produces more than one crop per year, and as a result, is often counted more than once in estimates of total irrigated acreage.

Figure 4. Overall California Urban and Agricultural Water Withdrawals, 2000



Source: DWR 2005a

Today, California's agricultural sector uses the vast majority of California's developed water supply. Approximately 80% of the 44.3 million acre-feet of water withdrawn in the year 2000 was used for agriculture (Figure 4). The remaining 20% supplied urban areas for residential, commercial, institutional, and industrial uses (DWR 2005a).

Water Use Terminology

Water reports are rife with confusing and often misleading terminology to describe water use, such as water demand, withdrawals, applied water, consumptive use, and non-consumptive use. It is important to clarify these terms, as different meanings can lead to different conclusions about the potential for improving the efficiency of water use. Water "use" and "withdrawals" are used synonymously here to refer to water taken from a source and used by humans. In the case of agriculture, these withdrawals include either groundwater or surface water taken from local sources or water transported via large infrastructure projects like the CVP.

Prior to delivery to a farm, water withdrawn for use is subject to conveyance losses, e.g., seepage or evaporation from aqueducts and canals. According to the California Department of Water Resources (DWR), the quantity of water that is actually delivered to the farm (water withdrawals minus conveyance losses(is referred to as "applied water." Applied water can then be divided into two categories: consumptive and non-consumptive use (Gleick 2003). Consumptive use refers to water made unavailable for reuse in the same basin, e.g., soil evaporation, plant transpiration, seepage to a saline sink, or contamination (see Box 3 for a detailed discussion about evapotranspiration). Non-consumptive use, on the other hand, refers to water that is available for reuse within the basin from which it was extracted, e.g., return flow.

Some agricultural experts have argued that at the basin scale, agricultural water use can be nearly 100% efficient even if on-farm efficiencies are much lower, because all of the applied water is used by the plant, returned to the source via return flows, or later pumped and used by another farmer. Thus, they argue, the only real water savings can be achieved through reductions in *consumptive use* by reducing unproductive evaporative losses, deep percolation, and/or losses to saline sinks. Such water savings are, we believe, especially valuable. But there are also compelling reasons to seek reductions in overall *withdrawals*. Reductions in withdrawals can have important implications for: soil salinity, water quality, the amount and timing of instream flows, fish and wildlife, energy use, and the need to build capital-intensive infrastructure.

- **Soil Salinity.** According to the USGS, between 1995 and 2010 the Central Valley may lose an estimated 400,000 to 700,000 acres of arable land as a result of increasing water and soil salinity (USGS 1995) by 2010. Irrigation water contains salts, and the application of this water increases soil salinity. Reducing the quantity

- **Water Quality.** Runoff from agricultural lands often contains pesticides, fertilizers, salts, and fine sediments from surface erosion. These pollutants can contaminate surface and groundwater sources, increasing treatment costs for downstream users and degrading fish and wildlife habitat. Reducing excessive water use and withdrawals can reduce runoff, thereby minimizing these water-quality problems.

- **Quantity of Instream Flows.** The withdrawal of water directly reduces the amount of water left in the stream (also referred to as instream flows) between where the water is extracted and where it is returned. Instream flows serve many purposes (see, for example, Postel and Richter 2003, Maunder and Hindley 2005). They serve to:

    - Remove fine sediments that cement river substrate and smother fish and invertebrate eggs and larvae.
    - Maintain suitable water temperatures, dissolved oxygen concentrations, and water chemistry.
    - Establish stream morphology, including the formation and maintenance of river bars and riffle-pool sequences.
    - Prevent riparian vegetation from invading the channel and altering stream form and function.
    - Flush waste products and pollutants.
    - Allow and support fish passages and migrations.

- **Timing of Instream Flows.** While excessive water applications may lead to return flows that eventually flow back to a stream via surface runoff or groundwater percolation, there is a lag time between when the water is withdrawn and when it flows back into the river. Timing is important because the life cycles of many aquatic and riparian species are timed to either avoid or exploit flows of certain magnitudes. For example, high flows often signal anadramous fish migration (Maunder and Hindley 2005). Thus altering the timing of instream flows can have deleterious impacts on ecosystems.

- **Fish and Wildlife.** In addition to the indirect threats to wildlife, diversions from waterways can pose a direct threat to fish and wildlife populations. For example, the large pumps for the SWP and CVP kill fish on the intake screens and at the fish diversion facility.

- **Energy Use.** Capturing and conveying water to agricultural users often requires an input of energy. For example, conveying surface water to farmers in the Tulare Lake hydrologic region requires up to 970 kWh per acre-foot.17 Likewise, pumping groundwater requires between 175 kWh and 740 kWh per acre-foot, depending on pumping depth (Wolff et al. 2004). As a result, reducing water withdrawals can save energy and reduce related greenhouse-gas emissions.[18]

- **Capital-Intensive Infrastructure.** Building and siting new reservoirs is time-consuming, extremely expensive, and politically controversial. Water savings achieved through efficiency improvements, however, are just as effective as new centralized water storage and infrastructure, assuming that such new infrastructure could be sited, funded, approved, and built.

Our analysis focuses on the benefits of reducing both overall withdrawals and consumptive use. The source of the savings—whether they represent consumptive or non-consumptive uses—depends on a variety of factors, including soil type, evapotranspiration (ET) rates, and management practice. For example, the majority of water savings from deficit irrigation are from reductions in crop water requirements (a consumptive use). Switching from flood to sprinkler irrigation reduces both unproductive evaporative losses (a consumptive use) and return flows (which can be consumptive or non-consumptive uses). In this analysis, we quantitatively estimate changes in water withdrawals and provide qualitative estimates of changes in consumptive use where possible. We note that far more detailed, region-specific data and agricultural water-use assessments will help improve our understanding of the kinds of savings different efficiency policies can produce, and we urge such assessments be conducted.

[17] Based on State Water Project energy requirements from CEC 2005. we estimate the upper range on the energy intensity at Wheeler Ridge.
[18] In some cases, water-efficiency improvements may increase on-farm energy use, e.g., through conversion from flood to sprinkler irrigation. See the section on “Opportunities and Challenges for Achieving Water Conservation and Efficiency Improvements” for a more detailed discussion.

The Critical Role of the Sacramento-San Joaquin Delta

The Sacramento-San Joaquin Delta is California's agricultural and environmental heart. Almost half of the water used for agriculture in the state comes from water that originally flowed into the Delta and more than half of Californians rely on water conveyed through the Delta for at least some of their water supplies (Isenberg et al. 2008).[19] The Delta encompasses a diverse array of ecosystems that provide habitat for 700 native plant and animal species. In addition, important transportation, energy, and communication infrastructure is located throughout the Delta.

The Delta is in a state of crisis. Native fish populations, such as the Delta smelt and Chinook salmon, have crashed, and face extinction (Moyle et al. 1996, Brown and Moyle 2004). Levees that protect land, lives, and property from flooding are in a state of disrepair, with some collapsing even during calm conditions. And the threat of climate change, with rising seas and a greater likelihood of floods and droughts, looms on the horizon (Isenberg et al. 2008, Lund et al. 2007, Kiparsky and Gleick 2003).

Friant-Kern Canal, Credit: Peter Gleick

In recent years, the agricultural sector has come under increasing scrutiny, as evidenced by various legal and legislative actions. In 1992, for example, Congress signed the Central Valley Project Improvement Act (CVPIA), which reallocated 800,000 acre-feet of CVP water (600,000 in dry years) from agriculture to previously neglected environmental needs. Several years later, environmental groups filed suit seeking the release of water from Friant Dam to the San Joaquin River, which ran dry for more than 60 miles in most years. The resulting agreement effectively reduced water supplies to farmers in the Central Valley served by the Friant-Kern Canal. In 2007, the "Delta smelt decision" established a stringent set of flow requirements to avoid killing threatened Delta smelt. And in April 2008, Judge Wanger ruled that state agency guidelines intended to protect two species of endangered salmon and steelhead in the Sacramento River were not adequate, which will put upstream diversions of Delta water under greater scrutiny (see Box 1 for an overview of recent court decisions affecting Delta water withdrawals). By late spring 2008, it was clear that natural conditions were going to be extremely dry, putting further pressure on water deliveries to junior water rights holders and reopening talk about the need for new water policies, infrastructure, and river management.

[19] Total diversions from the Delta for urban water use between 1995 and 2005 were 3.2 million acre-feet per year (Lund et al. 2007). In 2000, California's total urban water use was 8.9 million acre-feet (DWR 2008). Thus, a third of California's urban water supply comes from Delta sources.

As a result, policy makers, academic and public policy research groups, and local communities are increasingly focused on trying to develop new solutions to move beyond the historical stalemate that has stalled water policy reform for the Delta. After the collapse of previous efforts to develop a broad consensus, the Governor convened a Delta Vision Blue Ribbon Task Force to identify a strategy for managing the Sacramento-San Joaquin Delta "as a sustainable ecosystem that would continue to support environmental and economic functions that are critical to the people of California."[20] Diverse stakeholder groups, ranging from growers to fishing interests to local communities, are now meeting to discuss alternative management approaches. New bonds are being proposed to fund an array of infrastructure and management options. Recent research by the Public Policy Institute of California recommends an updated version of a peripheral canal to move water around the Delta (Lund et al. 2008). A new assessment by the Environmental Defense Fund attempts to lay out an innovative water management strategy for the Delta region (Koehler et al. 2008). These are all valuable efforts.

A key common finding of recent court decisions, scientific assessments, and the Delta Vision Blue Ribbon Task Force is that the absolute volume of water exported from the Delta is too high.[21] As a result, the Task Force concluded that a "revitalized Delta ecosystem will require reduced diversions—or changes in patterns and timing of those diversions upstream, within the Delta, and exported from the Delta—at critical times" (Isenberg et al. 2008). If reducing diversions and rethinking the pattern and timing of diversions are key solutions, we must explore how to accomplish these changes while maintaining a healthy agricultural community.

In addition to reducing water use, improving the efficiency of irrigation systems can provide a number of other benefits: higher yields, reduced fertilizer and pesticide application, improved crop uniformity and quality, and less erosion. A recent Agricultural Water Management Council report (AWMC 2006a) notes that irrigation system improvements also reduce drainage water runoff thereby reducing the regulatory burden on farmers and providing downstream environmental and public health benefits. Below we describe current water withdrawals from the Delta, and later evaluate the potential to reduce those withdrawals through water-use efficiency and conservation improvements.

[20] Executive Order S-17-06, September 2006.
[21] Natural Resources Defense Council v. Kempthorne, E.D.Cal., 2007; Pacific Coast Federation of Fisherman's Associations, Institute for Fishery Resources v. Gutierrez, E.D.Cal., 2007.

Water Withdrawals from the Delta

The Delta provides water for urban and agricultural uses. Total annual consumption from the Delta system is estimated at 17.7 MAF (Table 1), of which more than 14 MAF, or 80%, goes to agricultural users. Approximately 18% of Delta water is consumed by urban users and the remaining 2% meets environmental flow requirements within the Delta service area. Additional water is withdrawn from the Delta but is assumed to be available for reuse through return flows from surface water runoff and groundwater recharge.

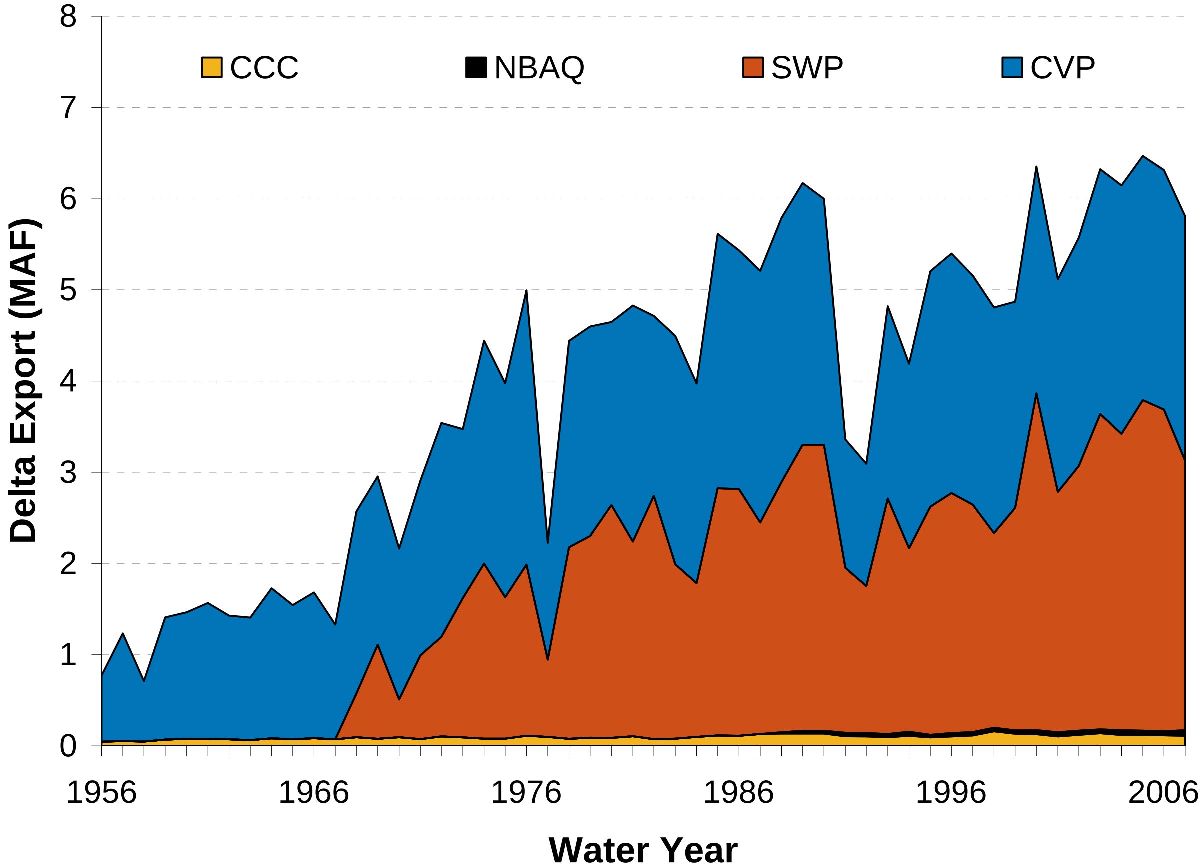
Table 1. Estimated Annual Consumptive Use of Delta Water, 1995-2005

	Agriculture (MAF)	**Urban** (MAF)	**Environment** (MAF)	**Total** (MAF)
Upstream Use	9.5	1.7	0.1	11.3
In-Delta Use	0.8	0	0	0.8
Direct Delta Exports	3.8	1.5	0.3	5.6
Total	14.1	3.2	0.4	17.7

Source: DWR 2008a, Lund et al. 2007, Trott 2007

Water is extracted from the Delta through upstream diversions, withdrawals from within the Delta for local use, and large exports to regions far removed from the Delta. Upstream diversions from the Delta occur throughout the Sacramento Valley and along the San Joaquin River, accounting for about 64% of the consumptive use of Delta water. Direct Delta exports occur primarily through two major water infrastructure projects, the CVP and SWP, and account for 32% of total consumptive use (see Box 2). In-Delta diversions (i.e., withdrawals for local use) are relatively small, accounting for 5% of total consumption.

Figure 5. Delta Exports, 1956-2007



Notes: SWP=State Water Project; CVP=Central Valley Project; CCC=Contra Costa Canal; NBAQ=North Bay Aqueduct
Source: DWR 2008a

As described above, direct Delta exports account for about one-third of the consumptive use of Delta water between 1995 and 2005. These exports totaled an estimated 0.8 MAF of water each year through the Central Valley Project (CVP) and Contra Costa Canal (CCC) in 1956. Since then, Delta exports have increased steadily, with short-term reductions during droughts, such as those during 1977-78 and the early 1990s (Figure 5). By 2005, Delta exports reached their highest level, totaling nearly 6.5 million acre-feet.

Water Conservation and Efficiency Scenarios

Agriculture has long played an important role in California, and as noted earlier, water from the Delta plays a central role in the state's agriculture. Today, the challenge is to envision an agricultural sector that continues to supply food to the state and nation, to support rural livelihoods, and remains consistent with the goal of long-term sustainable water use for the state as a whole. There are many different ways for irrigators to use water productively. Farmers have long shown themselves to be flexible, dynamic, and innovative in response to water constraints. But rapid and unplanned changes in water availability can result in labor dislocations, debt, and production losses.

Water is only one of many constraints and incentives farmers must balance; constraints that may indirectly affect water use include fluctuating market conditions; agricultural policies; local soils and climates; and previous investment in irrigation technologies, farm equipment, and processing machinery. In general, farmers make economically rational decisions to maximize profits. Farmers also make choices independent of profit maximization: experience, family traditions, and community values all factor into their decisions. Each of these factors and decisions can affect the health and condition of the Delta.

Our assessment developed a set of "scenarios" to evaluate changes in agricultural water use given a set of decisions farmers make about crop type, irrigation method, and management practices. Analysts and decision makers often construct scenarios to better understand the consequences of choices or policies on a wide range of possible future conditions. Sometimes scenarios explore outcomes that are unlikely or incongruent with current decisions and policies. Sometimes these scenarios are purely descriptive and are designed to study outcomes that had not previously been considered. Sometimes the scenarios are quantitative and represent discrete outcomes drawn from a range of possible futures. In any effort to look into the future, it is critical to keep in mind that no matter how thoughtful any scenario is, there will be surprises and unexpected events. Ultimately, the point—and power—of scenarios are not to develop a precise view or prediction of the future. It is to enable us to look at the present in a new and different way, and to find new possibilities and choices we might have previously ignored.

For the purposes of this report, we focus on a set of scenarios that offer the potential to reduce agricultural withdrawals from the Delta while minimizing economic disruptions or dislocations. As a starting point, we use land- and water-use data from the 2005 California Water Plan Update (DWR 2005a) for the year 2000 to construct a baseline estimate of irrigated crop acreage, agricultural water use, and economic productivity.

- **Baseline –** adopts DWR assumptions about irrigated crop area and crop water use for the year 2000 that were used in the 2005 California Water Plan Update (DWR 2005a).

We then compare this baseline scenario to four alternative scenarios:

- **Modest Crop Shifting –** shifting a small percentage of lower-value, water-intensive crops to higher-value, water-efficient crops
- **Smart Irrigation Scheduling –** utilizing irrigation scheduling information to help farmers more precisely irrigate to meet crop water needs

- **Advanced Irrigation Management –** applying advanced management methods that save water, such as regulated deficit irrigation
- **Efficient Irrigation Technology** – shifting a fraction of the crops irrigated using flood irrigation to sprinkler and drip systems

Methods

Agricultural Water Use

Figure 6. Map Showing Hydrologic Regions Included in this Study

The DWR routinely produces estimates of agricultural water use that are used in long-term planning efforts. In the most recent California Water Plan Update (DWR 2005a), DWR used a model developed by David Groves to evaluate future water-demand scenarios. The model was implemented in a graphically-based computer environment called Analytica, available from Lumina Decision Systems.[22] The DWR Analytica model estimates urban, agricultural, and environmental water use for each of California's ten hydrologic regions. Here, we focus on agricultural water use, which includes irrigation use, delivery and conveyance losses, and other uses. We also only look at the three hydrologic regions that account for the primary agricultural uses of Delta water: the Sacramento River, the San Joaquin River, and the Tulare Lake (Figure 6). While farmers in these regions also use other sources of water, any reduction in water use could theoretically lead to reductions in withdrawals from the Delta. A more comprehensive, statewide analysis is underway at the Pacific Institute and will be completed and released shortly.

Water Use

Using the DWR Analytica model, we developed a baseline estimate of agricultural water use. For the Modest Crop Shifting and Efficient Irrigation Technology Scenarios, water savings were

[22] See Groves et al. 2005 for a thorough description of the model structure.

determined by comparing output from the model for each of the scenarios with the Baseline Scenario. For the Advanced Irrigation Management and Smart Irrigation Scheduling Scenarios, we performed a literature review to determine a plausible percent savings for each management practice. We then applied this estimate to the agricultural water-use estimate in the Baseline Scenario to estimate the potential water savings associated with each management practice (greater detail on the percent savings is provided in each scenario description).

Consumptive Use

Reductions in water use will not result in a 1-to-1 reduction in withdrawals from the Delta or from groundwater aquifers because of the reuse of return flows. As already noted, consumptive-use reductions are especially valuable. Such reductions can be found by reducing unproductive evaporative losses from the air, soil, or plant surface; deep percolation; and losses to saline sinks.[23] DWR uses the California Central Valley Groundwater-Surface Water Simulation Model (C2VSIM) to estimate water withdrawals within the Sacramento-San Joaquin Valley.[24] However, this model makes several important assumptions that make it less useful for our purposes, which include: using fixed evapotranspiration rates that do not reflect changes in temperatures or irrigation technologies; using inadequate irrigated crop acreage data and insufficient groundwater data; calculating agricultural water reuse (or water that runs off of one farm to be used on another) based on anecdotal evidence rather than on actual measurement; and failing to account for losses to saline sinks. While the model is effective for tracking annual diversions and estimating pumping levels, it is not able to accurately parse out the consumptive and non-consumptive uses of agricultural water. Increasing the collection and reliability of water-use data, one of our key recommendations (see Conclusions and Recommendations), would improve the accuracy of this model.

Although we are unable to quantify consumptive use, we can qualitatively describe the changes in consumptive use associated with each of our four scenarios. The Advanced Irrigation Management Scenario, for example, results in water savings that correspond directly to reductions in consumptive use because the simulated management strategy—regulated deficit irrigation—reduces the evapotranspiration of crops. The Modest Crop Shifting Scenario would also decrease consumptive use substantially, as crops with generally higher evapotranspiration rates are substituted by crops with lower evapotranspiration rates. However, water savings from the Smart Irrigation Scheduling and Efficient Irrigation Technology Scenarios are a combination of reductions in consumptive use (i.e., deep percolation and losses to saline sinks) along with reductions in non-consumptive use (i.e., groundwater recharge and return flows).

Economic Impacts

Production Value

There are many ways to look at the contributions California's agricultural sector has made to the state's economy, including measures of employment, farm revenue, the value-added, and more. The USDA Economic Research Service maintains data on the total value of the agricultural sector's production of goods and services. Table 2 shows the average production value per acre

[23] Half of the farmland in the San Joaquin Valley, for example, overlies a saline, shallow groundwater sink (DWR 2008b). As noted by the Agricultural Water Management Council, "Reduction of losses flowing into saline sinks always results in saved water" (AWMC 2005).

[24] For more information about the structure and assumptions of the C2VSIM model, contact DWR Bay Delta modeling office.

of irrigated land for each major crop type. These estimates were calculated by dividing the statewide estimates of gross production values for each crop type for 2000-2003 (USDA 2007a) by the DWR irrigated acreage estimates for the same period (DWR 2008c).

To evaluate how a particular scenario would affect agricultural productivity, we multiplied the irrigated acreage of each crop type by the values shown in Table 2. For example, in year 2000, DWR estimates that 4.3 million acres were planted in field crops in the three hydrologic regions. Given that the average gross production value of field crops is $524 per acre, we estimate that field crops generated $2.3 billion in gross revenue in the region. If we reduce field crop acreage by 10% or 0.4 million acres, then the field crop production value would decline by $230 million.

The numbers shown in Table 2, however, are based on gross returns. No one maintains data on net returns, defined as total production returns minus production costs, by crop type. However, we do know that costs (capital and operation and maintenance) vary among crop types. A more detailed study would evaluate the net production value of each crop type so as to capture this variability and provide a better assessment of changes in economic productivity and profitability. In the absence of this data, we provide a separate qualitative discussion of energy, labor, and irrigation costs (see section on "Challenges and Opportunities to Achieve Conservation and Efficiency").

Table 2. Average Gross Production Value by Crop Type

	Gross Production Value (2005$/acre)
Field crops	$524
Fruits and nuts	$3,134
Vegetables	$5,171

Note: Production values are based on estimates of statewide crop production for each crop type in county agricultural commissioner reports from 2000-2003, compiled by the Economic Research Service (USDA 2007a). The production value of nursery products was excluded because of insufficient data on irrigated acreage for this crop. Pasture production values typically include an estimated number of AUMs per acre and/or average leasing rates per acre to reflect the added income from livestock/dairy production on pastureland (Bengston, D., Agricultural Commissioner, Mendocino County, personal communication. August 26, 2008).

Cost Effectiveness

While agriculture has social and cultural importance, it is also an economic endeavor; farmers must make choices about investments based on expected costs and returns. A farmer may pursue a measure if the benefits exceed the costs over the lifetime of the measure. For example, if a drip system is expected to last for 15 years, then investment in drip irrigation makes economic sense if the benefits over the 15-year period, such as reduced operation and maintenance costs or improved yield or quality, are sufficient to offset the initial capital investment.

A cost-effectiveness analysis provides an alternate, and perhaps better way to determine whether to invest in a particular water conservation or efficiency improvement. A cost-effectiveness analysis is best suited for a situation where we desire to maintain the level of service, in this case to support crop production. This type of analysis compares the cost of conserved water with that of the marginal water supply cost. For example, if a measure saves 1,000 acre-feet of water and costs a total of $150,000, including both capital investment and operation and maintenance costs over the life of the measure, the cost of conserved water would then be $150 per acre-foot. If we compare the cost of conserved water with the cost of water from the proposed dam at Temperance Flat on the San Joaquin River, which is projected to cost at least $350 per acre-foot (DWR 2007a), then we would conclude that the conservation measure is more cost effective.

For this analysis, we calculated the cost of conserved water where possible. We based these calculations on literature reviews and, in the case of the Efficient Irrigation Technology Scenario, on an online cost calculator provided by the Irrigation Association. We note that a more detailed economic assessment is needed to capture the social, economic, and environmental benefits of these efficiency improvements. These efficiency improvements should then be compared with new water supply and conveyance options, particularly the "dual conveyance" system which is estimated to cost between $4.2 and $17.2 billion (DWR 2008d).

Results

The results of each scenario are summarized below. Appendix A contains additional data on assumptions about irrigated crop type, applied water, and production value for each of the scenarios.

Baseline Scenario

For the Baseline Scenario, we use year 2000 as the base year because it was a "normal" water year and sufficient data are available on water use, irrigated acreage, and crop production value. Our baseline estimate of total agricultural water use in the Delta system in 2000 was 26.5 MAF (Table 3). Based on the baseline irrigated acreage for each crop type and the values shown in Table 2, we estimate that the total crop production in 2000 in the three hydrologic regions was $12.8 billion in 2005 dollars, representing about 70% of California's total crop production value.

Table 3. Baseline Scenario, Year 2000

	Water Withdrawals (1,000 AF)	**Production Value** (2005$ billions)
Sacramento River	8,714	$2.9
San Joaquin River	7,018	$4.0
Tulare Lake	10,800	$5.9
Total	26,532	$12.8

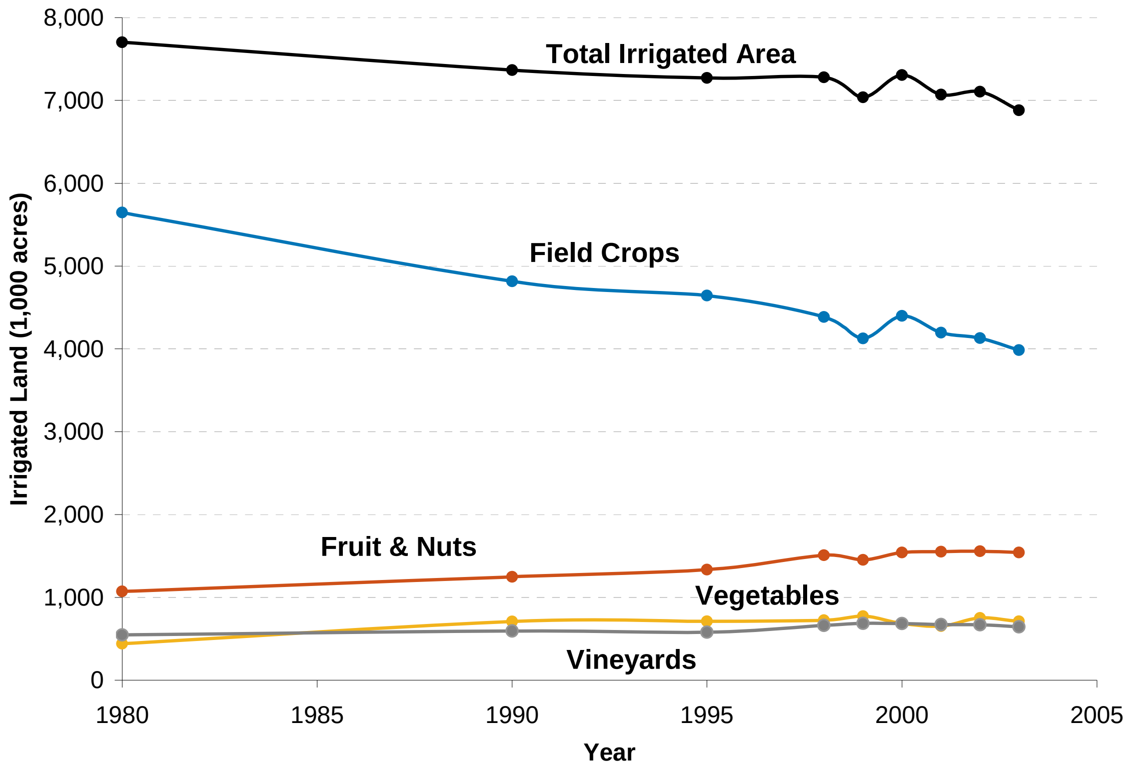
Note: All production value estimates are in 2005 dollars. We estimate the value of agricultural products based on crop production value by acre (Table 2) for each major crop type multiplied by the estimated crop area.

Modest Crop Shifting Scenario

Cropping patterns in the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions are already changing. In 1980, more than 5.6 million acres of land in these three hydrologic regions were planted with field crops, accounting for 73% of the total irrigated area in the region (Figure 7). While field crops decreased by 1.7 million acres, by 2002 this was offset by an increase in orchard, vineyard, and vegetable acreage, which resulted in a net decline in total irrigated area of about 0.8 million acres. Note these changes are nearly identical to the statewide trend, in large part because nearly 80% of the state's irrigated agricultural land is within these three hydrologic regions.[25]

[25] California's statewide irrigated crop area in 2000 was 9.5 million acres (DWR 2005).

Figure 7. Irrigated Area by Crop Type in the Three Delta Hydrologic Regions, 1980-2003



Source: DWR 1983, 1993, 1998, 2008c

Replacing crops that are associated with high rates of applied water per unit area with those that use less water can result in substantial water savings.[26] Because plant water requirements in much of California are met by irrigation, water saved from crop shifting can reduce water withdrawals as well as consumptive uses. Crop shifting may also provide economic advantages to the region. Field crops are generally more water-intensive and generate lower value per acre compared with other crop types (Figure 4). Thus, well-planned crop shifting could reduce water use while increasing revenue. Note that we do *not* recommend shifting away from field crops entirely, or even to a large degree—field crops can provide important benefits including, but not limited to: price stability for farmers (in comparison to other commodities); nitrogen fixation (in the case of alfalfa, lotus species, and legumes); lower fertilizer and pesticide inputs (depending on farm management); and, in some cases, wildlife habitat (Putnam et al. 2001).

In this scenario, we simulate a continued transition from field crops to vegetable crops, shifting 25% of irrigated field crop acreage to irrigated vegetable crop acreage. We do not reduce the total area of irrigation, but simply change its use from more water-intensive field crops to less

[26] Rice, alfalfa, and pasture have the highest average rates of applied water in the three hydrologic regions, with rates of 5.19, 4.69, and 4.49 acre-feet per acre respectively (DWR 1998-2003). However, other field crops, and in particular safflower and grain, have significantly lower average rates of applied water, e.g., 1.15 and 1.19 acre-feet per acre respectively. Thus, some field crops are actually less water-intensive than some tree and/or vegetable crops. Yet, over half of the field crop acreage in the three hydrologic regions is planted in the most water-intensive field crops (DWR 2008b).

water-intensive vegetable crops. We chose to model this shift in cropping patterns because it is already occurring. In addition, vegetable crops remain a more flexible agricultural land use than permanent crops (orchards and vineyards) and can therefore be more easily shifted (or fallowed) in response to changing climatic or market conditions.

Table 4 shows the results of this scenario by hydrologic region. Total irrigated crop area remains the same, while agricultural water use declines by 1.2 MAF and production value increases by $5.1 billion. These water savings exceed the 1.1 MAF of groundwater overdraft in the three hydrologic regions, demonstrating that agricultural policies can help rebalance the hydrologic cycle, while maintaining, and even increasing, economic productivity and profitability. These savings can also result in reductions in Delta water use.

Table 4. Modest Crop Shifting Scenario: Shifting 25% of Field Crop Acreage to Vegetable Acreage

	Water Withdrawals (1,000 AF)	**Production Value** (2005$ billions)
Sacramento River	-545 (-6%)	$1.7 (57%)
San Joaquin River	-240 (-3%)	$1.3 (33%)
Tulare Lake	-440 (-4%)	$2.1 (36%)
Total	-1,225 (-5%)	$5.1 (40%)

Farmers change the crops planted and the irrigation of those crops based on a variety of factors, including the market value of the crop, local weather conditions, crop subsidy programs, the need to rotate crops, and the seniority of their water rights. In addition, past investments in harvesting and processing equipment were based on the quantity and type of crops grown. Thus, crop shifting may need to occur incrementally to avoid stranding infrastructure. As described previously, the economic impacts of crop shifting are assessed by evaluating changes in the gross production value. We note that there are increased operation and maintenance costs associated with particular crop types, which are not reflected in the gross estimates because net estimates are not available by crop type. However, the fact that crop shifting is already occurring suggests it is cost effective for many farmers. Future assessments should evaluate how shifting crop type affects the net production value.

Smart Irrigation Scheduling Scenario

Crop water requirements vary throughout the crop life cycle and depend on weather and soil conditions. Irrigation scheduling provides a means to evaluate and apply an amount of water sufficient to meet crop requirements at the right time. While proper scheduling can either increase or decrease water use, it will likely increase yield and/or quality, resulting in an improvement in water-use efficiency.[27] Despite the promise of irrigation scheduling and other new technologies, California's farmers still primarily rely on visual inspection or personal experience to determine when to irrigate (Table 5).

[27] Water-use efficiency is defined here as yield divided by applied water.

Soil or plant moisture sensors, computer models, daily evapotranspiration reports, and scheduling services, which have long been proven effective, are still fairly uncommon, suggesting there is significant room for improvement.

Table 5. Method Used by California Farmers to Decide When to Irrigate, 2003

Method	Percent of Farmers
Condition of crop	71%
Feel of soil	36%
Personal calendar schedule	27%
Scheduled by water delivery organization	11%
Soil moisture sensing device	10%
Daily ET reports	8%
Other	6%
Commercial or government scheduling service	5%
When neighbors irrigate	4%
Plant moisture sensing device	3%
Computer simulation model	1%

Note: Many farmers use more than one method when deciding when to irrigate, thus the total of all methods exceeds 100%.
Source: USDA 2003

The California Irrigation Management Information System (CIMIS), for example, is an integrated network of automated weather stations throughout the state that provides information needed to estimate crop water requirements. Since its inception in 1982, the CIMIS network has expanded to include more than 125 fully automated weather stations across California. A survey by the Department of Agriculture and Resource Economics at the University of California, Berkeley evaluated the water use and yield of all the major crop types of 55 growers across California who were using CIMIS to determine water application (Eching 2002). Their study concluded that the use of CIMIS increased yields by 8% and reduced water use by 13% on average (DWR 1997). We apply these percentages to the baseline estimate, resulting in a water savings of 3.4 MAF and an increase in production value of $1 billion (Table 6).

Table 6. Smart Irrigation Scheduling Scenario

	Water Withdrawals (1,000 AF)	Production Value (2005$ billions)
Sacramento River	-1,133 (-13%)	$0.2 (8%)
San Joaquin River	-912 (-13%)	$0.3 (8%)
Tulare Lake	-1,404 (-13%)	$0.5 (8%)
Total	-3,449 (-13%)	$1.0 (8%)

Note: Percentages shown represent percent change from the baseline scenario. All production value estimates are in 2005 dollars. We estimate change in the value of agricultural products by multiplying the baseline estimate of agricultural production by the projected increase in yield (8%).

This scenario assumes that farmers are able to apply the necessary amount of water to crop requirements when needed. In reality, there are many irrigation systems that do not provide water on demand, like a rotational irrigation system, which may provide water once every 16 days. In situations such as these, the farmer does not have the ability to apply water where or when it is needed. As noted by the Food and Agriculture Organization, "farmers' dependence on a timely and adequate water supply determines their ability to accurately apply water to the field. Inadequacies in the irrigation system and poor management of the water supply result in inadequate and unreliable water supplies to the field, frustrating any attempts at accurate crop irrigation scheduling" (FAO 1996). Thus, district-wide infrastructure investments may be needed to achieve these water savings. Financing district-wide improvements may be less difficult because funding for these types of improvements is more readily obtainable from state or federal agencies. There are fewer actors needed to make these improvements yet a larger base from which to distribute the repayment cost.

Advanced Irrigation Management Scenario

The traditional irrigation strategy is to supply irrigated areas with sufficient water so that crops transpire at their maximum potential. In other words, water is provided to meet full crop ET requirements throughout the season. However, water scarcity and concerns about the effect of agricultural diversions on aquatic ecosystems and groundwater resources have called this practice into question. There are a number of innovative approaches to irrigation management that have been shown to reduce crop water use, including deficit irrigation, tail water recovery, and surface residue management.

Here, we focus on regulated deficit irrigation. A growing body of international work shows that consumptive water use can be reduced in orchards and vineyards without negative impacts on production. The concept of "deficit irrigation," defined as the application of water below the level of traditional, full crop ET, can be an important tool to both reduce applied water and increase revenue (Chaves et al. 2007, Fereres and Soriano 2006). A recent Food and Agriculture Organization report presents a number of deficit irrigation studies focused on various crops in semi-arid climates around the world, and concludes substantial water savings can be achieved with little impact on crop yield and quality (Goodwin and Boland 2002). Other studies, however, suggest that significant crop stress over multiple years can have a negative impact on yield (Burt et al. 2003).

Because crop response to water stress can vary considerably, a clear understanding of crop behavior and ecological conditions is required to maintain yields. While deficit irrigation is uncontrolled, regulated deficit irrigation (RDI) is generally practiced during stress-tolerant growth stages in order to minimize negative impacts on yield (Goldhamer 2007). In pistachios, for example, RDI is imposed during the shell-hardening phase which is particularly stress-tolerant (and therefore appropriate for reduced irrigation) while the bloom and nut-filling stages are not. Additionally, studies indicate that RDI may improve crop quality, particularly for wine grapes (Williams and Matthews 1990, Girona et al. 2006).

Thus far, RDI has been more widely applied with tree crops and vines than with field crops (Fereres and Soriano 2006): in trees and vines, the yield-determining processes are generally not as sensitive to water stress during particular growth stages as many field crops. This, coupled with the fact that crop quality, rather than total yield, is an important determinant of economic returns for tree crops, makes RDI more successful for these plant types. In the most recent California Water Plan (DWR 2005a), Goldhamer and Fereres (2005) calculate a range of water savings associated with the application of RDI techniques to tree crops and wine grapes in California, estimating savings between 1 and 1.5 million acre-feet per year.

Table 7. Studies of RDI in the Central Valley, California and Valencia, Spain.[28]

Study	Location & Year	Crop	Change in Applied Water	Change in Yield
Goldhamer et al. 2006	San Joaquin Valley 1993-1995	Almonds (high density)	-20%	-7%
Goldhamer et al. 2006	San Joaquin Valley 1993-1995	Almonds (low density)	-12%	-4%
Goldhamer et al. 2003	San Joaquin Valley 2001	Almonds	-5%	+4 %
Goldhamer et al. 2003	San Joaquin Valley 2001	Almonds	-42%	-9%
Goldhamer and Beede 2004	San Joaquin Valley 1998-1992	Pistachios	-23%	NA[(a)]
Average water savings for almonds and pistachios = -20%				
Goldhamer and Salinas 2000	San Joaquin Valley 1997-2000	Citrus (Navel orange)	-25%	-5%[(b)]
González-Altozano and Castel 2000	Valencia, Spain 1997-1998	Citrus (Clementine)	-12%	+4%
González-Altozano and Castel 2000	Valencia, Spain 1997-1998	Citrus (Clementine)	-22%	+1%
Average water savings for citrus = -20%				

Note: Almond yield figures are based on dry kernel weight, measured by weight per unit area. Citrus yields are based on “gross weight” or kilograms per hectare in Goldhamer and Salinas 2000, but are measured as “commercial yield” or kilograms per tree in González-Altozano and Castel 2000.
(a): This study did not include figures for the change in yield but did note that “Production scale tests have been conducted since 1992 with cooperating growers under a variety of soil conditions…We have observed no negative effects of irrigating at 50% ET during the shell hardening stage or post-harvest” (Goldhamer and Beede 2004).
(b): This study noted that although yield decreased, “many of the RDI regimes had higher gross revenue than the full irrigation control…This was due to significantly lower creasing (higher fruit quality), especially with early season stress” (Goldhamer and Salinas 2000).

The volume of water that can be saved using an RDI strategy depends on many factors, such as crop sensitivity to stress, climatic demand, stored available water at bud break, spring-summer rains, and the particular irrigation strategy.[29] After a literature review and discussion with agricultural water-use experts, we estimate that RDI can reduce applied water by 20% for almonds, pistachios, and citrus trees (Table 7). There are also a range of applied water savings for vines (Prichard 2007, 2000, 1997), however, for this scenario we use a conservative regional estimate of 39% reduction in applied water based on an average of values in Prichard (2002). This study concludes that “these savings can be achieved while having little to no impact on

[28] There are many studies of RDI throughout the world; here we cite those that are most relevant, given the climate and soils of California’s Central Valley. RDI is particularly sensitive to local conditions, as even slightly higher/lower soil moisture content can greatly affect the success of different levels of RDI.
[29] Water savings are described in comparison to a control that received full irrigation to meet ET requirements (estimated by the Penman-Monteith method).

yield and an increase in fruit quality given the appropriate deficit strategy is selected."[30] We note that statewide land-use data does not distinguish between other deciduous trees, like walnuts, peaches, pears, and olives, which have varying responses to RDI, and need further study (Marsal et al. 2008). Given the current data limitations, we do not apply any RDI treatment to other fruit and nut trees.

Table 8. Results for the Advanced Irrigation Management Scenario

	Water Withdrawals (1,000 AF)	Production Value (2005$ billions)
Sacramento River	-140 (-2%)	$0 (0%)
San Joaquin River	-423 (-6%)	$0 (0%)
Tulare Lake	-665 (-6%)	$0 (0%)
Total	-1,229 (-5%)	$0 (0%)

Note: Percentages shown represent percent change from the baseline scenario. We do not provide an alternate estimate of revenue as the effect of RDI on production yield can vary and there is little reliable data on changes in yield associated with RDI available for California.

The Advanced Irrigation Management Scenario applies a 20% average applied water savings to almonds, pistachios, and citrus trees and a 39% average applied water savings to vines, resulting in an estimated water savings of 1.2 MAF (Table 8). This scenario, however, assumes that no orchards or vineyards are currently grown with these methods. We agree with Burt et al. (2003) that a key question that needs to be addressed is: how many farmers are already practicing reduced deficit irrigation and to what extent are they deficit irrigating? Recently, the Mendocino County Cooperative Extension found that while the vast majority of wine growers already practice some deficit irrigation, the deficit level varied considerably among farmers (Lewis et al. 2008). This variability underscores the need for better metering and measurement of on-farm water use both to demonstrate current levels of efficiency and to inform statewide estimates of water use and potential additional water savings. Even if a more accurate understanding of farmers' current practices minimizes potential water savings, the potential water savings related to applying RDI to a variety of orchard crops classified as "other deciduous trees" were not included. RDI remains an important and feasible efficiency measure that requires no change in the types of crops grown. It may, however, require additional infrastructure and/or labor to monitor plant stress and soil moisture.

Efficient Irrigation Technology Scenario

Numerous irrigation methods are currently available to deliver water where and when it is needed. These methods are typically divided into three categories: flood, sprinkler, and drip/microirrigation systems.[31] Each irrigation method is described below.

[30] Prichard (2002) estimates a 28% water savings on vineyards in the San Joaquin Valley and a 50% water savings on vineyards in the Lodi area. We use the average of these values (39%), while noting that water savings from RDI are extremely site-specific along with being spatially and temporally variable.

[31] Drip and microirrigation systems are defined as low-pressure, low-volume irrigation systems and include surface and sub-surface drip as well as micro-sprinkler systems.

Flood Irrigation

The oldest form of irrigation, floor irrigation, is the application of water by gravity flow to the surface of the field. It is most often used on field crops but can be used on any crop not adversely affected by some ponding. Either the entire field is flooded (by uncontrolled flood or basin irrigation) or the water is fed into small channels (furrows) or strips of land (borders) (Figure 8).

Figure 8. Furrow irrigation

Photo courtesy of USDA NRCS

Flood irrigation offers a number of important advantages, including simplicity of design, minimal capital investment, and low energy requirements. Surface irrigation systems are also less sensitive to source water quality than sprinkler or drip. On the other hand, there are also some notable disadvantages. Surface irrigation systems are typically less efficient in applying water than either sprinkler or drip. Using the field surface as a conveyance and distribution facility requires that fields be well graded and land-leveling costs can be high. These systems tend to be labor-intensive because of the need to move pipes and machinery (Renault 1988), and they are less flexible in terms of management options.

Sprinkler Irrigation Systems

Sprinkler irrigation, introduced in the 1930s, delivers water to the field through a pressurized pipe system and distributes water via rotating sprinkler heads, spray nozzles, or a single gun-type sprinkler. The sprinklers can be either permanently mounted (solid set) or mounted on a moving platform that is connected to a water source (traveling). Although they have the poorest overall water-use efficiency among the sprinklers, traveling sprinklers are well-suited to irregularly sized or shaped fields and can be easily moved between fields (Evans et al. 1998). Low-energy precision application (LEPA) and low elevation spray application (LESA) sprinklers are an adaptation of center pivot systems that use drop tubes that extend down from the pipeline to apply water on the ground or a few inches above the ground (Figure 9). LEPA and LESA systems can conserve both water and energy by applying the water at a low-pressure close to the ground, which reduces water loss from evaporation and wind, increases application uniformity, and decreases energy requirements.

Figure 9. Low Elevation Spray Application (LESA) Sprinkler

Photo courtesy of USDA NRCS

Sprinklers provide a number of important advantages. If managed properly, they can improve water-use efficiency. Sprinklers often result in less ineffective runoff than a surface system, thereby reducing erosion, pollution of downstream water sources, and the economic cost of dealing with drainage. In addition, sprinklers tend to require less labor, thereby reducing labor costs and vulnerability to labor shortages (Burt et al. 2000).

Sprinkler systems, however, also have a number of disadvantages. Installing sprinkler systems is an expensive upfront investment, ranging from $1,000 to $1,500 per acre for permanent, solid set sprinklers with PVC pipes to $3,500 per acre for hand-move aluminum sprinklers (Bisconer, I., Chair of the Drip/Micro Common Interest Group, Irrigation Association, personal communication, August 6, 2008). Unlike drip or flood irrigation systems, the application efficiency of sprinklers may be lower under windy or extremely hot, dry conditions. In addition, sprinkler systems continuously or periodically wet crop foliage or fruits, which can damage some crops directly or indirectly through the promotion of plant disease growth (Jensen and Shock 2001).

Drip/Microirrigation Irrigation Systems

Drip irrigation refers to the slow application of low-pressure water from plastic tubing placed near the plant's root zone. Drip systems commonly consist of buried PVC pipe mains and sub-mains attached to surface polyethylene lateral lines (Figure 10).

Figure 10. Lateral drip lines in a vineyard

Photo courtesy of USDA NRCS

A less expensive, but also less durable, option is drip tape. Water is applied through drip emitters placed above- or below-ground, referred to as surface and subsurface drip, respectively. Microirrigation systems are similar to drip systems with the exception that water is applied at a higher rate (5-to-50 gallons per hour) by a small plastic sprinkler attached to a stake (Evans et al. 1998).

Drip irrigation has been in use since ancient times when buried pots were filled with water that slowly seeped into the soil. Modern drip was facilitated by the advent of plastics during World War II and was first introduced in Israel. Although traditionally applied to specialty crops such as vegetables and grapes, drip irrigation systems are increasingly applied to row crops, and there are examples of use on field crops such as cotton, corn, alfalfa, and potatoes (M. Dowgert, Irrigation Specialist, Netafim USA, personal communication, July 23, 2008).

Drip irrigation allows for the precise application of water and fertilizer to meet crop needs and can increase crop yield and/or quality. In a recent AWMC report, a Westlands farmer notes that with drip irrigation, "We consistently use less water, less fertilizer, and find tillage and ground preparation less costly. In addition, yields are higher and the quality of the product we grow is better. Drip irrigation pays, it doesn't cost!" (AWMC 2006a). Furthermore, "the potential for improved water and chemical management can benefit water quality, reduce potential runoff, and reduce potential leaching of nutrients and chemicals" (Evans et al. 1998). Drip systems can be automated, thereby reducing labor costs. With drip systems, diseases are less likely to develop because water does not come into contact with crop leaves, stems, or fruit (Shock 2006). Drip systems can be used on oddly shaped or hilly terrain.

One of the major disadvantages to converting to drip is the initial investment, which is estimated at $500 to $2,000 per acre (Bisconer, I., Chair of the Drip/Micro Common Interest Group, Irrigation Association, personal communication, August 6, 2008). However, these costs can be offset with a reduction in operation costs and/or increase in crop revenue. Using the "Drip-Micro Irrigation Payback Wizard,"[32] we compared the costs and benefits associated with converting from flood to drip/micro for cotton and almonds in Central California. We assumed that the cost of water is $46.19 per acre-foot, which is equal to the average cost of water from the State Water Project in the San Joaquin Valley (DWR 2005b). The Payback Wizard estimates that the payback period for converting cotton and almonds is 1.9 years and 0.6 years, respectively (Tables 9 and 10). In these examples, water, fertilizer, labor, and chemical costs decline under drip irrigation compared to flood. These benefits are partially offset by higher energy costs, which result from pressurizing water.

The economic savings associated with conserving water is relatively small because water for agriculture is typically inexpensive in California. While conserving water may not be an economic driver for converting to drip, the additional revenue provided by increased yields and/or quality often make these investments worthwhile. Additionally, saved water may be applied elsewhere to increase overall production, resulting in no net savings but an overall increase in agricultural production and income. We note that economics are an important, but not the only, factor affecting the farmer's choice of irrigation technology.

[32] The Payback Wizard was developed by the Irrigation Association and allows farmers to input region, crop type, acreage, and water price to determine the payback period for converting from flood to drip/microirrigation system.

Table 9. Costs, Revenue, Payback Period for Drip/Microirrigation System for 100 Acres of Cotton in Central California

Cotton	Flood System	Drip-Micro System
Water Cost ($/acre)	$172.35	$131.16
Energy Cost ($/acre)	$46.34	$69.51
Fertilizer Cost ($/acre)	$47.00	$37.60
Chemical Cost ($/acre)	$177.00	$141.60
Irrigation Labor Cost ($/acre)	$55.00	$27.50
Maintenance Cost ($/acre)	$16.26	$16.26
Cultural Cost ($/acre)	$12.00	$6.00
Equipment Cost ($/acre)	$88.00	$88.00
Harvest Cost ($/acre)	$76.00	$91.20
Investment for new system ($/acre)	N/A	$1,000.00
Revenue/unit ($/acre)	$90.00	$108.00
Estimated payback period (yrs)	N/A	1.86

Note: Default multipliers are used to calculate these results, such as the 1.2 multiplier that increases yield when converting from flood to drip. You can customize these defaults on the Payback Wizard website: http://www.dripmicrowizard.com/.

Table 10. Costs, Revenue, Payback Period for Drip/Microirrigation System for 100 Acres of Almonds in Central California

Almonds	Flood System	Drip-Micro System
Water Cost ($/acre)	$292.93	$222.92
Energy Cost ($/acre)	$78.77	$118.16
Fertilizer Cost ($/acre)	$228.00	$182.40
Chemical Cost ($/acre)	$383.00	$306.40
Irrigation Labor Cost ($/acre)	$28.00	$14.00
Maintenance Cost ($/acre)	$10.32	$10.32
Cultural Cost ($/acre)	$35.00	$17.50
Equipment Cost ($/acre)	$87.00	$87.00
Harvest Cost ($/acre)	$284.00	$340.80
Investment for new system ($/acre)	N/A	$1,000.00
Revenue/unit ($/acre)	$200.00	$240.00
Estimated payback period (yrs)	N/A	0.58

Note: Default multipliers are used to calculate these results, such as the 1.2 multiplier that increases yield when converting from flood to drip. You can customize these defaults on the Payback Wizard website: http://www.dripmicrowizard.com/.

In addition to a relatively high initial cost, there are a number of other disadvantages associated with drip irrigation. Drip requires management to ensure that emitters do not leak or become clogged by silt, chemical deposits, or even algal growth in the drip lines. Because of the danger of clogging and the need to provide water continuously, drip systems typically require a more reliable, higher quality water source and/or a filter system. Farmers may switch to using groundwater because of its consistency in quality and availability, which may further exacerbate groundwater overdraft. Rodents can also be a problem, especially where the drip line is buried (Shock 2006).

Comparison of Irrigation Technologies

With proper management and design, drip and micro irrigation are the most efficient at maximizing crop-yield-per-unit water use; flood irrigation is the least efficient because of the larger volumes of unproductive evaporative losses that occur, water application to non-targeted surface areas, and the propensity for deep percolation since the application rate is somewhat fixed. The potential irrigation efficiencies[33] for flood irrigation systems range from 60-85%, whereas for sprinklers, the potential irrigation efficiencies range from 70-90%. Potential irrigation efficiencies for drip and micro irrigation systems are even higher, ranging from 88-90% (Table 11).

Irrigation technologies, however, are only methods to distribute water, not measures of efficiency. A recent University of California Cooperative Extension study, for example, showed that vineyards using drip irrigation systems varied widely in the amount of water applied per acre (from 0.2 acre-feet to 1.3 acre-feet), suggesting that management practices are an important determinant of applied water (Lewis et al. 2008). Thus, effective management is essential for achieving the water savings of an efficient irrigation system.

Table 11. Irrigation System Efficiency

Type of Irrigation System	Efficiency
Flood	
Basin	85%
Border	77.5%
Furrow	67.5%
Wild Flooding	60%
Gravity	75%
Average	**73%**
Sprinkler	
Hand Move or Portable	70%
Center Pivot and Linear Move	82.5%
Solid Set or Permanent	75%
Side Roll Sprinkler	70%
LEPA (Low Energy Precision Application)	90%
Average	**78%**
Drip /Micro irrigation	
Surface Drip	87.5%
Buried Drip	90%
Subirrigation	90%
Micro Sprinkler	87.5%
Average	**89%**

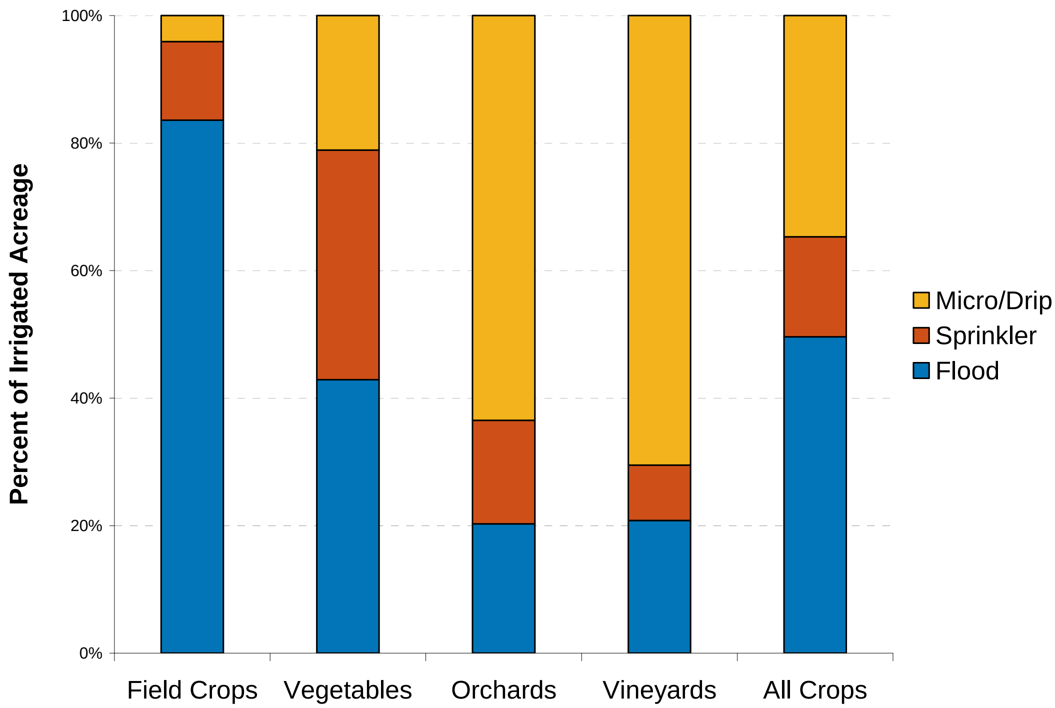
Note: Efficiency is defined here as the volume of irrigation water beneficially used (equal to ET) divided by the volume of irrigation water applied minus change in storage of irrigation water.
Source: Salas et al. 2006

[33] Irrigation efficiency is defined here as the volume of irrigation water beneficially used by the plant divided by the volume of irrigation water applied minus change in storage of irrigation water.

Irrigation technologies in California vary substantially by crop type (Figure 11). Drip and sprinkler systems are common on orchards and vineyards, accounting for about 80% of the irrigated acreage for these crop types, with the remaining 20% using flood systems. Flood systems are still employed on a high percentage of vegetable and field crops, with more than 40% of vegetable and 80% of field crops still using this technology.

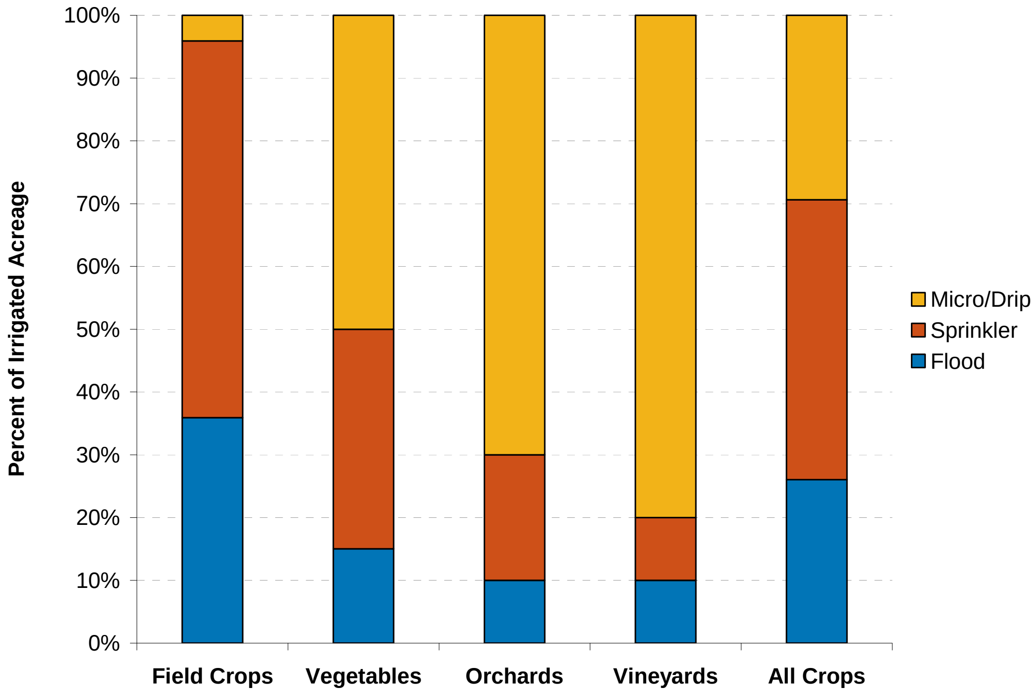
In the Efficient Irrigation Technology Scenario, we reduce the acreage that is irrigated using flood systems while simultaneously increasing the acreage irrigated by sprinkler and drip systems (Figure 12). We assume drip becomes the most common irrigation technologies for vegetables, orchards, and vineyards. Given that drip is rarely used on field crops, we assume that flood systems are partly replaced with sprinklers. In total, we estimate that flood irrigation remains in use on 26% of California's irrigated land area, while sprinklers and drip/microirrigation are used on 45% and 30% of California's irrigated land area, respectively. These changes are consistent with the trend that is already occurring in California, where farmers are replacing inefficient flood systems with more efficient sprinkler and drip irrigation systems (Orang et al. 2005).

Figure 11. Irrigation Technology by Crop Type, 2001



Source: Based on data in Orang et al. 2005

Figure 12. Irrigation Technology by Crop Type for the Efficient Irrigation Technology Scenario



We use the DWR Analytica model to estimate the effect of changing irrigation method on applied water. Using this model, we combine changes in irrigation method and the average irrigation efficiencies of each irrigation method to estimate reductions in applied water. Our results indicate the increasing use of sprinkler and drip systems can reduce agricultural water use in the Sacramento-San Joaquin hydrologic regions by 0.6 MAF. The total irrigated acreage and agricultural revenue did not change because there is no change in crop types over the Baseline Scenario (Table 11). However, it has been widely documented that adoption of sprinkler and drip systems often results in improvements in crop yield and quality. Therefore, excluding production value increases in this scenario is conservative, as value may increase with the adoption of sprinkler or drip technology.

Table 11. Results for the Efficient Irrigation Technology Scenario

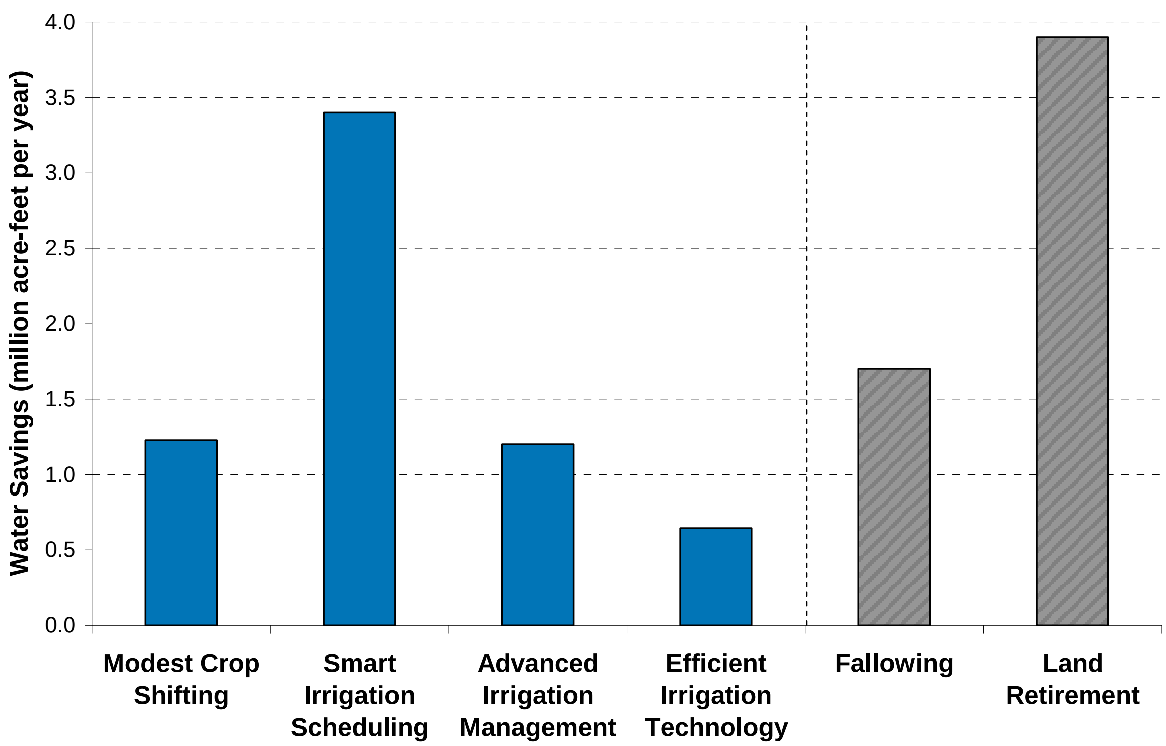
	Water Withdrawals (1,000 AF)	**Production Value** (2005$ billions)
Sacramento River	-145 (-2%)	$0 (0%)
San Joaquin River	-198 (-3%)	$0 (0%)
Tulare Lake	-300 (-3%)	$0 (0%)
Total	-643 (-2%)	$0 (0%)

Note: Percentages shown represent percent change from the baseline scenario. All production value estimates are in 2005 dollars. We measure the value of agricultural products here based on crop production value by acre shown in Table 2 for each crop type multiplied by the estimated crop area.

Summary of Results

A wide range of options are available for improving the efficiency of water use in California agriculture. The four scenarios we evaluated here all show the potential for significant water savings without economic disruptions—indeed, in several the gross production value increases (Figure 13). All of the scenarios would save, sometimes substantially, in excess of 0.6 MAF, thereby helping to satisfy legal restrictions on Delta withdrawals and potentially reducing groundwater overdraft in the three hydrologic regions. Furthermore, these savings can be achieved without adversely affecting the economic productivity of the agricultural sector. In fact, by shifting lower-value field crop acreage to vegetables, the crop shifting scenario actually increases the economic productivity of the agricultural sector. It is important to note that these savings are not necessarily additive, that is combining the crop shifting and efficient irrigation technology scenario would not necessarily equal 1.8 MAF of water savings (0.6 MAF from efficient irrigation technology plus 1.2 MAF from crop shifting). However, combining strategies would likely result in savings higher than any one scenario alone.

Figure 13. Potential Water Savings Associated with Each Water Efficiency Scenario compared to Fallowing and Land Retirement



While we do not consider land fallowing to be a water-efficiency measure, planned short-term fallowing could also produce significant water savings during a drought or supply disruption (see Box 4). Planned, short-term fallowing of 10% of the field crop acreage would save 1.7 million acre-feet of water and provide revenue for capital and other needed improvements. Furthermore, permanently retiring 1.5 million acres of drainage-impaired lands in the San Joaquin Valley would save 4.6 million acre-feet of water per year, while also reducing clean-up costs and minimizing the social and environmental impacts associated with polluted surface and groundwater.[34,35]

These water savings are just as effective as new centralized water storage and infrastructure, even if such new infrastructure could be approved, funded, and built. For example, the savings we find in these scenarios can be compared using "dam equivalents." Assuming a dam yields 174,000 acre-feet of "new" water,[36] our scenarios create "new" water in efficiency improvements and/or conservation equivalent to 3 to 20 dams of this size. A strong argument can also be made that these savings are more effective: implementing efficiency savings in a wide variety of locations may provide more flexibility to deliver saved water to users and ecosystems most in need of additional supply. Additionally, water conservation and efficiency improvements are often far less expensive than other water supply alternatives (LAEDC 2008).[37]

[34] Department of Water Resources (DWR). 2007. San Joaquin Valley Drainage Monitoring Program: 2002. Sacramento, California.
[35] Drainage-impaired lands are areas where the water table is within 20 feet of the ground surface. To estimate the water savings, we multiplied estimates of the drainage-impaired land by the weighted average of applied water in the San Joaquin and Tulare Lake hydrologic regions from 1998 to 2003, which was 3.11 acre-feet per acre (DWR 2008b).
[36] Based on recent proposals to build Temperance Flat Dam (DWR 2007a).
[37] According to a recent LAEDC report, conservation would be the least costly water supply alternative for Southern California at $210 per acre-foot of treated water as compared to water recycling at about $1,000 per acre-foot, ocean desalination at more than $1,000 per acre-foot (depending on energy prices), and surface storage options—including proposals such as the Sites Reservoir in Northern California and the Temperance Flat dam near Fresno—which would cost $760 to $1,400 per acre-foot.

Challenges and Opportunities to Achieve Conservation and Efficiency

In some cases, the incentives for water conservation seem clear—lower input costs and increased production value. Yet challenges also exist that act as barriers to implementation. Below we outline some of the key challenges for water conservation and efficiency based on our discussions with farmers, representatives of agricultural organizations, and extension specialists. We provide specific recommendations for overcoming these financial, legal, institutional, education, and scientific barriers.

Water Rights

California has a dual water rights system, referred to as the California Doctrine that recognizes both riparian and appropriative water rights.[38] Riparian rights, developed from English common law, tie water rights to property ownership. Property owners that are adjacent to a water course are allowed to use or divert water as they see fit, but not to the harm of those downstream. Riparian rights are limited rights that are reduced proportionally in times of shortage.

Surface water in California is also subject to the *prior appropriation doctrine*, which was developed in the western United States and differs from riparian rights in several important ways. Under prior appropriation, mere ownership of land confers no rights to use the water; rather, water flowing in a stream in its natural condition is un-owned and is held by the state for acquisition by users. The user must apply for a water right and divert that water for "beneficial use."[39] Additionally, priority of use is determined by the date when the water was first applied to a beneficial use or when the user first applied for an appropriative right. Thus, when water runs short, junior appropriators must yield to senior appropriators, leading to the maxim "first in time, first in right." Interestingly, since an appropriative right is based on use, it can be rendered null and void if it is shown that a right is not being fully used. The "use it or lose it" principle provides a strong disincentive for appropriators to conserve water if doing so results in forfeiture of their water rights.

California and other Western states have experimented with different strategies to modify the "use it or lose it" principle of prior appropriation in order to encourage improvements in efficiency. For example, California Water Code Sections 1010(b) and 1011(b) allow appropriators to keep water saved from use of recycled, desalinated, or polluted water or water salvaged by conservation efforts. In addition, California Water Code Section 1707(a) allows water right holders to dedicate all or part of their rights for instream purposes, therefore transferring water from a consumptive use to a non-consumptive use. Challenges with section

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[38] A few communities in Southern California also have pueblo rights. Pueblo rights were allowed under Spanish and Mexican law and gave missions the right to use adjacent water sources. In addition, there are federal reserved rights, which imply a sufficient supply of water to satisfy the purposes of reserves of public land, such as Native Reservation reservations and national parks.

[39] Beneficial uses include water stored and used for domestic and industrial water supply, irrigation, hydropower, commercial navigation and transportation, fishing and boating, tribal cultural uses, and wildlife. Definitions of beneficial use can change over time, illustrated by the California Supreme Court ruling that severe drought conditions affect determinations of reasonable use: "what constitutes a reasonable water use is dependent upon not only the entire circumstances presented but varies as the current situation changes" (Environmental Defense Fund v. East Bay Municipal Utility District, 1977).

1707 dedications are the interaction with other water rights and enforcement. In terms of existing water rights, riparian rights holders and downstream appropriators with a senior water right may have the ability to divert the "dedicated" instream flow.

On the other hand, groundwater in California is largely unregulated. Groundwater in California is subject to overlying land rights. With few exceptions (described below), overlying landowners are allowed to make reasonable use of groundwater without obtaining permission or approval and can continue to extract water regardless of the condition of the aquifer. As there is little to no oversight and measurement of groundwater, there are few incentives for conservation or efficiency. Rising energy costs (which increase the price to pump water out of the ground) along with groundwater overdraft (or shortages) and competition are bringing this issue to the table. Measurement and management of groundwater could reduce this problem, but powerful forces are firmly opposed to any changes in groundwater law and have succeeded in preventing the adoption of new legislation or regulations to address these problems.

However, there are some exceptions. The State Water Resources Control Board has a formal process for granting water rights if the groundwater is classified as return flow or "subterranean stream." [40] Additionally, adjudicated basins—where groundwater withdrawals and management are legally reviewed and accepted by all users—are subject to monitoring by a court-appointed Water Master. There are presently 19 adjudicated basins in California, most of which are located in Southern California.

Broadly speaking, the structure of water rights in California can—but doesn't have to—serve as a disincentive to rational water management. California's water rights system should be re-examined given changing social, economic, and environmental conditions. We recommend two key steps toward a more sound and sustainable water rights system: 1) define instream flow as a beneficial use in California, and 2) regulate groundwater use, especially in areas where overdraft is most severe. Today, all Western states except for California and Texas regulate groundwater. In Arizona, for example, the State Legislature passed an innovative Groundwater Management Code that created "Active Management Areas" to respond to severe overdraft. This code restructured water rights, prohibited irrigation of new agricultural lands in these areas, created a comprehensive system of conservation targets updated every decade, developed a program requiring developers to demonstrate a 100-year assured water supply for new growth, and required groundwater users to meter wells and report on annual water withdrawal and use. Additionally, Oregon was the first state to define instream flows as a beneficial use and today eight other Western states have followed suit.[41]

Subsidies

Broadly speaking, agricultural subsidies are government payments that affect the production, distribution, and consumption of an agricultural product. This definition includes a range of programs that provide both direct and indirect support to the agricultural sector, including commodity, conservation, nutrition, and trade programs. Indirect subsidies also include general

[40] The jurisdiction of the State Water Resources Control Board to issue permits and licenses for the appropriation of underground water is limited by section 1200 of the California Water Code to "subterranean streams flowing through known and definite channels" (SWRCB 1990).
[41] Alaska, Arizona, Colorado, Idaho, Montana, Nevada, Oregon, and Wyoming all allow new appropriative rights to be granted based on putting water to the beneficial use of instream flow.

support for agriculture through investments in water supply and conveyance systems and reduced water and energy costs. Government payment to treat contaminated drainage water also constitutes an indirect subsidy.

Subsidies play a major role in U.S. agricultural policy and were first initiated back in the 1920s in response to a severe drop in global and domestic commodity prices after World War I. Today, subsidies for the agricultural sector are laid out in a various pieces of legislation, but particularly in the U.S. Farm Bill. The 2002 Farm Bill authorized $619 billion in crop subsidies, of which $53 billion was provided in direct payments to support field crops, including corn (40%); wheat (22%); upland cotton (12%); soy (11%); and rice (8%) (EWG 2008). Field crops typically provide lower economic value than many other crops, averaging $520 per acre compared to $5,170 per acre for vegetables and $3,130 per acre for fruits and nuts (Table 2).[42] In some cases, direct payments make the production of certain field crops economically viable. Field crops, however, tend to be water intensive as a result of high water requirements and greater likelihood for inefficient flood irrigation. Thus subsidies for field crops encourage the production of water-intensive crops.

Indirect agricultural subsidies can also have a significant influence on agricultural water use. An indirect agricultural subsidy is not a direct payment to a farmer for the planting of certain crops, but rather discounted prices on items necessary for production, such as water and infrastructure. In California, for example, the federal government invested a substantial amount of money for the construction of the Central Valley Project (CVP), a vast network of reservoirs and canals that supplies water to agriculture. Prices for water from the CVP range from $7.14 to $56.73 per acre-foot for irrigation and are slightly higher ($9.00 to $76.67 per acre-foot) for municipal and industrial uses (USBR 2007). As a result of these low prices, the agricultural contractors had repaid only 18% of the original capital investment as of September 2005 (USBR 2007). This failure to repay constitutes an indirect subsidy, artificially lowering the price of water for some agricultural uses in California and encouraging inefficient water use.

The price of water can affect crop choice, irrigation method, management practice, and ultimately, the amount of water applied. Because conserving water often requires some capital investment, particularly when converting from flood to sprinkler or drip irrigation systems, artificially low water prices may not provide sufficient economic incentive to justify conserving water. Thus indirect water subsidies create an artificially inexpensive supply of water and, in so doing, provide a disincentive for water conservation and efficiency.

Subsidies can be realigned so as to promote more efficient water use. The U.S. Farm Bill funds several major cost-share programs that can be used to fund water conservation practices, most notably the Environmental Quality Incentives Program (EQIP), which is administered by the Natural Resources Conservation Service. EQIP provides up to a 75% cost share for structural and vegetative practices that address resource concerns, including water conservation and efficiency. The 2008 Farm Bill includes a new stipulation that priority will be given to water conservation or irrigation efficiency measures that will reduce total water use, or in which the producer agrees not to use the conserved water to bring new land under irrigation production. The 2008 Farm Bill authorizes EQIP funding at $1.2 billion in 2008, rising to $1.8 billion in

[42] All values in year 2005 dollars.

2012, however this only accounts for about 1% of the overall Farm Bill budget ($618.5 billion). Funding should be increased substantially.

Energy Considerations

Energy requirements vary considerably among irrigation systems (Table 11). Typically, flood irrigation has the lowest on-farm energy requirements as distribution networks are often gravity-fed (sometimes requiring a pump to lift water at the head of the system). On the other hand, standard sprinklers and drip/microirrigation generally have the highest energy requirements because these systems are "pressurized," requiring 30-60 psi depending on the terrain, and are supplied primarily by electric booster pumps.

Table 11. Approximate On-Farm Energy Requirements of Different Irrigation Methods

Activity	Approximate Energy Requirements (kWh/AF)
Flood irrigation without on-farm lift	0
Lifting water 10 feet for flood irrigation[a]	30
Booster pumping for drip/microirrigation (statewide average)[b]	206
Booster pumping for standard sprinklers (statewide average)[b]	284

Source: (a) Wolff et al. 2004; (b) Burt et al. 2003

Although Table 11 suggests sprinkler and drip/microirrigation are more energy intensive than flood systems, this can be misleading when dealing with water that is pumped long distances, with elevational changes, or from groundwater aquifers. When one considers water's embedded energy—the energy required to capture and convey water to agricultural users,[43] the total energy required to supply water for irrigation can significantly change. For example, transporting water from the Delta over the Tehachapi Mountains to Southern California via the State Water Project requires between 2,500 kWh to 5,000 kWh per acre-foot because of the substantial lift required. Once water is supplied to the farmer, additional energy may be required on site to distribute the water around the farm. It is only when we consider both the embedded and on-farm energy that we gain a clear sense of the energy intensity of supplying water for irrigation.

It is important to consider the net energy impact associated with a particular management practice or irrigation method. The embedded energy of groundwater and surface water in the San Joaquin and Tulare Lake hydrologic regions is relatively high, ranging from 175 to 971 kWh per acre-foot (Table 12). As a result, a well-functioning sprinkler or drip/microirrigation system that reduces applied water, and therefore decreases the amount of water withdrawn from these energy-intensive sources, may decrease the overall energy consumption of water. It is important to note that the potential for energy savings varies greatly by region, water source, crop type, irrigation method, and irrigation management strategy.

[43] Typically water for agriculture is not treated, except when using recycled wastewater or treating tailwater.

Table 12. Energy Intensity of Water Sources in the San Joaquin and Tulare Lake Hydrologic Regions

	Energy Intensity (kWh/AF)	
	Surface Water[a]	**Groundwater[b]**
San Joaquin	296-434[c]	292
Tulare Lake	434-971[d]	175-740

Note: Additional energy may be required to deliver surface water to the boundaries of the farmers' properties.
(a) Refers to the energy intensity of the major state and federal water supply systems.
(b): Based on data in Wolff et al. 2004
(c): Based on State Water Project energy requirements from CEC 2005. We estimate the low range based on the energy intensity of water at the Harvey Banks pumping plant and the high range based on the energy intensity of water at the Dos Amigos pumping plant.
(d): Based on State Water Project energy requirements from CEC 2005. We estimate the low range based on the energy intensity of water at the Dos Amigos pumping plant and the high range on the energy intensity at Wheeler Ridge.

In some areas, switching from an un-pressurized 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 applies 100 AF of water to field crops, which are entirely irrigated by surface water from the Central Valley Project's Coalinga Canal, which has an energy intensity of 718 kWh per AF.[44] If we assume that switching from flood to drip irrigation reduces the applied water to 75 AF, then the associated energy saving would be 18,000 kWh. Switching to drip, however, would increase on-farm energy use by 200 kWh per AF (Table 11), or 15,000 kWh. In this example, switching from flood irrigation to drip results in a net energy savings of 3,000 kWh. Additional water conservation measures, such as RDI, could reduce water use further, providing additional energy savings.

Even though this example produces a net energy savings, on-farm expenses go up, providing a disincentive for both water and energy conservation. In such instances where implementing on-farm conservation measures results in a net energy savings, the state, federal government, and/or water or energy provider should offer rebates or incentives to overcome these economic disincentives. The Pacific Gas and Electric Company, for example, provides special rebates for water conservation in the agriculture sector through the "Flex Your Power" energy conservation program. Rebates of $44 per acre are available to vegetable, orchard, and vineyard growers for conversion from high-pressure, impact-type, sprinkler irrigation systems to microirrigation systems. In addition, the program provides rebates of $1.15 per nozzle to growers who convert from high-pressure to low-pressure sprinkler system nozzles. These types of incentive programs, common in residential and commercial settings, are useful models for the agricultural sector.

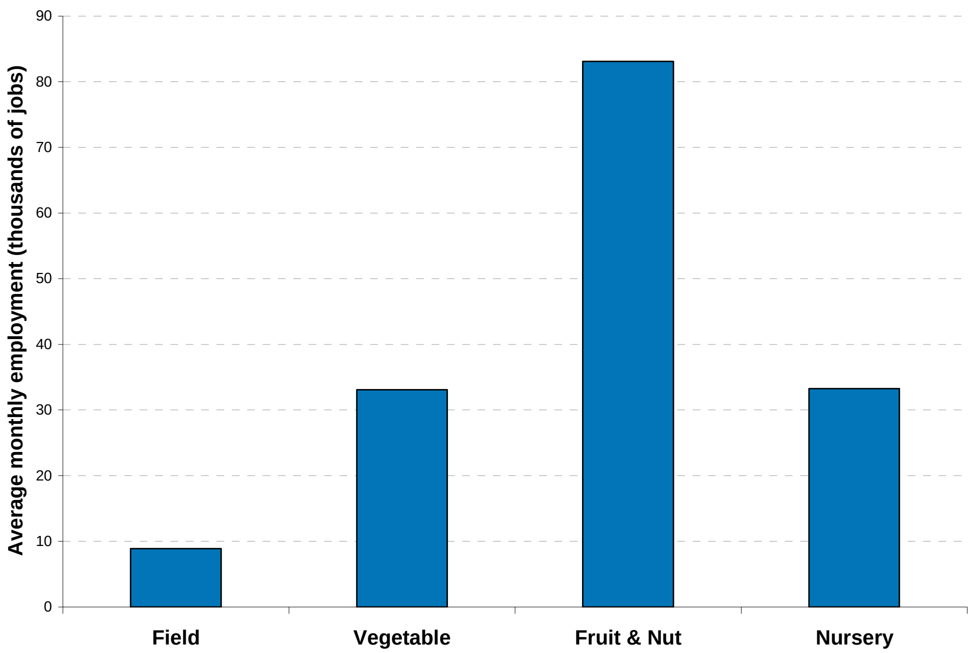
Labor Costs and Availability

The Modest Crop Shifting Scenario described above evaluates the impacts of reducing field crop acreage while increasing vegetable acreage. Shifting to vegetables rather than perennials requires less initial infrastructure investment. However, labor costs and availability can greatly influence the feasibility of this shift. Of all the major crop types grown in California, field crops are the least labor-intensive, accounting for only 5% of average monthly employment related to crop production (CEDD 2006) while accounting for over half of irrigated acreage statewide (DWR

[44] Wolff et al. (2004) estimates that the energy intensity of water drawn from the Coalinga Canal ranges from 673-763 kWh/AF; we use the average energy intensity for these calculations.

2005a). In comparison, vegetables and nursery crops each account for 22% of average monthly employment related to crop production, which is three to four times as many jobs as field crops. Fruits and nuts account for 42% of average monthly employment (Figure 12)—eight times as many jobs and on much less acreage. Thus shifting from field crops to any of the other crop categories would require significant increases in labor costs, but could also result in significant increases in employment.

Figure 12. Average Monthly Employment by Crop Type in California, 2006



Source: CEDD 2006

There are recent examples of labor shortages, particularly on vegetable and fruit and nut farms. These shortages may be a disincentive for shifting from field to vegetable crops. In 2002, 53% of U.S. crop workers were categorized as unauthorized (U.S. Dept. of Labor 2005). Increased oversight and deportations have reduced the number of unauthorized workers, further contributing to labor shortages. The Emergency Agricultural Relief Act of 2008, authored by California Senator Dianne Feinstein, proposed ways to forestall labor shortages by revising the immigration procedures for agricultural workers. This bill did not pass, and new reforms are unlikely in the current political climate. This adds another consideration when deciding to shift toward more labor-intensive crops.

Education and Technical Support

The benefits of efficient irrigation technologies and practices are widely acknowledged, although adoption of these measures in California has been slow. Institutional and educational barriers, along with economics, have long been known to be primary factors inhibiting widespread adoption of these technologies (Gleick et al. 1995). State, local, and regional policy should be directed at identifying and overcoming these implementation barriers. There are many effective approaches.

Agricultural Extension Services

The University of California is a land-grant college that, under the Morrill Acts of 1862 and 1890, received federally-controlled land and, in return, was required to teach practical arts to the public. The mission of land-grant institutions was later expanded by two acts of Congress (the Hatch Act of 1887 and the Smith-Lever Act of 1914) that provided funds to establish a series of agricultural experiment stations and develop a Cooperative Extension program, sending specialists into rural areas to bring the results of agricultural research to end users. In California, Cooperative Extension offices are headquartered at the University of California's Berkeley, Davis, and Riverside campuses. Cooperative Extension technicians, specialists, and advisors conduct field-based research on a wide range of topics from animal husbandry to water management. This research represents the majority of empirical studies on agriculture in California. Cooperative Extension agents often work in close collaboration with farmers and agricultural organizations, attempting to respond to key challenges and data gaps and serving as a valuable information source. Nevertheless, statewide there are fewer than 400 agricultural technicians, Cooperative Extension specialists, and advisors, and recent state budget shortfalls could reduce staff further. We believe Extension services should be expanded, not reduced.

Natural Resources Conservation Service

Originally called the Soil Conservation Service, the Natural Resources Conservation Service (NRCS) is part of the U.S. Department of Agriculture. Today, NRCS works primarily with farmers to implement a series of voluntary conservation programs funded by the Farm Bill. These conservation programs help reduce soil erosion on agricultural lands, enhance water supplies, improve water quality, and increase wildlife habitat. NRCS administers the Environmental Quality Incentives Program (EQIP), referred to earlier, which provides cost-shares to agricultural producers who make water conservation and efficiency improvements. This program is one of the only of its kind, and is critical to realizing potential water savings that require substantial on-farm investment (i.e., the Efficient Irrigation Technology Scenario). In many areas, however, NRCS is unable to provide cost-shares to promising projects due to lack of staff and funding. One bottleneck is the lack of engineers on staff, necessary for project approval, as the agency is not able to offer competitive salaries to professional engineers (Epifanio, C., NRCS District Conservationist, personal communication, August 15, 2008).

Agricultural Water Management Council

The Agricultural Water Management Council was established in 1996 to build consensus among agricultural water suppliers, environmental groups, and other interested parties in California. Members of the Council sign a Memorandum of Understanding that outlines a process for developing voluntary water management plans and implementing cost-effective Efficient Water Management Practices (EWMPs). All signatories are supposed to implement the following EWMPs: (1) adopt a water management plan; (2) designate a water conservation coordinator; (3) support water management services such as mobile irrigation labs, irrigation scheduling, and water quality testing; (4) improve communication and cooperation among water suppliers and users; (5) identify institutional changes that will improve the potential for more flexible water deliveries and storage; and (6) improve pump efficiency to reduce operational costs. Water suppliers may also implement 11 other EWMPs if their implementation is deemed cost-effective.[45] As of 2005, 76 water suppliers, representing 4.6 million irrigated acres, were

[45] For a complete list of the EWMPs. Visit http://www.owue.water.ca.gov/agmanage/details/ewmp/detail.cfm.

signatories of the Council. More than 85% of these signatories have water management plans that have been endorsed by the Council (AWMC 2006b). In total, only 44% of California's irrigated land area is covered by these management plans.

While these efforts represent a step in the right direction, the EWMPs should be expanded to include changes in technologies, shifting cropping patterns, and better on-farm management practices. Furthermore, the EWMPs should be mandatory and enforced by a state agency, such as the State Water Resources Control Board.[46] This expansion of authority would need to be accompanied by increased funding and capacity within this agency.

Mobile Irrigation Laboratories
The Department of Water Resources provides mobile laboratory services to California farmers. The mobile labs evaluate the performance of irrigation systems by measuring the water application rates and the system distribution uniformity. The distribution uniformity is defined as the minimum water infiltration depth divided by the average infiltration depth. If a system has poor distribution uniformity, then a farmer would need to increase the amount of water applied to ensure that all parts of the field receive adequate water. Improving distribution uniformity does not necessarily result in a water savings as the farmer may continue to over-irrigate. However, good distribution uniformity is necessary to achieve the "maximum potential irrigation efficiency of a properly-managed irrigation system" (Hanson et al. 1998). After an on-site evaluation, the lab technicians provide farmers with recommendations to improve the efficiency of the irrigation system. Interest in and funding for the program is highly variable, intensifying during a drought but waning during non-drought periods.

Data Accuracy and Availability

One of the many challenges to studying water issues in California is the lack of a consistent, comprehensive, and accurate estimate of actual water use, by sector or by region. Different institutions and groups track, record, and report water use in different ways, and no single accepted historical record exists. Further complicating smart water policy, many water uses are not monitored; thus, reported water use is a combination of actual use and estimates of uses. For example, some cities still do not require residential water metering, especially for multi-family homes. Many agricultural groundwater withdrawals are not measured or reported. Actual agricultural water use in California is estimated, not measured, based typically on the kinds of crops grown, climatic factors, and simple assumptions about crop water use. More and better data on actual use must be collected. These data must include finer-scale information due to the regional heterogeneity throughout the state. In a state with such contentious and difficult water challenges as California, the failure to accurately account for actual water use contributes directly to the failure to manage it sustainably. In turn, this affects planning, policy making, and ultimately the state's economic and environmental health.

[46] In 2005, Senator Kuehl initiated legislation (SB 820) that would require water suppliers to implement the EWMPs in order to be eligible for State funding. This bill passed the Assembly and Senate but was vetoed by the Governor. We note that the State Water Resources Control Board currently has some oversight over implementation of the urban Best Management Practices, although this oversight could also be strengthened.

Conclusions and Recommendations

With existing technologies, management practices, and educational and institutional resources, agricultural withdrawals from the Delta can be reduced substantially while maintaining a healthy agricultural economy. Conservation and efficiency improvements, along with a greater emphasis on developing local resources, would allow California to reduce water withdrawals from the Sacramento-San Joaquin Delta, while ***increasing*** the reliability and quality of those withdrawals. In addition to reducing withdrawals from the Delta, efficiency improvements help promote the long-term sustainability of the agricultural sector and allow farmers to respond to a series of mounting pressures. Our vision for the future of the Delta moves us toward more responsive water management, without negatively impacting the profitability of agriculture. We recommend some key political, legal, and economic initiatives that would create incentives to encourage more productive, efficient, and, ultimately, more sustainable water management.

Our analysis concludes that

- All four agricultural efficiency scenarios show substantial potential water savings, ranging from 0.6 to 3.4 million acre-feet.
- These savings can be achieved without adversely affecting the economic productivity of the agricultural sector.
- Improvements in efficiency are just as effective as, and can be far less expensive than, new, centralized water storage and infrastructure, even if such new infrastructure could be sited, funded, approved, and built.
- These efficiency improvements can reduce the size and cost of any infrastructure that may subsequently have to be built.

Conclusions and Recommendations

Agriculture is important to our economy, culture, and environment but is subject to mounting pressure from uncontrolled urbanization, global market pressures, and threats to the reliability and availability of fresh water. Actions are needed to both ensure a sustainable agricultural sector and to reduce the water required for it.

- Better combined land and water planning is needed. For example, strengthen recent legislation, such as the Costa and Kuehl Acts (SB 610 and SB 221) to ensure all new developments have an adequate water supply for at least 100 years. In addition, the number of new housing units required to trigger implementation of these acts should be reduced.

- Modify and expand the Williamson Act to encourage protection of prime agricultural land from urban and suburban development.

Water conservation and efficiency improvements can reduce water use and improve water quality while maintaining or increasing crop yield. Yet these improvements often entail significant investment (capital and operation and management costs), which can be a barrier to implementation. Smart policies can reduce this barrier.

- Provide sales tax exemptions or rebates on efficient irrigation equipment to help offset capital investments for these systems.

- Provide property tax exemptions for farmers who upgrade to more water-efficient irrigation systems. Exemptions apply to the value added to a property by the irrigation system and be valid for 5 to 10 years.

- Develop new legal mechanisms by which municipal water or state or local wildlife agencies could invest in farmers' irrigation systems in exchange for some portion of the water conserved.

- The state, federal government, and/or energy providers should offer rebates or incentives to farmers who implement on-farm conservation measures that result in a net energy savings.

- The state and/or federal government should investigate and establish other mechanisms that encourage water-use efficiency if they achieve broader social or environmental benefits.

Agricultural commodity-support programs typically subsidize field crops, inadvertently encouraging the production of low-value, water-intensive crops. These programs should be refocused on the potential to save water.

- Reduce or realign subsidies from low-value, water-intensive crops to less water-intensive crops.

- Provide greater emphasis on water conservation and efficiency improvements within the federal Environmental Quality Incentives Program and expand funding for these initiatives.

- Implement new water rate structures that encourage efficient use of water.

Federal and state government has invested substantially in the construction of irrigation systems, without full repayment. By creating an artificially-inexpensive supply of water, these indirect water subsidies provide a disincentive for water conservation and efficiency improvements. Eliminate programs that encourage inefficient use.

- Ensure federal contracts for the Central Valley Project achieve full repayment by 2030 or sooner.

- Avoid inappropriate public subsidies for new water-supply options that are more expensive than efficiency improvements.

The existing water rights system in California provides disincentives for water conservation and efficiency improvements. More aggressive efforts are needed to apply the constitutionally mandated concepts of reasonable and beneficial use in ways that encourage improvements in water-use efficiency.

- Give legislative, regulatory, and administrative support to developing a more rational water rights system. In particular, the State Water Resources Control Board's authority and funding should be expanded to include groundwater and to challenge inefficient use as neither reasonable nor beneficial.

• Establish groundwater management areas in regions where overdraft is most severe as an immediate stop-gap measure.

• Define instream flow as a beneficial use in California.

Many proven technologies and practices can improve water-use efficiency. Strengthen and expand efforts to promote the use of these technologies and practices.

• Revise and expand "Efficient Water Management Practices" for agricultural water agencies.

• Make agricultural "Efficient Water Management Practices" mandatory and enforceable by the State Water Resources Control Board.

• Expand the development and deployment of efficient irrigation technologies and new crop types.

• Develop institutional mechanisms to increase the reliability of agricultural water deliveries to users meeting high standards of water-use efficiency.

One of the many challenges to studying water issues in California is the lack of a consistent, comprehensive, and accurate estimate of actual water use. The failure to accurately account for water use contributes directly to the failure to manage it sustainably. Efforts should be implemented immediately to improve our understanding of actual water use in the agricultural sector.

• Create a statewide system of data monitoring and data exchange, especially for water use, available to all users.

• Use satellite and other technology to improve data collection and analysis, particularly for annual assessments of crop area.

• Design and implement comprehensive local groundwater monitoring and management programs statewide.

Education and technical assistance programs are important to encourage the widespread adoption of these technologies. Existing programs should be expanded and new ones implemented.

• Expand water-efficiency information, evaluation programs, and on-site technical assistance provided through Agricultural Extension Services and other agricultural outreach efforts.

• Improve online data collection and dissemination networks to provide farmers with immediate meteorological and hydrological information on climate, soil conditions, and crop water needs.

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Box 1. Court Decisions Affecting Delta Water Withdrawals

A number of recent court decisions have affected water withdrawals from the Delta. Below, we summarize some of the key rulings.

The Friant Dam Decision

The Friant Dam, located on the San Joaquin River, is one of the main features of the Friant Division of the Central Valley Project. Nearly 95% of the San Joaquin River's flow is diverted for irrigation, causing over 60 miles of the river to run dry in most years. In 1988, a coalition of 13 conservation and recreation groups led by the Natural Resources Defense Council filed a lawsuit against the Bureau of Reclamation under terms of the California Fish and Game Code for failing to allow sufficient water to maintain fisheries below the dam (NRDC 2007a). Sixteen years later, in August of 2004, U.S. District Judge Lawrence K. Karlton ruled that the Bureau of Reclamation was, in fact, violating the law (Natural Res. Def. Council v. Patterson, 333 F. Supp. 2d 906, E.D. Cal., 2004). In September 2006, the Natural Resources Defense Council, the Friant Water Users Authority, and the U.S. Departments of the Interior and Commerce reached an agreement for managing the river with two objectives: (1) to restore the river so that it supports continuous flows to the Delta and naturally reproducing chinook salmon population and (2) to minimize the effects of river restoration on San Joaquin River users (Friant Water Users Authority 2006). The settlement was recently approved by the Senate Energy and Natural Resources Committee but has not yet received the full support of Congress (Doyle 2008).

Friant Dam, Credit: Peter Gleick

The Delta Smelt Decision

Delta smelt are found only in the Sacramento-San Joaquin estuary. In 1993, they were listed as threatened under both the California state and federal Endangered Species Acts. Under the Endangered Species Act, it is illegal for federal agencies to authorize or carry out any action that will further jeopardize a species listed as threatened or endangered (FWS n.d.). Therefore, the Fish and Wildlife Service must provide documentation, commonly in the form of a biological opinion, showing that their operations will not jeopardize listed species. In 2005, a biological opinion regarding the impacts of CVP and SWP operations on Delta smelt found that increased pumping would not negatively impact the fish. Based on this information, the Bureau of Reclamation and the California Department of Water Resources increased pumping from the Delta. Delta smelt population continued to decline and in 2005, the fish count was only 2.4% of that in 1993 (NRDC 2007b).

A coalition of conservation groups sued the Fish and Wildlife Service over the scientific validity of the biological opinion. In May of 2007, Judge Wanger ruled that the biological opinion did not ensure that necessary mitigation action would take place, failed to use the best-available science, did not take into consideration the current status of the species, and failed to consider the impacts of the project operations on critical smelt habitat (Natural Resources Defense Council v. Kempthorne, E.D.Cal., 2007). In December 2007, U.S. District Judge Wanger provided interim management policies for the Delta, including increased monitoring of the Delta smelt and decreased pumping from the Delta. Some estimate that water exports from the Delta could be reduced by 1 million acre-feet as a result of this ruling, although exports are dependent on environmental conditions (Taugher 2007). Under the worst case scenario, it was estimated that water deliveries by the state and federal water projects could be reduced up to twice that much, resulting in reductions of 35% (Ellis 2007).

Pending Decision on Salmonids in the Sacramento River

A similar lawsuit was filed in 2004 that challenged a separate biological opinion issued by the Fish and Wildlife Service regarding the impacts of water project operations on endangered winter-run Chinook salmon, threatened spring-run Chinook salmon, and threatened steelhead in the Sacramento River. Like the Delta smelt biological opinion, the Fish and Wildlife Service provided documentation that SWP operations would not jeopardize these salmon and steelhead species. In April of 2008, Judge Wanger invalidated this biological opinion as well, bringing water withdrawals north of the Delta under scrutiny. A new biological opinion will not be ready until March of 2009, and a court order regarding interim management is expected (Breitler 2008).

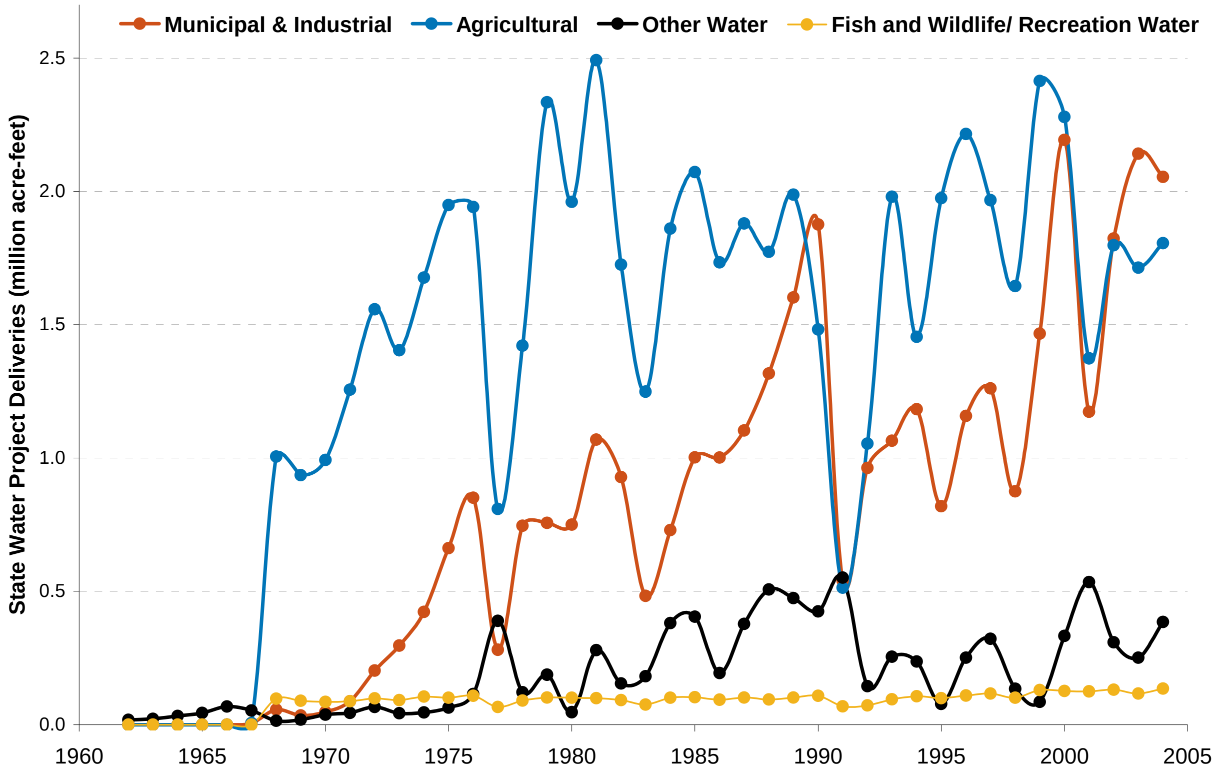
Box 2. Major Water Projects in California

The State Water Project

The State Water Project's California Aquaduct
Credit: Peter Gleick

The State Water Project is operated and managed by the Department of Water Resources (DWR). The SWP conveys water to meet agricultural, municipal and industrial, environmental, and recreational needs. Exports for agriculture increased rapidly through the 1970s but have remained steady since the mid-1980s, averaging about 1.8 million acre-feet per year (Figure B2-1). By contrast, exports for municipal and industrial uses have steadily increased since 1970. Today, municipal and industrial uses of water conveyed through the SWP are nearly equal to agricultural uses. DWR currently has long-term water contracts with 29 agencies to deliver up to 4.2 million acre-feet of water through the SWP. Actual deliveries, however, are "based on hydrologic conditions, current reservoir storage, and total requests by the SWP water contractors" (Bulletin 132-05). Between 2000 and 2004, the SWP conveyed about 3.3 million acre-feet of water, or about 79% of the maximum amount, to the long-term contractors. An additional 0.9 million acre-feet was transferred through short-term agreements with SWP contractors or other agencies.

Figure B2-1 State Water Project Deliveries, 1962-2004



Source: Data from DWR 2005b

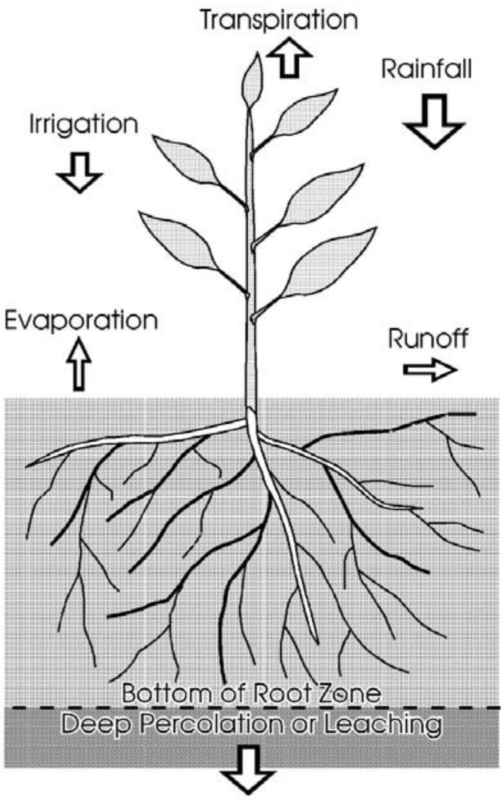
The Central Valley Project

The Central Valley Project (CVP) is a federally built and operated water supply system with a series of dams, reservoirs, and aqueducts running up and down the foothills of the Sierra Nevada and the Central Valley. Construction of the CVP began in the late 1930s, and today, the CVP is one of the largest water storage and transport systems in the world, consisting of 22 reservoirs and a combined storage of 11 million acre-feet. The Bureau of Reclamation, which operates the CVP, has 250 long-term contracts with water suppliers, delivering 7 million-acre feet of water annually in an average year or about 20% of all water used in California.

The CVP primarily provides water to irrigate farms in the Central Valley. Although the CVP conveys water to meet agricultural, municipal and industrial, environmental, and recreational needs, an overwhelming 90% of all delivery is supplied to agriculture (USBR 2008a). The CVP provides water to more than 6,800 farms in the Central Valley (EWG 2004).

Box 3. Debunking the Evapotranspiration Myth

Figure B3-1. Plant Root Zone Water Balance



Source: Colorado State University, Resource Center

Figure B3-1 provides a graphical representation of a complete crop water balance, showing the inflows and outflows of water from the plant's root zone. Water inflows include rainfall, irrigation, dew, and capillary rise from groundwater, while water outflows include evaporation, transpiration, runoff, and deep percolation. In many cases, evaporation and transpiration are described as a single process: evapotranspiration (ET). This is incorrect and hinders any discussion of efficiency. While both evaporation and transpiration involve the transformation of water from a liquid to a gas, they occur by very distinct mechanisms. Transpiration is the movement of water through the plant, which has a direct, beneficial relationship with plant yield. Evaporation, in comparison, occurs on the soil or plant surface and has little beneficial impact on plant yield.

Numerous studies treat ET as a single process. This assumption may be true in some cases, but not necessarily. Efficient irrigation methods often result in an increase in yield, which may increase transpiration. Efficient irrigation methods, if managed properly, are likely to reduce evaporation. Thus the potential increase in transpiration could be offset by a reduction in evaporation. As a result, evapotranspiration may increase, decrease, or stay the same. By ignoring the evaporation component we are ignoring the potential reduction in water consumption associated with more efficient irrigation methods. A more comprehensive assessment would separate these two processes and focus on "unproductive" evaporative losses—water lost to evaporation that contributes nothing to the actual production of the crop. Very few detailed estimates of unproductive evaporative losses by crop type, or irrigation method, are available. More are needed.

Box 4. Fallowing and Land Retirement

In comparison to our four water-use efficiency scenarios, short-term fallowing and permanent retirement of drainage-impaired lands are more controversial approaches to achieving water savings in the agriculture sector. While not considered a water-efficiency measure, planned short-term fallowing and land retirement can produce significant water savings. Below we quantify the potential savings associated with these approaches.

Short-Term Fallowing

Farmers fallow land for many reasons: poor market conditions, temporary water shortage due to drought or a short-term supply disruption, and to restore soils. Fallowing can be short-term or long-term and is best implemented by planting a drought-resistant cover crop that fixes nitrogen. Land fallowing can also produce water-quality benefits and, if managed properly, can reduce soil erosion and improve the productivity of the soil. Mitigation of impacts on agricultural workers and the community, often referred to as third-party impacts, should be included in the fallowing agreement.

As a comparison to the other scenarios, we offer a quantitative assessment of the water implications of fallowing 10% of irrigated field crop acreage. This reflects both the decreasing trend in field crop acreage over time, as noted in the Modest Crop Shifting Scenario, and a likely short-term response to drought. Because field crops tend to be low-value, water intensive crops, reductions in field crops achieve the greatest water savings with the least economic impact.

Table B4-1 shows the results of this scenario for agricultural water use and production value for each of the hydrologic regions. Fallowing 10% of field crop acreage reduces total irrigated crop land by 440,000 acres and water use by 1.7 MAF, exceeding the estimates of groundwater overdraft in the three hydrologic regions. Production value decreases by $230 million; we note that this estimate is similar to the current statewide estimate of total farm losses ($245 million) resulting from the drought and Delta pumping restrictions as of July 2008 (Shultz 2008). Total farm losses are likely to increase over the growing season. Planned fallowing, however, could serve to minimize these losses as well as third-party impacts, such as job losses and associated social, economic, and environmental hardships borne in the local community.

Table B4-1. Fallowing 10% of Field Crop Acreage

	Water Withdrawals (1,000 AF)	**Production Value** (2005$ billions)
Sacramento River	-661 (-8%)	-$0.08 (-3%)
San Joaquin River	-410 (-6%)	-$0.06 (-2%)
Tulare Lake	-630 (-6%)	-$0.1 (-2%)
Total	-1,701 (-6%)	-$0.2 (-2%)

Note: Percentages shown represent percent change from the Baseline Scenario. All production value estimates are in 2005$. We calculate the value of agricultural products based on crop production value by acre shown in Table 2 for each major crop type multiplied by the estimated irrigated crop area.

Planned fallowing may be a superior option under numerous situations. Planned fallowing allows dry-year leasing arrangements that can provide certainty and predictability to farmers as well as a dependable revenue stream for capital and other needed investments. It can also provide for a more comprehensive approach to define mitigation measures that reduce third-party impacts. Yardas and Kusel (2006) suggest that such measures would ideally involve a "community benefits agreement" that includes interim assistance to directly impacted third parties (and/or targeted classes of third parties where individual identification is difficult) and transitional assistance efforts (e.g., job re-training, apprenticeship programs, interim support stipends, community development for extended fallowing) over some definite period of time.

Fallowing of Drainage-Impaired Lands

Agriculture in the western San Joaquin Valley is highly productive but given the hot and dry conditions, is highly dependent on irrigation. Because even freshwater contains salt, continued application of water, and evaporation of that water, has increased the soil's salt concentration. In addition, a shallow clay layer impedes removal of these salts through deep percolation. As a result, agricultural productivity in large parts of the San Joaquin Valley is threatened by saline shallow groundwater. According to DWR, "this marginal-to-poor quality groundwater has mounded up to reach crop root zones in this area and is threatening the viability of agriculture there" (DWR 2005a).

Since the mid-1950s, state and federal agencies have been planning for drainage facilities to serve the San Joaquin Valley (USBR 2008b). In 1968, the Bureau of Reclamation began construction of the San Luis Drain and Kesterson Reservoir. Agricultural drainage water from the San Luis Drain was to be stored in the Kesterson Reservoir, located within the Kesterson National Wildlife Refuge, prior to disposal in the Sacramento-San Joaquin Delta. The northern section of the drain, which would have linked Kesterson Reservoir to the Delta, was never completed. Flows of drainage water into Kesterson Reservoir, however, continued, and by 1981, all flows into the reservoir were from agricultural drainage. In 1983, fish mortalities and severe deformities of birds made national headlines. Subsequent studies linked these impacts to selenium, which is found in naturally high concentrations in soils in the western San Joaquin Valley. Elevated selenium levels continue to complicate disposal of the drainage water.

Treating and disposing of the agricultural drainage water continues to be problematic and no long-term solutions have yet been found. In addition to treating and disposing of the drainage water, efforts to solve the drainage problem include reducing the quantity of drainage water produced. Drainage water reduction can be achieved through water conservation and efficiency improvements and land retirement. A recent USGS report notes that "Land retirement is a key strategy to reduce drainage because it can effectively reduce drainage to zero if all drainage-impaired lands are retired" (Presser and Schwarzback 2008). Land retirement refers to removing land from irrigated agricultural production, but does not preclude the use of the land for grazing or dry farming.

According to DWR, an estimated 250,000 acres of land had a water table within 5 feet of the ground surface and were classified as a "present problem area" in 2002. An additional 1.0 million acres of land had a water table 5 and 20 feet below the ground surface and were classified as "potential problem areas" (DWR 2007b). We estimate that the weighted average applied water in the Tulare Lake and San Joaquin hydrologic regions is 3.11 acre-feet per acre (DWR 2008b). Based on this assumption, retiring present and potential problem areas would result in an annual water savings of 0.8 and 3.1 million acre-feet, respectively (Table B4-2).

While land retirement imposes losses on agricultural producers in the region, but it also reduces the economic cost of clean-up of drainage water and the social and environmental costs of polluted surface and groundwater.

Table B4-2. Present and Potential Drainage Problems and Associated Water Savings for Sub-basins in San Joaquin Valley

	Present Drainage Problems		Potential Drainage Problems	
	Area (acres)	Potential Water Savings (acre-feet per year)	Area (acres)	Potential Water Savings (acre-feet per year)
Grasslands	129,000	401,190	234,000	727,740
Kern	6,000	18,660	214,000	665,540
Tulare	45,000	139,950	281,000	873,910
Westlands	67,000	208,370	280,000	870,800
Total	**247,000**	**768,170**	**1,009,000**	**3,137,990**

Note: DWR defines "present problem areas" as those where the water table is within 5 feet of the ground surface at any time during the year and "potential problem areas" as those where the water table is between 5 and 20 feet below the ground surface. To estimate the potential water savings, we assume a weighted average applied water of 3.15 acre-feet per acre for the Tulare Lake and San Joaquin River hydrologic regions (DWR 2008b).