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Sustaining California Agriculture in an Uncertain Future

Heather Cooley, Juliet Christian-Smith, and Peter Gleick

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About the Pacific Institute

The Pacific Institute is one of the world's leading independent nonprofits conducting research and advocacy to create a healthier planet and sustainable communities. Based in Oakland, California, we conduct interdisciplinary research and partner with stakeholders to produce solutions that advance environmental protection, economic development, and social equity—in California, nationally, and internationally. We work to change policy and find real-world solutions to problems like water shortages, habitat destruction, global warming, and environmental injustice. Since our founding in 1987, the Pacific Institute has become a locus for independent, innovative thinking that cuts across traditional areas of study, helping us make connections and bring opposing groups together. The result is effective, actionable solutions addressing issues in the fields of freshwater resources, climate change, environmental justice, and globalization. More information about the Institute and our staff, directors, funders, and programs can be found at www.pacinst.org.

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Acronyms and Abbreviations

ABARE – Australian Bureau of Agricultural and Resource Economics
AF – acre-feet
AWMC – Agricultural Water Management Council
CCID – Central California Irrigation District
CDFA – California Department of Food and Agriculture
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
EQIP – Environmental Quality Incentives Protocol
FAO – Food and Agriculture Organization
LEPA – low-energy precision application
LESA – low-elevation spray application
MAF – million acre-feet
NRCS – Natural Resources Conservation Service
PIER – Public Interest Energy Research
RDI – regulated deficit irrigation
SEBAL – Surface Energy Balance Algorithm for Land
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

What could California agriculture look like in the year 2050 – still many years in the future? The answer, of course, is almost anything: from a smaller, weaker sector to a healthier, stronger global producer and exporter of food and fiber. What the future holds depends on decisions made today and tomorrow. This report offers a positive vision for California agriculture and water – a vision of a sustainable, healthy agricultural community.

Agriculture in 2050: Our Vision

It is now the year 2050 and California agriculture is thriving, leading the world in sustainable production, the efficient use of water, the fair and humane treatment of its workforce, and the protection of ecological services. Over the past several decades, innovative thinking, smart policies, and careful actions transformed disputes over water into efficient use and cooperative management.

Some California farmers have always been innovative and flexible, but the pressure to transform the sector built to a crescendo around 2010 when severe drought coupled with financial constraints and growing environmental problems forced many farmers and irrigation districts to change the way they operated. In particular, more farmers began to treat water as a scarce resource, exploring ways to boost yields while reducing water use. Sustainable water management practices already implemented in some areas of California became much more widespread, including efficient irrigation technologies, improved irrigation scheduling, rainwater collection, integrated groundwater management, and measures that enhance soil moisture retention.

The water crisis also led to long-overdue changes in water use monitoring and reporting. As hard as it is to believe today, groundwater use and quality were not consistently monitored and managed in California, nor did the state have an accurate estimate of agriculture's actual water use. Things began to change as unconstrained groundwater pumping and contamination began to hurt more farmers than it helped. All groundwater use and quality is now monitored and managed by local groundwater management groups, with the guidance of statewide standards. Long term over-pumping of groundwater – one of the clearest measures of the unsustainable water policies of the past century – has finally ended. A comprehensive system of integrated management has nearly doubled the amount of water stored in active groundwater basins for use during drought periods.

Several significant changes in the U.S. Farm Bill now encourage farmers to conserve water and use their working landscapes to provide multiple benefits, e.g., food and fiber production, wildlife habitat, and groundwater recharge. Growing competition for water by urban and ecological water users has made water-intensive crops increasingly unpopular and difficult to sustain. Direct commodity payments have been retooled to support payment for environmental services and irrigation efficiency improvements. Rice, cotton, alfalfa, and other field crops are still grown in California, but they no longer dominate the landscape due to a variety of factors including market changes and water availability. Furthermore, many crops use far less water than they used to because of genetic improvements in crop cultivars and more sophisticated *irrigation technologies. New federal and state programs provide financial incentives for farmers and irrigation districts to modernize their water management practices. Overall irrigation efficiency has risen significantly measured as both farm revenue and crop production per unit of water.*

The California agricultural community has also put in place several institutional innovations. Water management institutions ensure the "reasonable and beneficial" use of the state's water resources. Federal and state water contractors have repaid the cost of building major water infrastructure projects initiated in the 1950s, including the Central Valley Project and the State Water Project. Pricing is now used as a tool to encourage wise water use, and most urban and agricultural water suppliers have adopted tiered rates where those who use more water pay more per unit of water. The additional revenue gained from these rate structures finances on-farm and district improvements, including better measuring and monitoring of water use. Now that all water use is carefully monitored and reported, flexible market mechanisms permit growers to retain water rights while transferring the use of that water to other users. Thus, farmers regularly buy and sell water within a state-regulated market that also provides water for the restoration of aquatic ecosystems. While urban agencies sometimes apply for temporary use of water from these markets, most transfers are limited to farmer-farmer trades.

Farmers and environmentalists have worked together to define specific ecosystem goals, such as restoring and maintaining healthy populations of freshwater and anadromous fish, keeping salinity below certain levels, and protecting habitat for waterfowl in coastal and inland wetlands. These partnerships have helped to ensure environmental protection and increase the certainty of water supply to farmers. Fish populations in California's rivers that managed to survive to the turn of the century remain healthy. Every year tourists come to see the spectacle of millions of ducks, geese, and cranes wintering in the refuges of central and northern California.

Achieving the Vision

Farmers are already adapting to a changing world, but this can be expensive and risky. How can we, as Californians, help ensure that California continues to be a state of vast natural beauty and agricultural bounty for future generations? This question is a central focus of this report. We describe some of the tools that can help maintain a thriving agricultural sector, report on recent trends in the California agriculture, and address emerging challenges such as climate change that will impose new difficulties for growers. We then quantify the water conservation and efficiency potential of three water management scenarios. We describe some of the challenges that farmers and agricultural water suppliers face in capturing this potential and provide recommendations for overcoming these challenges. Throughout, we profile farmers and irrigation districts who are already moving in innovative directions and whose experiences will help overcome barriers to a healthy agricultural sector in the future.

Water Conservation and Efficiency – Future Scenarios

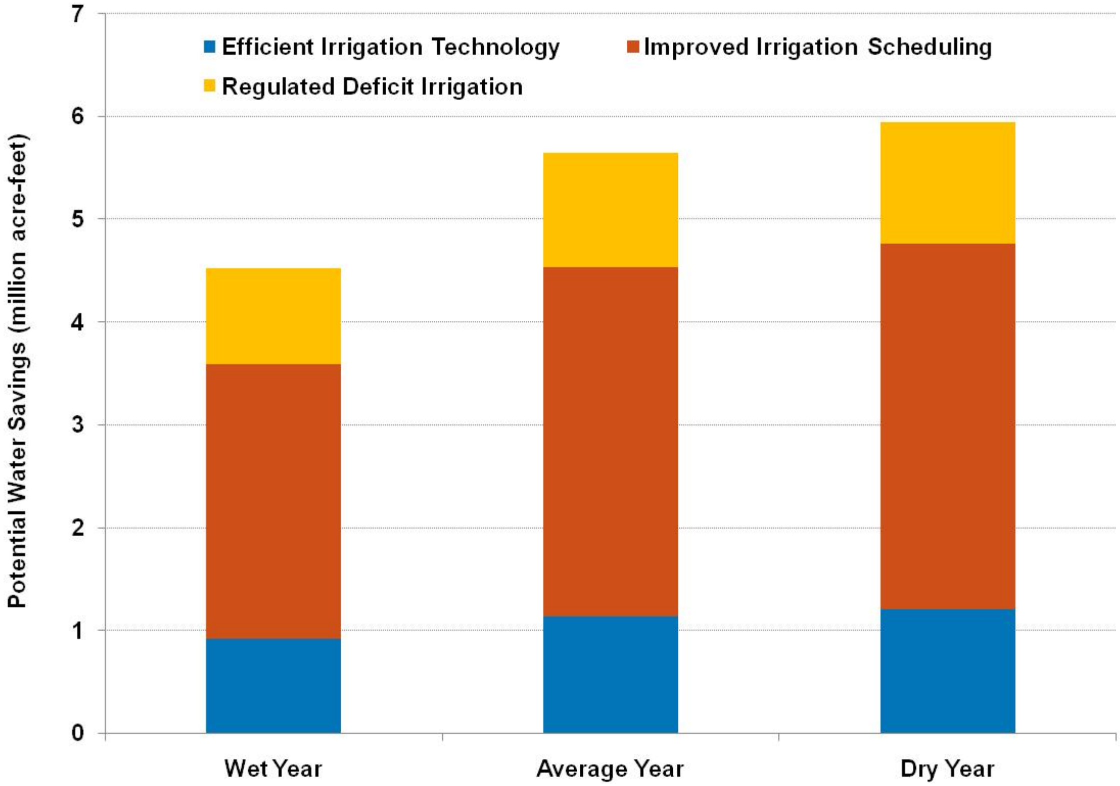
Many options are available for improving the efficiency of water use in California agriculture – this report quantitatively and qualitatively explores the following three technology and management scenarios:

- **Efficient Irrigation Technology –** shifting a fraction of the crops irrigated using flood irrigation to sprinkler and drip systems;

- **Improved Irrigation Scheduling –** using local climate and soil information to help farmers more precisely irrigate to meet crop water needs; and
- **Regulated Deficit Irrigation –** applying less water to crops during drought-tolerant growth stages to save water and improve crop quality or yield.

The three scenarios we evaluated here all conservatively show the potential for significant water savings. The combined potential savings from the technology and management scenarios are between 4.5 million acre-feet in a wet year and 6.0 million acre-feet in a dry year (Figure ES-1). In total, these scenarios would reduce agricultural water use by 17 percent. Water savings were substantial for all scenarios but were greatest in the Improved Irrigation Scheduling scenario.

Figure ES-1. Potential water savings (in million acre-feet) in a wet, average, and dry year



Our results also indicate that water conservation and efficiency improvements are particularly effective in dry years, when agricultural water demand is greater and conflict over scarce water resources is more severe and costly. By investing in "drought-proof" strategies, California farmers can reduce their vulnerability to the kinds of water-supply constraints experienced in the past three years due to drought. Because climate change is expected to increase the frequency and intensity of droughts, these measures can also help California farmers improve their resilience to a changing climate. We must learn from the example of the Murray-Darling basin in Australia, which concentrated primarily on building bigger storage for rains that, in the end, never came. This resulted in the widespread collapse and restructuring of agriculture in the region. Water conservation and efficiency are increasingly important tools that can help California adapt to a drier future and continue to be a world leader in agricultural production.

Conclusions and Recommendations

California's future is increasingly uncertain. Competition over limited water resources continues and climate change is increasing climate variability. With existing technologies, management practices, and educational and institutional resources, we can reduce agriculture's vulnerability to water supply constraints and improve its long-term sustainability. We conclude with a series of key political, legal, and economic initiatives that would promote more productive and, ultimately, more sustainable water management in California.

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.

- Implement California Assembly Bill 1404 in a timely manner, which would ensure coordinated water use measurement and reporting.
- Use satellite and other technology to improve data collection and analysis, particularly for annual assessments of crop area and evapotranspiration.
- Ensure that the Landsat-7 follow-on mission is equipped with a thermal band to allow for the continued use of satellite imagery for data collection and analysis.
- Design and implement comprehensive local groundwater monitoring and management programs statewide.
- Require the state to evaluate the measurement needs for accurately monitoring return flows.
- Implement a statewide system of data monitoring and data exchange, especially for water use and quality, available to all users.

While agriculture has social and cultural importance, it is also an economic endeavor and farmers must make choices about investments based on expected costs and returns. While investments in on-farm efficiency improvements can be offset by a reduction in operation costs and/or increased crop revenue, the initial investment required can be a significant barrier. Policies are needed to overcome this economic barrier.

- Federal funding for conservation programs, especially the Environmental Quality Incentives Program, should be increased.
- State and county governments should provide property tax exemptions for farmers that upgrade to more efficient irrigation systems. Exemptions could apply to the value added to a property by the irrigation system and would be valid for 5-10 years.
- The State should 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.

In California, irrigation water is predominantly delivered through canals designed and constructed in the early and middle of the 20th century. Nearly 80% of these water systems fail to provide water on-demand, which is a necessary precondition for many on-farm water efficiency improvements.

- State and federal governments should expand efforts to finance district-wide improvements that provide water to farmers when needed, such as lining and automating canals and distribution systems.
- Irrigation districts should implement new water rate structures that encourage efficient use of water. This additional revenue generated from large water users can be used to finance on-farm and district-wide 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. Implementation of the State Water Resources Control Board's mandate will be stymied by political forces until the appointment and confirmation processes and funding of the board are significantly altered.

- As a regulatory agency, the State Water Resources Control Board should be an independent body with a secure funding source, e.g., fees or regular funding increases consistent with the consumer price index, outside of the political budget process.
- Establish a panel of independent judges to review and recommend candidates for the State Water Resources Control Board.
- Change Water Code Section 275 to eliminate the "and" between the State Water Resources Control Board and the California Department of Water Resources. The State Water Resources Control Board should have independent authority to prohibit waste.

A more sound and integrated water management system is needed given changing social, economic, hydrologic, and environmental conditions. In particular, California's water rights system should be expanded to include groundwater and the potential impacts of climate change.

- Legislative, regulatory, and administrative support should be given to update the water rights system given future hydrologic uncertainties.
- Current state law allows local government to create local groundwater management authorities. The law should be changed to require local government to create these authorities.
- The state and local agencies should immediately establish groundwater management authorities in regions where overdraft is most severe.

Many agricultural water users in California receive water from the State Water Project (managed by the California Department of Water Resources) and the Central Valley Project (managed by the United States Bureau of Reclamation). These water projects, however, have over-allocated and under-priced water.

- The United States Bureau of Reclamation should revisit its water rate structures, ensuring that all water use does not fall within the first tier and that there are large increases between tiers.
- The United States Bureau of Reclamation should renegotiate all Central Valley Project contracts in light of the new biological opinions issued by the National Marine Fisheries Service and Fish and Wildlife Service.

- The United States Bureau of Reclamation should require all project contractors to provide a valid "Needs Assessment" that conforms to state law by demonstrating reasonable and beneficial use of water and prohibiting the waste of water.
- The State should require that all water deliveries, including the settlement contractors, be measured at the turnout with sufficient accuracy (generally ± 6%) and be subject to tiered pricing.
- The California Department of Water Resources should make the water contract amendment process reliant on an evaluation of the efficiency of current water use in the contractor's service area.

Education and outreach programs are critical for disseminating new research, information, and technical assistance directly to farmers. Programs are available but underfunded. These on-the-ground efforts are central to achieving a sustainable agricultural future.

- Expand water-efficiency information, evaluation programs, and on-site technical assistance provided through Agricultural Extension Services and other agricultural outreach efforts.
- Ensure a stable source of funding for education and outreach programs.
- Expand development and deployment of efficient irrigation technologies and new crop types.
- Fund the Agricultural Water Management Council to update and expand its Efficient Water Management Practices.

California Agriculture 2050: A Sustainable Vision

What could California agriculture look like in the year 2050 – still many years in the future? The answer, of course, is almost anything: from a smaller, weaker sector to a healthier, stronger global producer and exporter of food and fiber. What the future holds depends on decisions made today and tomorrow. Agriculture is a key component of California's history, culture, and economy – the truth is, California is a wonderful place to grow food. We believe it should stay that way. Here we offer a positive vision for California agriculture and water – a vision of sustainable, healthy agricultural communities.

This vision is not a prediction. After all, our crystal ball is no clearer than anyone else's. Instead, readers should consider this vision as a possible future, one of many plausible ways agriculture could change in response to different policies and practices. This vision of 2050 offers a target for which to aim – an attractive future where water is used efficiently, allocated flexibly and equitably, and managed sustainably for present and coming generations. The point of thinking about such a vision is to move away from traditional scenarios of a gloomy, conflict-ridden, resource-limited future, and toward a more sustainable future. Without developing such a vision and exploring how to reach it, California, and the western U.S. as a whole, will remain stuck in the quagmire of endless political wrangling by polarized interests that characterizes water policy debates today. Defining a vision is important not only for setting goals, but also for thinking about how to attain these goals. A vision makes underlying values explicit and opens a dialogue on the purposes of policy and planning.

Can a viable agricultural future be achieved? Yes – such a future can be achieved by applying technological innovations, rethinking priorities, adopting smart economic policies, integrating water into statewide planning, modifying water management institutions, and ultimately, by working collaboratively with farmers, industries, communities, water agencies, laborers, and the public. But, will a sustainable future be achieved? That depends on the commitment of all actors to move from individually-focused interests to a deeper understanding of the interdependence of agriculture and other sectors - including the environment - and a recognition that cooperation can generate benefits across multiple sectors. Agreeing on a commonly held vision is a prerequisite to attaining it. We hope that this report will initiate a broader discussion to develop a shared vision and chart a path forward. In the next section, we provide our vision for a thriving, sustainable agricultural sector.

Our Vision

It is now the year 2050 and California agriculture is thriving, leading the world in sustainable production, the efficient use of water, the fair and humane treatment of its workforce, and the protection of ecological services. Over the past several decades, innovative thinking, smart policies, and careful actions transformed disputes over water. At the turn of the 21st century, the policies of the mid-to-late 1900s, which had enabled California to become a leading international agricultural and economic power, began to fail, especially in terms of managing water. Yet official institutions and policymakers were stuck in traditional approaches to understand and meet emerging challenges. Several seemingly irreconcilable problems exemplified this paralysis: the competition between urban and agricultural water interests, a lack of safe drinking water in some California communities, conflicts between human and *ecological water needs, gross mismanagement and misuse of groundwater, and severe and challenging budgetary constraints.*

Today, in 2050, California is home to nearly 60 million people. Few countries worldwide have larger populations, and even fewer have larger economies. All but a few million Californians live in cities. Three-quarters of the state's total population is concentrated in three major urban conglomerations: the greater Los Angeles-San Diego coastal zone, the San Jose-San Francisco Bay Area, and the Sacramento-Fresno metropolitan corridor. Strong urban growth limits have been set through participatory regional blueprint processes that have preserved prime agricultural lands in recognition of the multiple benefits that they provide. Total agricultural land today is only around 15% lower than it was in 2000.

Total water supply remains about the same as it was in the late 20th century, but there have been important changes. The first is climate change, which continues to dramatically reduce snowfall and snowmelt in the Sierra Nevada mountain range leading to a change in the timing of runoff. Skiers are trying to cope with the shorter winters; white-water rafters are delighted with flashier rivers. So far, water managers have been able to adapt to the changes by using smart and flexible operating rules, applying adaptive management techniques, and broadening their portfolio of supply options. Today, everyone has a basic, reliable water supply. Californians increasingly rely on water conservation and efficiency, state-of-the-art wastewater treatment and reclamation facilities, integrated groundwater and surface water management, and several expensive desalination plants along the coast to meet water demands. Land use policies promote natural recharge and capture to maximize local supplies. While local conflicts still occur occasionally, there is a stronger sense that we are all working to achieve the same goal.

Agricultural Transformation

Food demand has been increasing since the turn of the century. In just a few more years, the total population of humans will peak at around 9 billion, and then for the first time in human history, start to decrease. In order to feed this population – 50% larger than it was in the year 2000 – California has become the model of efficient food production. The state has continued to achieve some of the highest agricultural yields in the world, the lowest water-use rates per unit of yield, and remains a globally important producer and exporter of food despite substantial changes in California's climate and water availability. The California farmer is also considered a model for innovative production methods and an inspiration for family growers who prize small-scale, diverse, and highly efficient local production.

Since 2000, substantial changes have occurred in the structure of the agricultural sector. Some California farmers have always been innovative and flexible, but the pressure to transform the sector built to a crescendo around 2010 when severe drought coupled with financial constraints and growing environmental problems forced many farmers and irrigation districts to change the way they operated. In particular, more farmers began to treat water as a scarce resource, exploring ways to boost yields while reducing water use. Sustainable on-farm practices that were already being implemented in some areas of California became much more widespread, including efficient irrigation technologies, improved irrigation scheduling, rainwater collection, and practices that enhanced soil moisture (Polaris Institute 2008).

The water crisis also led to long-overdue changes in water use monitoring and reporting. As hard as it is to believe today, groundwater use and quality were not consistently monitored and managed in California, nor did the state have an accurate estimate of agriculture's actual water use. Things began to change as unconstrained groundwater use and contamination pumping began to hurt more farmers than it helped. Groundwater use and quality are now monitored and managed by local groundwater management groups, with the guidance of statewide standards. Enforcement of these standards helped to address the salinity concerns that threatened the sustainability of agriculture in some regions. Long-term over-pumping of groundwater – one of the clearest measures of the unsustainable water policies of the past century – has finally ended. A comprehensive system of integrated management has nearly doubled the amount of water stored in active groundwater basins for use during drought periods.

Several significant changes in the U.S. Farm Bill now encourage farmers to conserve water and use their working landscapes to provide multiple benefits, e.g., food and fiber production, wildlife habitat, and groundwater recharge. Growing competition for water by urban and ecological water users has made water-intensive crops increasingly unpopular and difficult to sustain. Direct commodity payments have been retooled to support payment for environmental services and irrigation efficiency improvements. Rice, cotton, alfalfa, and other field crops are still grown in California, but they no longer dominate the landscape due to a variety of factors including market changes and water availability. Furthermore, many crops use far less water than they used to because of genetic improvements in crop cultivars and more sophisticated irrigation technologies. New federal and state programs provide financial incentives for farmers and irrigation districts to modernize their water management practices. Overall irrigation efficiency has risen significantly measured as both farm revenue and crop production per unit of water.

California farmers lead the way in the deployment of more precise water management technologies, including computer-controlled irrigation systems, real-time soil moisture monitoring, and use of the new regional weather-forecasting services that provide seven-day estimates of evaporation demand, precipitation forecasts, and stream-flow projections. Agricultural drainage is now controlled to protect groundwater in vulnerable regions from pollution, and the continued trend toward high-value organic production has further reduced the threat from misapplied agricultural chemicals. Innovations in integrated pest management methods have reduced the application of chemicals. Many of these innovations were catalyzed by debate over fertilizers and pesticide use in the 1980s and 1990s. As a result, the state has witnessed a substantial improvement in water quality throughout the agricultural regions. Human health and the reproductive success of waterfowl also show noticeable improvements, especially in the rural communities of the Central Valley. For the first time since 2000, the number of California plants and animals on the endangered and threatened species list has begun to decline.

The California agricultural community has also put in place several institutional innovations. Water management institutions ensure the "reasonable and beneficial" use of the state's water resources. Federal and state water contractors have repaid the cost of building major water infrastructure projects initiated in the 1950s, including the Central Valley Project and the State

Water Project. Pricing is now used as a tool to encourage wise water use, and most urban and agricultural water suppliers have adopted inclining block rates where those who use more water pay more per unit of water. The additional revenue gained from these rate structures finances on-farm and district improvements, including better measuring and monitoring of water use. Now that all water use is carefully monitored and reported, flexible market mechanisms permit growers to retain water rights while transferring the use of that water to other users. Thus, farmers regularly buy and sell water on a state-regulated market that also provides water for the restoration of aquatic ecosystems. While urban agencies sometimes apply for temporary use of water from these markets, most transfers are limited to farmer-farmer trades.

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Farmers are already adapting to a changing world, but this can be expensive and risky. How can we, as Californians, help ensure that California continues to be a state of vast natural beauty and agricultural bounty for future generations? This question is a central focus of this report. We describe some of the tools that can help maintain a thriving agricultural sector, report on recent trends in the California agriculture, and address emerging challenges such as climate change that will impose new difficulties for growers. We then quantify the water conservation and efficiency potential of three water management scenarios. We describe some of the challenges that farmers and agricultural water suppliers face in capturing this potential and provide recommendations for overcoming these challenges. Throughout, we profile farmers and irrigation districts who are already moving in innovative directions and whose experiences will help overcome barriers to a healthy agricultural sector in the future.

California Agriculture: Recent Trends

California's agricultural sector is dynamic, responding to local and global conditions that change over time. We focus here on recent trends affecting agricultural water use, including irrigated acreage, cropping patterns, and recent water shortages, and address emerging challenges such as climate change that will impose new difficulties for growers.

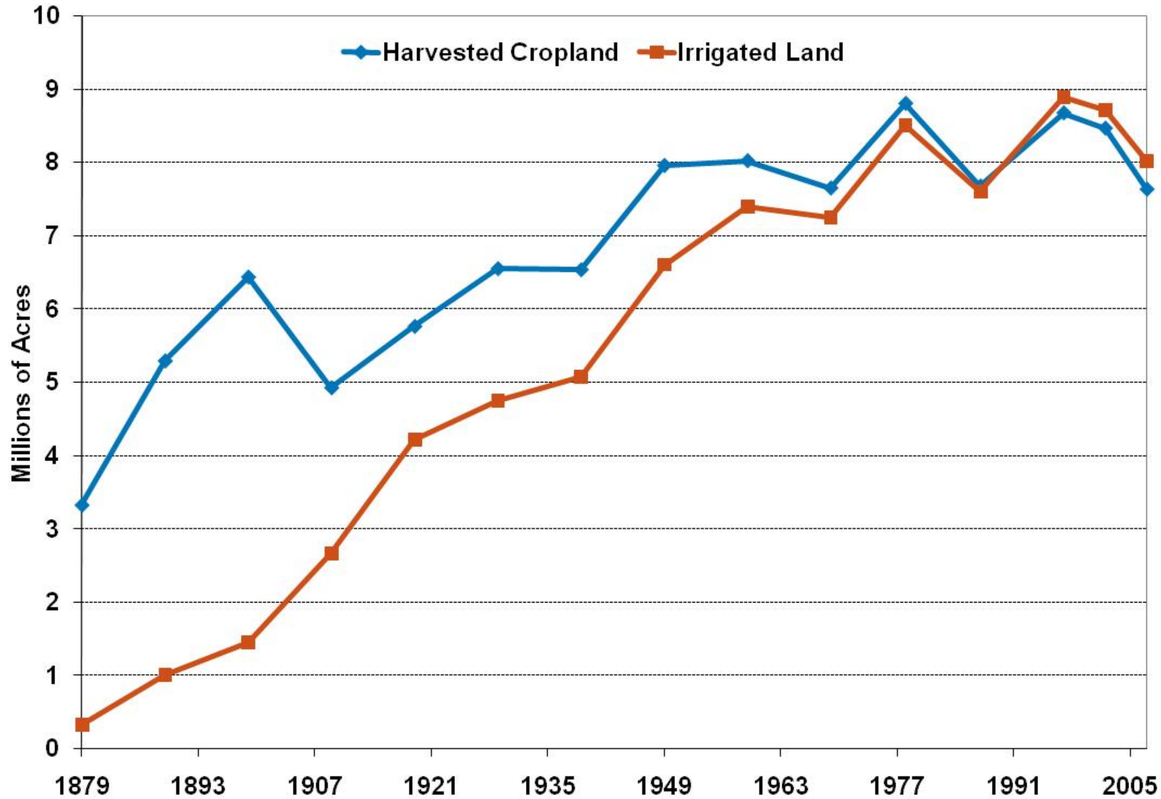
Irrigated Acreage

California is one of the most productive agricultural regions in the world. 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 total, California's agricultural sector produces $39 billion in goods and services each year (USDA 2008).

California's rich agricultural production has been made possible by irrigation supplied by a vast and integrated water infrastructure. The federal Central Valley Project (CVP), All-American Canal, and the State Water Project (SWP) are three of the largest water supply projects in California. The CVP was undertaken by the United States Bureau of Reclamation (USBR) in 1935 to move water from the northern end of the Sierra Nevada through the Central Valley to Southern California. USBR also began construction of the All-American Canal in the 1930s to move water from the Colorado River to the Imperial and Coachella Valleys in Southern California. Soon thereafter, the State constructed the SWP in the 1950s to transport water from Northern to Southern California for urban and agricultural uses. The CVP, SWP, the All-American Canal, 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 1). Following the completion of the CVP, the All-American Canal, 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 and since then declined by approximately 10% to 8 million acres.[1] According to the California Department of Water Resources (DWR), however, the irrigated crop area in 2005 totaled 9.2 million acres. This discrepancy highlights the need for good quality data to accurately evaluate trends.

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

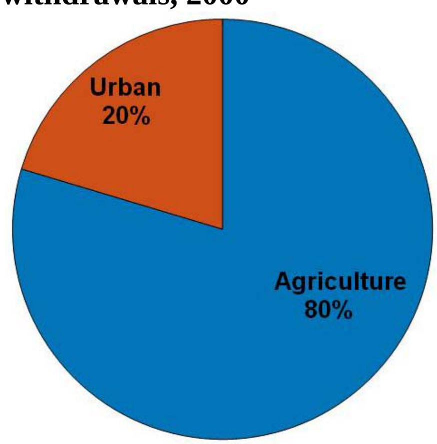
Figure 1. Harvested cropland and irrigated land in California, 1879-2007



Note: Total land in farms includes cropland, rangeland, and pasture.
Source: Johnston and McCalla 2004 (1869–1987 from Olmstead and Rhode 1997; 1997–2007 from USDA 2002 and 2007a)

Actual agricultural water use remains largely unknown. Estimates, however, suggest that California's agricultural sector uses the majority of California's developed water supply. In total, 43 million acre-feet (MAF) of water was withdrawn from surface waters or pumped from groundwater in the year 2000 (DWR 2005a). Approximately 80% of that was used for agriculture and the remaining 20% was for urban areas for residential, commercial, institutional, and industrial uses (Figure 2). This does not account for non-human uses such as environmental flows, which totaled 39 MAF in 2000 (DWR 2005a).

Figure 2. Total California urban and agricultural water withdrawals, 2000



Note: This figure shows total water withdrawn for human uses from surface and groundwater sources for the urban and agricultural sectors.
Source: DWR 2005a

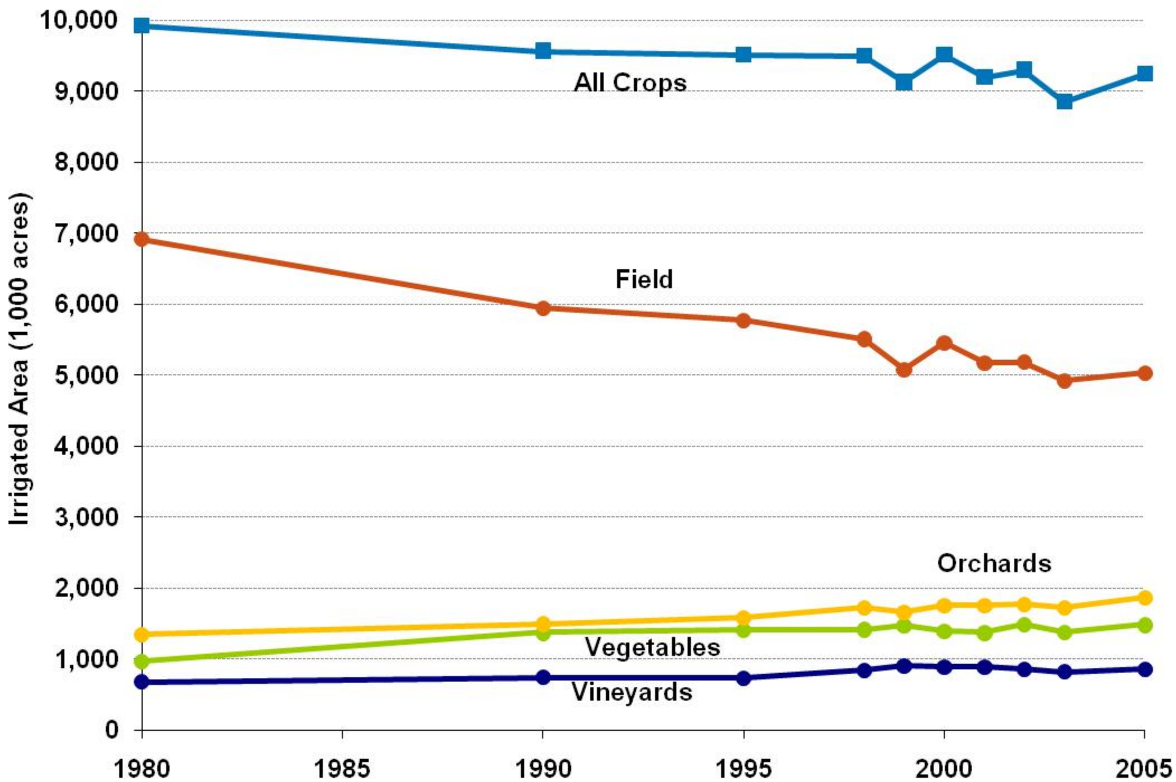
Cropping Patterns

The choice of what crop to grow is complex and based on a variety of factors, including the market value of the crop; local site conditions (soil type, slope, salinity, etc.); crop subsidy programs; the need to rotate crops; past investment in harvesting and processing equipment; production contracts; and the availability and reliability of water. Indeed, a recent article in the *Western Farm Press* notes that alfalfa acreage is expected to decline in 2009 despite relatively high prices because of concerns about the continued drought in California (Carol 2009). Conversely, high rice prices have resulted in increased rice production in 2009 in parts of the state where water is relatively abundant.

California produces a diverse array of agricultural products that can be grouped into four major crop types: field crops (including hay and pastureland), vegetables, orchards, and vineyards.[2] Since 1980, California's agricultural sector has experienced significant changes in cropping patterns (Figure 3). In 1980, nearly 7 million acres of land was planted with field crops, accounting for about 70% of the total irrigated area (Figure 3). Although field crops remain the dominant crop type, field crop acreage declined by 1.9 million acres between 1980 and 2005. Vineyard, vegetable, and orchard acreage increased by more than 1.2 million acres during this period – in 2005, these crops accounted for about 46% of the total irrigated acreage, up from 30% in 1980 (Figure 4). In some areas, field crop acreage was lost to urbanization, but in others, it was converted to vineyards, vegetables, and orchards.

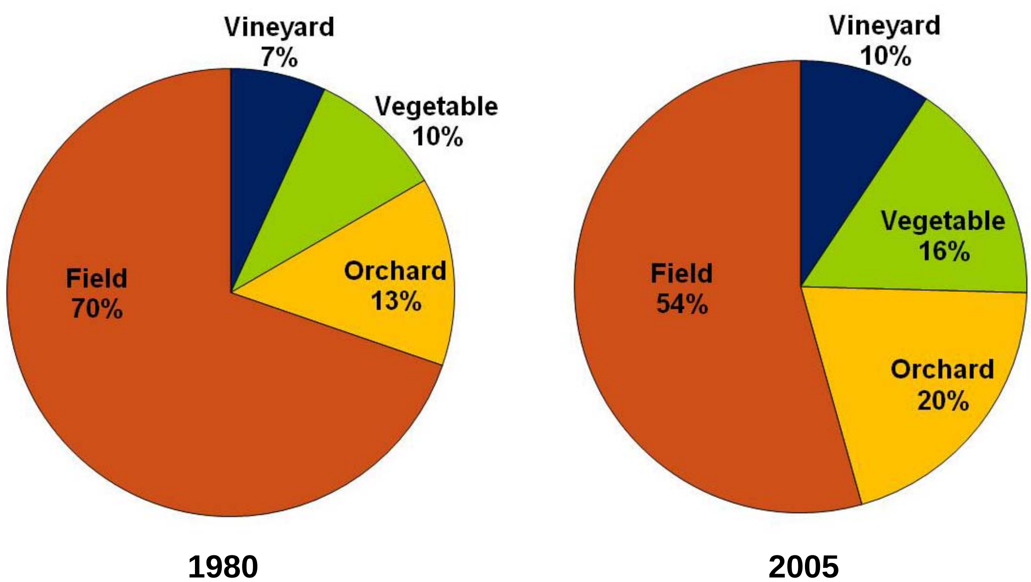
[2] California is also a major producer of livestock, poultry, and dairy products. We do not include these products in our analysis. We focus here on irrigated agricultural cropland.

Figure 3. Irrigated area by major crop type, 1980-2005



Source: Department of Water Resources 1983, 1993, 1998, 2005a, 2008a, In Review

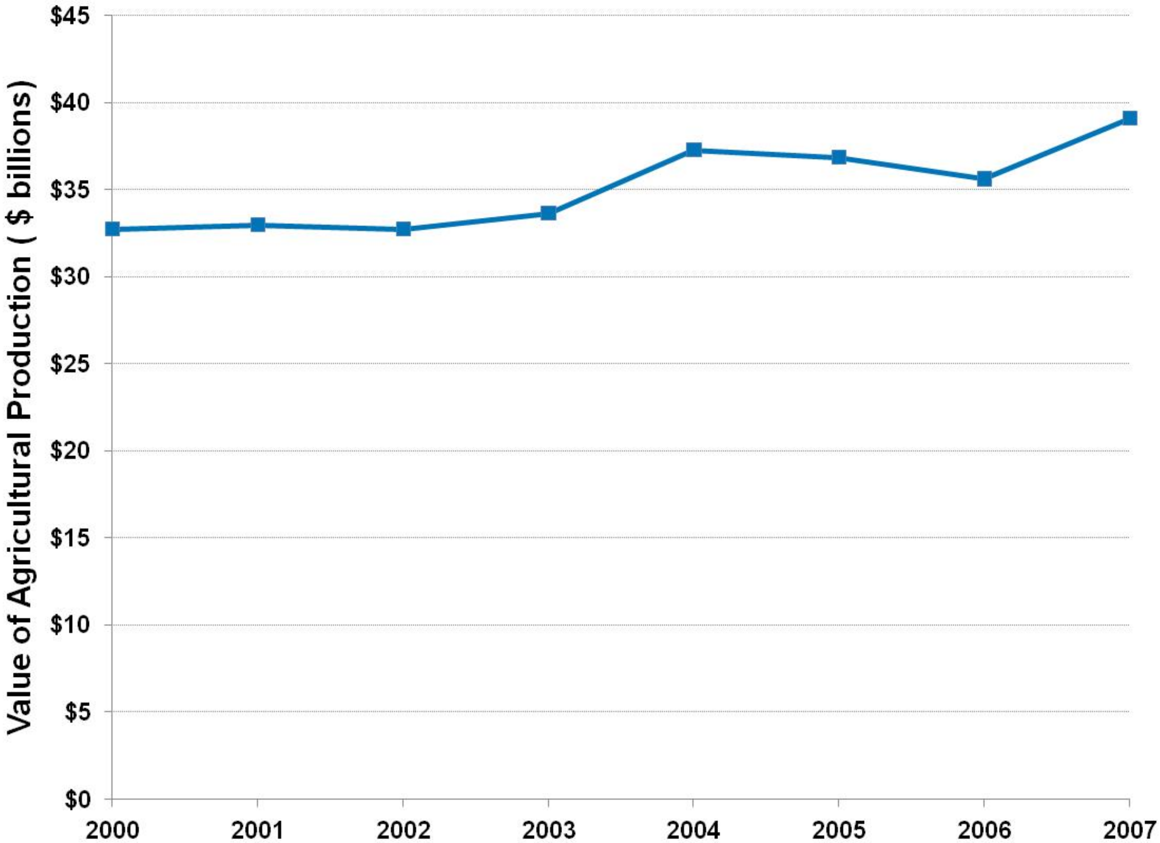
Figure 4. Changes in the proportion of major crops grown in California, 1980 and 2005



Source: Department of Water Resources 1983 and In Review

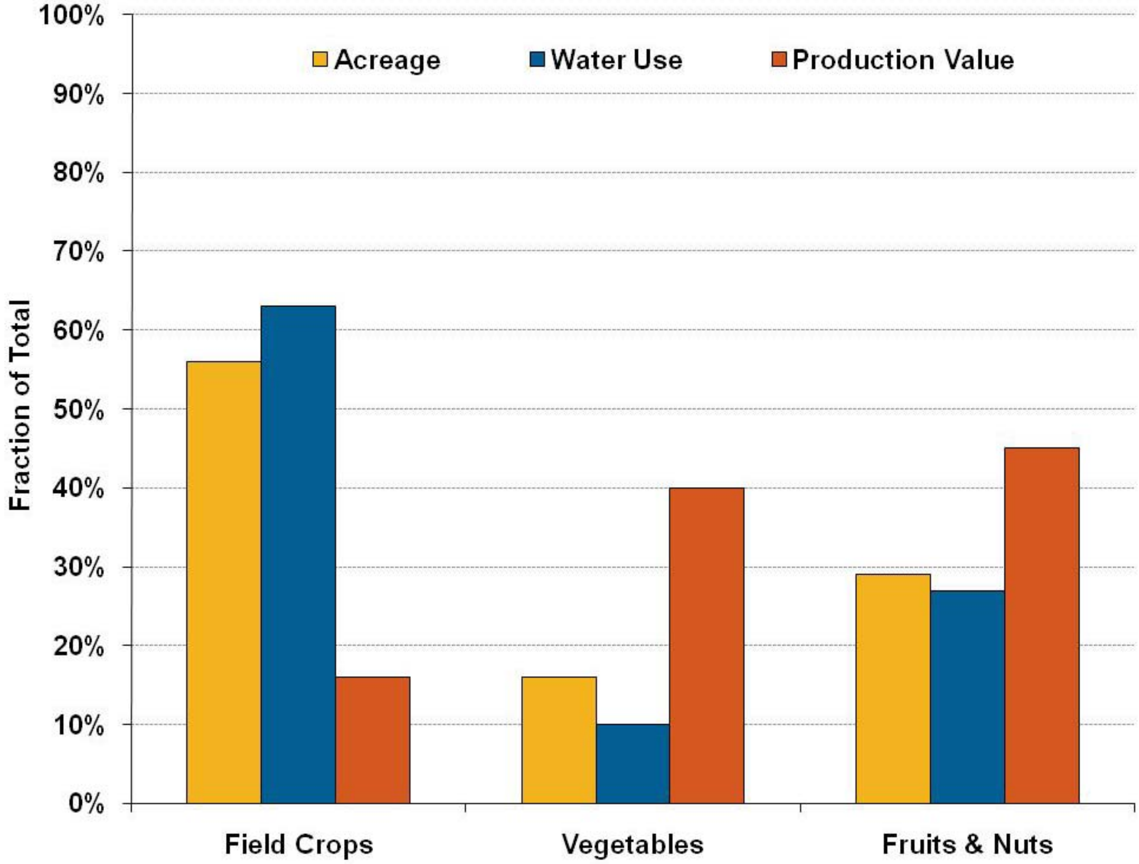
Crops exhibit significant variation in their resource use and economic value, and changing crop patterns are one of the factors responsible for increases in the production value of California agriculture (Figure 5). In 2003, field crops, for example, accounted for 56% of total irrigated acreage and an estimated 63% of the applied water (Figure 6). Yet, these crops generated only 17% of California's crop revenue. This does not, however, include the important role that many field crops play in supporting the state's dairy industry and the value it produces. In comparison, vegetables, orchards, and vineyards produced substantially more revenue per unit of land or water. Vegetables, for example, accounted for only 16% of the irrigated acreage, used 10% of the applied water, and generated 39% of California's crop revenue.

Figure 5. Economic productivity of California agriculture, 2000-2007



Note: All values are shown in year 2007 dollars.
Source: USDA 2008

Figure 6. Percent of irrigated acreage, applied water, and gross production value 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 from United States Department of Agriculture (2007b). The production value of nursery products was excluded because of insufficient data on irrigated acreage for this crop. Pasture production values typically reflect the added income from livestock/dairy production on pastureland (Bengston, Mendocino County Agricultural Commissioner, pers. comm., 2008). Applied water and irrigated acreage values were based on estimates from DWR for 2003.

Drought and On-Going Water Scarcity

California received 80% of its average precipitation and 60% of its average snowpack in 2009. Total statewide runoff for the most recent water year is estimated to be around 70% of normal. After multiple dry years, reservoir storage is 80% of the average (DWR 2009). Ground water levels are also low: the Main San Gabriel Basin, an underground aquifer that spans the San Gabriel Valley, is expected to reach its lowest level in 75 years if drought conditions continue.

We have had drier periods, in 1976-77 and 1987-92, but there are some important new challenges: California has grown by about 6 million people, Southern California lost a significant portion of its Colorado River water, and the decline of the Delta ecosystem has led to new legal restrictions that make it more difficult to move water through the Delta.

Due to this combination of drought-exacerbating conditions, Governor Schwarzenegger stated that "California is facing an unprecedented water crisis" (Office of the Governor 2008). We have already seen the impact this drought year has had on agriculture, causing mid-season fallowing and tree stumping for some farmers in 2008. In early 2009, the Governor declared a state of emergency due to continued drought conditions (Office of the Governor 2009). It is critical to acknowledge that no matter what we might want, it is very likely that there will continue to be serious constraints on the volume of water available to all California users, including agriculture.

Climate Change

Rising atmospheric greenhouse gas concentrations are causing large-scale changes to the Earth's climate system. The Intergovernmental Panel on Climate Change (IPCC) notes: "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level" (Bernstein et al. 2007). Human-induced climate change is altering the availability, timing, reliability, and quality of fresh water (Trenberth et al. 2007). The IPCC Fourth Assessment Report concludes that freshwater systems are among the most vulnerable sectors to climate change (Kundzewicz 2007). Climate change will directly affect agricultural production as a result of changes in temperature, precipitation, and extreme events. These changing climate conditions will produce secondary effects on the supply of and demand for water resources. For instance, research presented at the most recent American Geophysical Union predicts that more frequent heat waves will put more pressure on farmers to irrigate their crops (Sullivan 2008). The form and severity of climate change impacts, however, are subject to significant regional variation. Accordingly, a detailed assessment of climate change risks, combining the magnitude of the impact with the probability of its occurrence, requires thorough analysis at the regional level.

California has been at the forefront of conducting climate change research. The California Energy Commission's Public Interest Energy Research (PIER) program coordinates a series of comprehensive assessments to understand climate impacts on key sectors in the state, including agriculture. For this effort, significant research has been conducted to downscale output from global climate models to project changes to California's climate. Below, we describe research that examines the projected impacts of climate change on agricultural production in California. All projections are based on six climate models for medium to medium-high greenhouse gas emission scenarios from Cayan et al. (2009).

Recent studies show that climate change will affect California's perennial and field crops differently. Perennial crops are more vulnerable to climate change impacts in the near term (Lee et al. 2009, Lobell and Field 2009). Yields of cherries, berries, table grapes, wine grapes, walnuts, and freestone peaches are projected to decline by 2050, while almond yields slightly increase during this period (Lobell and Field 2009). Impacts on field crops were not significant up to 2050 but yields were projected to decline during the latter part of the century (Lee et al. 2009).[3] It is important to note that there were significant differences in the decline of field crop yields between the two emissions scenarios. For example, corn yields are expected to decline by

[3] The exception was alfalfa because its yields did not consistently respond to climate change across counties (Lee et al. 2009).

4% under the medium emission scenario but would decline by 12% by the end of the century under the medium-high greenhouse gas emissions scenarios (Lee et al. 2009).

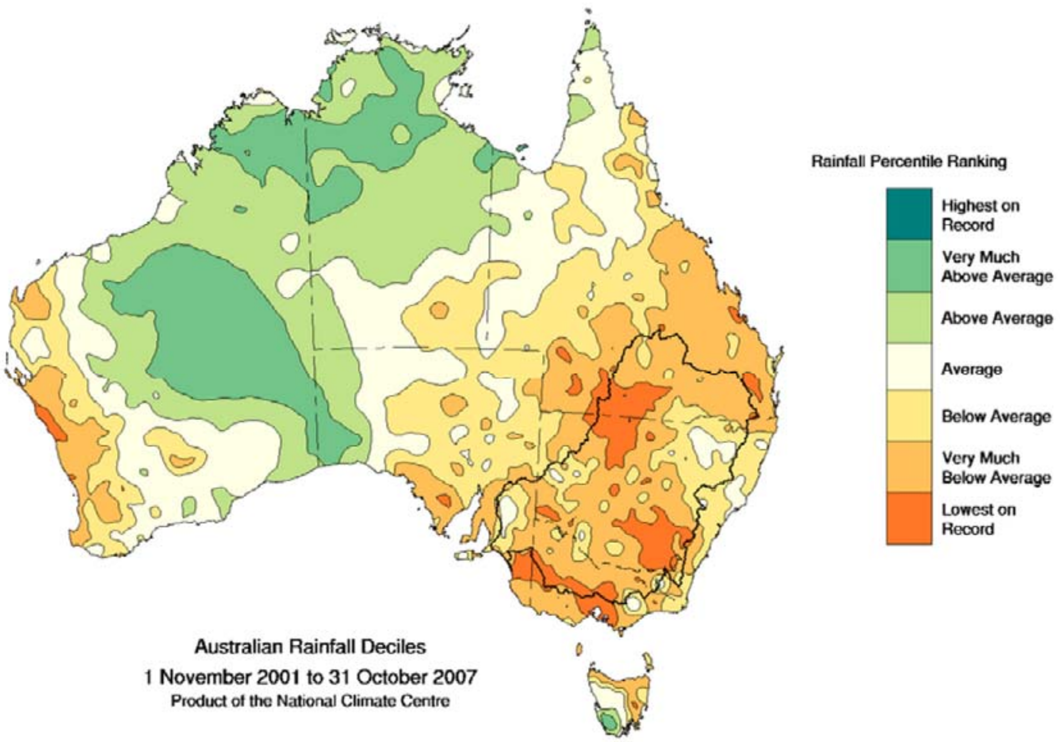
Both of these studies fail to take into account the effect of water supply limitations on crop yield. Previous studies have found that climate change will likely decrease annual water deliveries and increase water supply risk in agriculture, suggesting that "the modeled yield losses for the irrigated crops were possibly underestimated" (Lee et al. 2009). Water supply must be integrated into climate change impact studies, as the following case study of the Murray-Darling Basin illustrates.

A Case Study of Agriculture in Australia's Murray-Darling Basin

The Murray-Darling Basin accounts for 65% of irrigated agriculture in Australia and is commonly referred to as the nation's "food bowl," producing over one-third of Australia's food supply (Craik and Cleaver 2008). The Murray-Darling basin occupies one million square kilometers in the southeastern corner of Australia. Originally a predominately dryland farming region, the Basin became a center of irrigated agricultural production in the post World War II era when soldier resettlement schemes promised free or cheap land and later, expanded availability of water for irrigation uses.

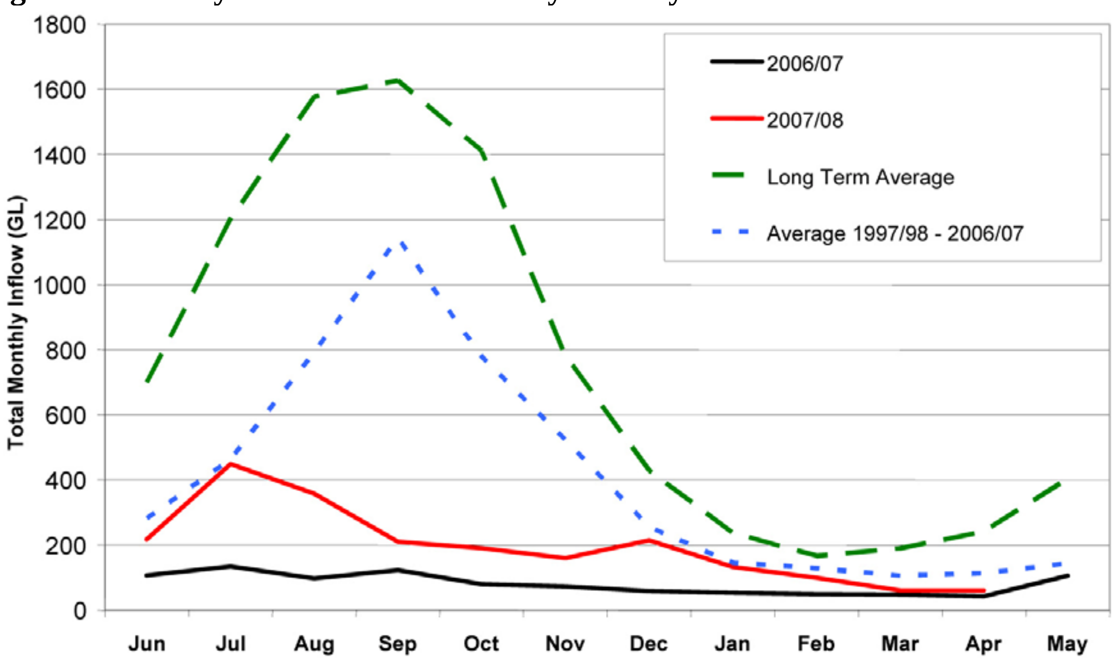
Irrigated agriculture in the southern Murray-Darling Basin is supported by large reservoirs in the Snowy Mountains and, to a lesser degree, groundwater aquifers across much of the region. Construction of the Snowy Mountains Scheme began in the 1940s to supply more water to the region and culminated in the early 1970s with the completion of 16 major dams, 145 km of tunnels, 80 km of aqueducts, and 7 major power stations. The American Society of Civil Engineering recognized the project as "one of seven civilian engineering wonders of the modern world." The project, and supporting government policies, successfully encouraged agricultural development and water use, diverting 86% of the natural flow of the Murray-Darling Basin by 1995 (Australia's Chief Hydrologist, pers. comm. 2/17/09).

Figure 7. Australian rainfall deciles from November 2001 to October 2007



Note: The outline of the Murray-Darling Basin is shown in the southeast Australia.
Source: Craik and Cleaver 2008

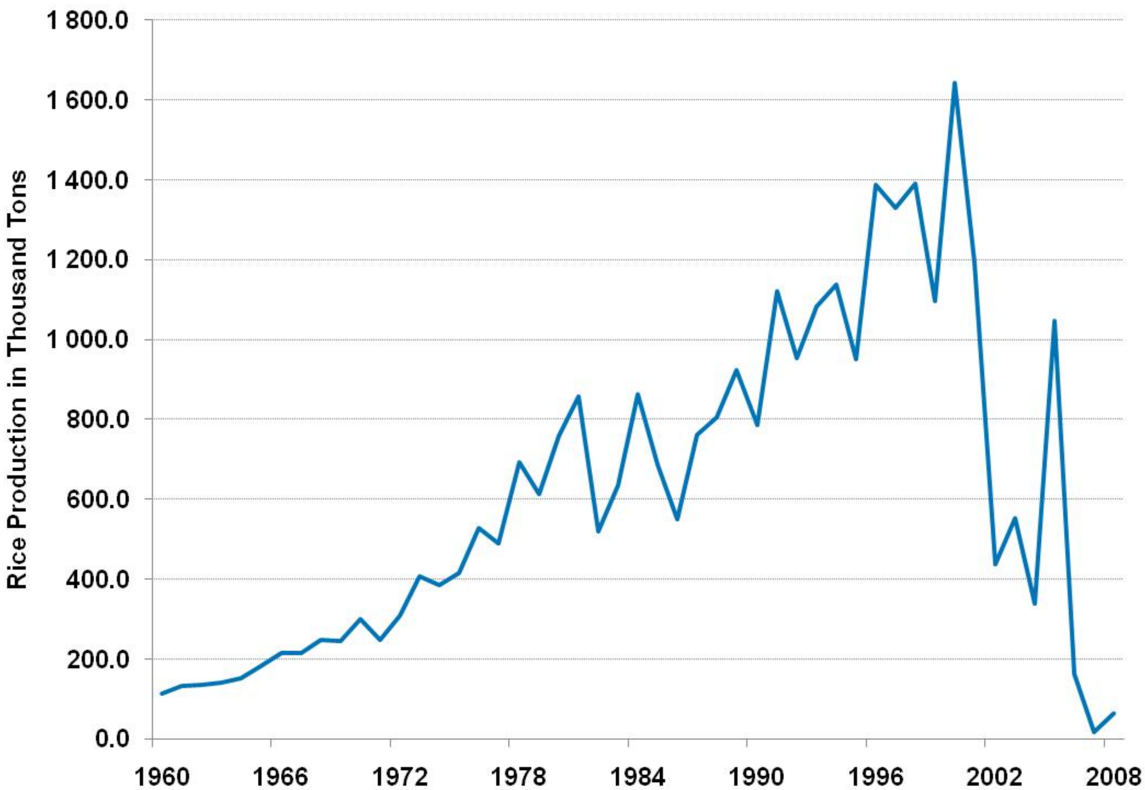
Figure 8. Monthly inflows into the Murray River system



Source: Craik and Cleaver 2008

Rising water diversions, however, were accompanied by emerging environmental problems in the region including toxic algal blooms, decreased water quality, loss of wetlands, and high soil salinity. Over the last decade, these issues have been exacerbated by prolonged drought and emerging climate change impacts. Between 2006 and 2008, much of the Basin received extremely low annual precipitation, and the 2006 water year had the lowest runoff on record in the Murray-Darling Basin (Figures 7 and 8). During this period, many farmers with general security allocations received zero percent of their annual water allocations, while those with high security entitlements received severely reduced allocations, with catastrophic impacts on the agricultural sector in both social and economic terms. Impacts on irrigated agricultural production are best illustrated by rice production, which declined from more than 1 million tons in 2006 to fewer than 20,000 tons in 2008, a 98% reduction (Figure 9). Production of other commodities such as wine grapes, citrus, vegetables, irrigated pastures for the diary industry and cereals production were also severely affected (ABARE 2009).

Figure 9. Rice production in the Murray-Darling Basin



Source: Annual crop reports from 1960-2008 from the Australian Bureau of Agricultural and Resource Economics (ABARE 2009).

Initially, the drought was considered simply one of many in a region that is prone to these events. Today, scientists believe that these recent events in Australia are a harbinger of long-term climate change. Indeed, Australia's Bureau of Meteorology predicts that within two to three decades, drought will occur twice as frequently and be twice as severe (Circle of Blue 2009). Increases in the frequency and intensity of droughts are consistent with recent projections for the western United States, including California.

In 2007, Australia commenced reform of its water management system to incorporate this new, water-scarce reality, passing the Commonwealth Water Act. The Act and accompanying intergovernmental agreements have seen Constitutional rights over water resources in the Murray-Darling Basin assigned by the States to the Commonwealth and investment of approximately $13 billion Australian dollars (~$US 10.5 billion) in water reform measures including:

- federalizing water data collection,
- requiring greater regulatory reporting (e.g. water balances and a National Water Account),
- moving to full cost recovery for all water infrastructure and services,
- creating a market for water trading (based on tradable property rights and in combination with a review of existing caps on water extractions),
- increasing on-farm efficiencies (e.g. canal lining, drip irrigation, shifting to more water-efficient crops), and
- purchasing water entitlements from willing sellers to restore aquatic ecosystems.

In retrospect, the Snowy Mountains Scheme did not protect the agricultural sector from severe and prolonged drought and emerging climate change impacts, best reflected in reduced snowmelt, precipitation, and runoff. Instead, Australia's Chief Hydrologist has argued that the project may have actually increased the vulnerability of the basin's farmers to water scarcity by creating an artificially inexpensive source of water that was perceived as a secure supply.

Today, farmers in the Murray-Darling Basin are leaders in implementing innovative, on-farm water conservation and water efficient production and management practices. Unfortunately, the focus on increased agricultural water conservation and efficiency came too late for many. While some have suggested that the fate of the Murray-Darling Basin could be California's future, we have the advantage of learning several important lessons from the management mistakes that contributed to severe agricultural decline there. Key among these lessons is that massive storage capacity in a basin is no guarantee of a reliable or predictable water supply, especially when total precipitation and runoff decline. Another is that the most innovative and efficient farmers are better able to withstand periods of shortage.

Water Conservation and Efficiency

Agriculture has long played an important role in California. Today, the challenge is to envision an agricultural sector that supplies food to the state and nation and supports rural livelihoods, while remaining consistent with long-term sustainable water use. Water conservation and efficiency can provide a relatively inexpensive, flexible, and resilient tool to adapt to the trends described in the previous section. In addition, today’s investments in conservation and efficiency are likely to provide a competitive advantage in the future and ensure that agriculture continues to play an important role in California.

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, technological changes, market forces, and changing agricultural policies, but a rapidly changing world can also result in labor dislocations, debt, bankruptcy, and production losses.
While the remainder of this report focuses on water, we recognize that water is only one factor among many constraints and incentives that farmers must balance. In general, farmers make economically rational decisions, trying to maximize profits, but farmers also make choices independent of profit maximization; experience, family traditions, and community values all factor into their decisions. These choices are subject to constraints that can affect water use, including market conditions; local soils and climates; available water sources (including ground water and surface water); and previous investment in irrigation technologies, farm equipment, and processing machinery. In the long term, farmers may shift investments toward more efficient irrigation technology, increase the efficiency of on-farm delivery systems, install more groundwater pumping capacity or on-farm surface storage, permanently retire land, or leave farming altogether.

In our vision, agriculture is thriving in 2050 rather than shrinking, due to a focus on doing more with less. We believe that water conservation and efficiency are necessary elements to develop a thriving agricultural sector in light of current and future challenges. Some of the water saved could be rededicated to agricultural production; support new urban and industrial activities; and restore California’s stressed rivers, groundwater aquifers, and wetlands. This will require great strides in terms of increasing the water efficiency of California’s agricultural sector. Fortunately, some farmers and irrigation districts are already making water-use efficiency improvements. Profiles of “early adopters” are highlighted throughout the report, and their experiences can help guide future action.

Profile of Jim Marshall, Suncrest Nurseries

Suncrest Nurseries is one of the oldest nurseries in California. First established in 1878 as Leonard Coates Nurseries, it was acquired by Stan Iversen and investors in 1989. The wholesale nursery specializes in California native plants and more unusual plants, with over 3,000 varieties in production at any given time.

"One of the long-term objectives was to make our water system more efficient…Just purely looking into the future and seeing that groundwater would become regulated at some point."

Manager Jim Marshall has brought a conservation ethic to the business. Suncrest has reduced its water use significantly, while increasing production, through a number of on-farm system improvements. Drip irrigation is installed on the larger potted plants. Low-pressure sprinklers are used on the smaller potted plants and the sprinkler system is optimized so that water is distributed uniformly. In addition, the irrigation system is automated, allowing for greater control over the application of water to specific areas. They have also installed a network of underground drains and surface ditches that collect drainage water and surface runoff. The recaptured tailwater is collected in a pond at the lowest point of the property, filtered, and mixed with well water before being reapplied. This "closed loop" system cut their consumptive water use in half and reduced the amount of fertilizer that needs to be applied. Marshall is currently experimenting with sub-irrigation mats that could decrease water use even further.

"When you use as much water as you have to in a business like this, you should be conserving it [but]…saving water still has to be a rational process to a grower, you know, what is it worth?"

Marshall believes that water supply challenges can be dealt with locally. "We really felt like one of the strongest means of keeping our watershed viable was through conservation. The agency [Pajaro Valley Water Agency] took a different tact and put a lot of emphasis on a pipeline to bring Central Valley Project/State Water Project water to the area. That met with a lot of resistance locally." The work of Marshall and others in the area has stalled proposals to tap into the state's large water infrastructure projects thus far.

A Note on Terminology

Further discussion of specific conservation and efficiency measures must be predicated upon a common understanding of terms. The water literature is rife with confusing, and often contradictory, understandings of the terms "water use" and "water efficiency." It is important to clarify the uses of these terms, as different meanings can lead to different conclusions about water-management options. Here, we focus on definitions relevant to the agricultural sector, though the terms are used broadly across all sectors. We also discuss some of the common fallacies about agricultural efficiency.

Defining Agricultural Water Use

A variety of terms are used to describe agricultural water use, including water withdrawal, applied water, and consumptive use. Water "use" and "withdrawals" are used synonymously here to refer to water taken from a source and used for agricultural purposes. These withdrawals include groundwater and surface water taken from local sources or water transported via large infrastructure projects like the CVP. Prior to delivery to a farm, water withdrawn from a source is subject to conveyance losses, i.e., seepage or evaporation from reservoirs and canals. The "applied water" is the quantity of surface and groundwater delivered to the farm, i.e., water withdrawals minus conveyance losses.

Agricultural water use can be categorized as consumptive or non-consumptive. Consumptive use refers to water that is unavailable for reuse in the basin from which it was extracted, due to soil evaporation, plant transpiration, incorporation into plant biomass, seepage to a saline sink, or contamination. 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., through return flows.

Figure 10. Examples of beneficial and non-beneficial consumptive and non-consumptive uses

	Consumptive Use	Non-consumptive Use
Beneficial	Crop evapotranspiration Evaporation for cooling Evaporation for frost protection	Water for leaching
Non-beneficial	Phreatophyte evapotranspiration Weed evapotranspiration Spray evaporation Evaporation from soil Reservoir and canal evaporation	Excess deep percolation Excess surface runoff Operational spill

Note: The evapotranspiration of phreatophytes, or deep-rooted riparian vegetation, is not defined as beneficial in this figure, but may provide important ecological services and therefore could be considered beneficial in some cases.
Source: Heerman and Soloman 2007

Agricultural water use can be further divided into beneficial and non-beneficial uses. Beneficial uses include those that contribute to crop production, including crop transpiration and leaching salts from the root zone. Non-beneficial uses include those uses that do not contribute to crop production, such as transpiration from weeds and evaporation from reservoirs, canals, sprinklers, soil, and plant surfaces. Beneficial use can be either consumptive or non-consumptive. Likewise, non-beneficial use can be either consumptive or non-consumptive (Figure 10).

Many water conservation measures increase crop productivity while reducing non-beneficial, consumptive uses. Models that separate evaporation and transpiration have found that the largest differences in water consumption between flood and drip systems are due to soil evaporation. A 2005 study, for example, found that soil evaporation was 75-85% lower with drip systems compared to flood irrigation during the early stages of cotton development (Luquet et al. 2005). While the shift from flood to drip increased plant transpiration slightly, overall crop water requirements declined by 26% on tomatoes and 27% on cotton in Mediterranean climate conditions (Luquet et al. 2005). Ignoring the potential to reduce non-beneficial, consumptive losses may grossly underestimate potential water savings. Nearly 60% of crops in California are flood irrigated (based on Orang et al. 2005), suggesting that there are opportunities to decrease unproductive evaporation.

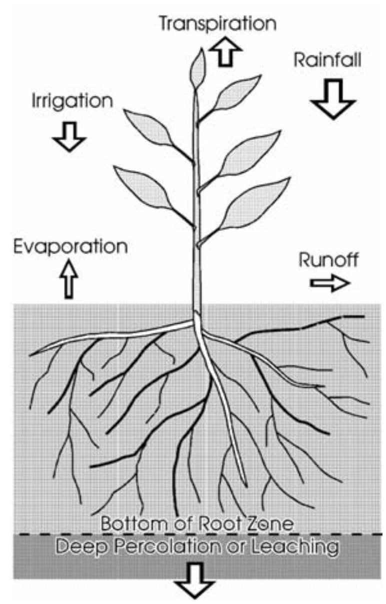
Defining Efficiency

Within an agricultural context, measures of water efficiency can take a variety of forms. In general terms, efficiency refers to the ratio of outputs to inputs:

Efficiency = Outputs/Inputs

Both the inputs and outputs can be evaluated at various spatial (i.e., field, basin, irrigation district, watershed) and temporal (i.e., single irrigation event, season, water year) scales. In most cases, inputs refer to the water applied to the system, or applied water. This can occur through natural (precipitation, dew, capillary rise) or artificial (irrigation) means. In the broadest sense, applied water includes irrigation, dew, precipitation, and capillary rise from groundwater (Figure 11). Because capillary rise from groundwater is often difficult to quantify, most measures of efficiency include only irrigation and precipitation.

Figure 11. Plant root zone water balance



Source: Colorado State University, Resource Center

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 much of the applied water that is not consumed on a particular field is returned via surface runoff and groundwater percolation to be used consumptively elsewhere. In some cases, basin efficiency can exceed field efficiency. In these cases, conserving water does not necessarily increase the available water supply. This has led some to assert that the only “real” basin-wide water savings are reductions in consumptive uses since non-consumptive uses are, in theory, endlessly recycled (Howell 2001).

Water balances are needed in order to determine how water is currently used and where changes in management can produce water savings. “With water, we need a good accounting of water supplies, of changes in storage, and of water destinations to make intelligent decisions regarding proper management of the resource. There is no choice in the matter” (Burt 1999). A detailed water balance should identify irrigation water destinations and partition those into “beneficial” and "non-beneficial" uses (Burt et al. 1997). These data are not being collected, or are not being reported to the state. We, therefore, reject the notion that we should simply assume that agricultural water use is extremely efficient at the basin scale. In fact, many irrigation districts agree that there is significant potential for improving water conservation and efficiency. Rather, it suggests that we need to employ focused efforts at the basin or sub-basin level to understand how water is currently being used and the potential to improve that use.

There are also many compelling reasons to seek reductions in the total amount of applied water, including non-consumptive uses like excess deep percolation, surface runoff, and operational spills. From the farmer's perspective, reducing applied water can provide a number of important benefits, in particular, reducing the cost to purchase water and, if the farmer is using groundwater, reducing energy costs. Many farmers have also found that reducing applied water allows them to apply chemicals more effectively, thereby reducing total chemical use and associated costs. Furthermore, studies suggest that improving water management through irrigation scheduling and efficient irrigation technologies can improve crop quality and/or yield, thereby increasing farm revenue. Finally, reductions in applied water reduce the farmer's vulnerability to drought and other water scarcity concerns.

Conserving water also provides benefits beyond the farm boundaries, including water quality improvements, instream flow augmentation, and less need for capital-intensive infrastructure, as described in greater detail below.

- **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 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 are valuable for:

    - Removing fine sediments that smother fish and invertebrate eggs and larvae.
    - Maintaining suitable water temperatures, dissolved oxygen concentrations, and water chemistry.
    - Establishing stream morphology, including the formation and maintenance of river bars and riffle-pool sequences.
    - Preventing riparian vegetation from invading the channel and altering stream form and function.
    - Flushing waste products and pollutants.
    - Allowing and supporting 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 anadromous fish migration (Maunder and Hindley 2005).

- **Fish and Wildlife.** In addition to some of the indirect threats to wildlife described above, diversions from waterways can pose a direct threat to fish and wildlife populations. For example, water diversions, especially 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 kilowatt-hour (kWh) per acre-foot.[4] 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.[5]
- **Soil Salinity.** According to the United States Geological Survey (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). Irrigation water contains salts, and the application of this water increases soil salinity. Reducing the quantity of water applied to the field reduces salt accumulation, thereby reducing the risk of further loss of arable land. At times, farmers may wish to increase water use to leach salts from soils. Recent research has shown that traditional estimates of the leaching requirement often overestimate the volume of water needed, which can exacerbate soil salinity problems (Letey and Feng 2007, Corwin et al. 2007). A 2007 study in the Imperial Valley, California found that using updated models decreased the estimated leaching requirement significantly and reduced the drainage volume by 100,000 acre-feet per year (Corwin et al. 2007). Careful soil and water management are required to balance salt levels.
- **Capital-Intensive Infrastructure.** Building and siting new reservoirs is time-consuming, extremely expensive, and politically controversial. Water savings achieved through efficiency improvements should be evaluated alongside centralized water storage and infrastructure. These innovative efficiency improvements can be thought of as distributed infrastructure.

The multiple benefits associated with reducing overall applied water by reducing both consumptive and non-consumptive uses that are non-beneficial, strongly argue for a comprehensive approach that evaluates the potential for applied water reductions and creates policies to encourage water conservation and efficiency. Many farmers have already adopted water-saving practices for these multiple benefits.

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[4] Based on State Water Project energy requirements from CEC 2005. We estimate the upper range on the energy intensity at Wheeler Ridge.

[5] 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.

Profile of Craig McNamara, Sierra Orchards

An organic walnut farmer, Craig McNamara has owned and operated Sierra Orchards in Winters, California for 28 years. In 1993, he began working with local schools, creating the Center for Land-Based Learning on his property. The Center engages youth in learning experiences on the land that foster respect for the critical interplay of agriculture, nature, and society.

"As a farmer I think of myself first and foremost as a conservationist and environmentalist. Protecting our nation's land, water and air resources are my most important goals. As a farmer, it is incumbent upon me to be an example for the rest of society. Therefore, it is natural that I would want to create educational and demonstration projects on our land."

Sierra Orchards

Sierra Orchards employs a number of innovative water management practices including buried drip irrigation on all new plantings, tailwater recovery ponds, and sediment trapping ponds. Cover crops both fertilize the fields as well as retain winter moisture and runoff. They have also created over two miles of hedgerows and riparian habitat on their farm. In order to stabilize the creek banks and eliminate soil erosion, they have planted over ten acres of native upland oak forest. Efforts to restore the watershed have been greatly enhanced by partnerships with willing organizations – Audubon California, local Resource Conservation Districts, the Xerces Society, and the local Stream Keeper.

"Conservation has to be a critical part of what we're doing on the farm and as citizens of California."

While the cost for these improvements exceeds tens of thousands of dollars, Sierra Orchards was able to receive matching funds through federal Farm Bill conservation programs, including the Environmental Quality Incentives Program and the Conservation Security Program. These programs defray the costs of implementing critical on-farm water conservation practices. McNamara argues that these funding programs are essential, "As a taxpayer, I think it's the best thing my taxes can go to; it's the long term conservation of our food supply."

In addition, today McNamara's Center for Land-Based Learning reaches thousands of students, teaching them about on-farm conservation practices through hands-on activities.

"One of the greatest acknowledgements that we have received…came in the form of Conservation Security Program funding. This funding partially compensated us for the voluntary conservation efforts that we had undertaken on our farm over the past 20 years."

Water Conservation and Efficiency Scenarios

Now that we have defined terminology, we turn to the details of our assessment. To explore the water conservation and efficiency potential, we developed a set of scenarios to evaluate changes in agricultural water use given a set of decisions farmers make about irrigation method and management practices. Many in the agricultural community have already implemented these improvements but more can, and should, be done. We highlight the achievements of a selection of innovative farmers and irrigation districts (see Profiles throughout the report).

Figure 12. Map of California's 10 hydrologic regions

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 is 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 water withdrawals. For this analysis, we chose practices that numerous studies indicate reduce water use while improving yield and/or quality. These options are not new and, in fact, some farmers have already adopted them. These practices may not be applicable under all conditions, yet there is ample opportunity to further improve water-use efficiency in many regions. Here, we explore the expanded adoption of these practices. As a starting point, we use irrigated crop area from 2005 (DWR in review) and data on crop water use for the years 1998, 2000, and 2001 to construct baseline estimates of agricultural water use in California's ten hydrologic regions (Figure 12) during "wet," "average," and "dry" years, respectively.[6]

[6] The classification of wet, average, and dry years was made by DWR based on precipitation data. In 1998, California received 171% of the state's average precipitation; in 2000, it received 97% of average precipitation; and in 2001, it received 72% of average precipitation (DWR 2005a).

- **Baseline** – adopts DWR assumptions about crop water use for the years 1998, 2000, and 2001 and irrigated crop area based on the most recent surveys completed in 2005. These data are included in the 2005 California Water Plan Update (DWR 2005a) and the 2009 California Water Plan Update (DWR in review).

We then compare this baseline scenario to three alternative scenarios:

- **Efficient Irrigation Technology** – shifting a fraction of the crops irrigated using flood irrigation to sprinkler and drip systems;
- **Improved Irrigation Scheduling** – using local climate and soil information to help farmers more precisely irrigate to meet crop water needs; and
- **Regulated Deficit Irrigation** – applying less water to crops during drought-tolerant growth stages to save water and improve crop quality or yield.

Methods

The DWR routinely produces estimates of agricultural water use that are used in long-term planning efforts. In the last 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.[7] 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 and delivery and conveyance losses for all regions in California.

We used the DWR Analytica model to develop our baseline estimates of agricultural water use in "wet," "average," and "dry" water years. For the Efficient Irrigation Technology scenario, we developed irrigation efficiency estimates for each irrigation method (e.g., flood, sprinkler, and drip); we then reduced the acreage irrigated by flood and increased acreage irrigated by sprinkler and drip systems. Finally, we compared the resulting water use estimate, as modeled by Analytica, with the baseline water use. For the Improved Irrigation Scheduling scenario, we performed a literature review to determine a plausible percent savings for this management practice (greater detail on the percent savings is provided in each scenario description). We then applied this percentage to the modeled agricultural water use estimates for the Efficient Irrigation Technology scenario. Similarly, for the Regulated Deficit Irrigation scenario, we performed a literature review to determine a plausible percent savings for this management practice. We then applied this percentage to the modeled agricultural water use estimates for the Improved Irrigation Scheduling scenario. This approach captures the incremental savings of each scenario by taking into account the potential water savings already achieved by the previous scenario and thus avoids double-counting. We then compared the combined incremental water savings of all three technology and management scenarios to the baseline in order to estimate the potential water savings in wet, average, and dry years.

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

Reductions in water use will not result in a one-to-one reduction in withdrawals from surface and groundwater aquifers because of the reuse of return flows. Little data, however, are available to estimate many components of the water balance necessary to quantify the volume and type of water conserved, e.g., consumptive use and return flows. In this analysis, we quantitatively estimate changes in water withdrawals and provide qualitative estimates of changes in consumptive use where possible.

Results

Baseline Scenario

For the Baseline Scenario, we evaluated agricultural water demand under three water years: a "wet," "average," and "dry" year. Irrigated crop area for each crop type was based on data from the Department of Water Resources for the year 2005. Water requirements for each crop type were based on applied water estimates for the years 1998, 2000, and 2001, as they represent "wet," "average," and "dry" water years (DWR 2005a). Our baseline estimate of California's total applied agricultural water is 26.6 MAF in a wet year, 33.8 MAF in an average year, and 35.4 MAF in a dry year (Table 2).

Table 2. Results for the Baseline Scenario

	Agricultural Water Use (1,000 acre-feet)		
Hydrologic Region	**Wet Year**	**Average Year**	**Dry Year**
North Coast	601	772	719
San Francisco Bay	106	130	142
Central Coast	967	1,080	1,270
South Coast	584	790	680
Sacramento River	6,560	8,550	9,030
San Joaquin River	5,560	7,090	7,560
Tulare Lake	8,160	10,900	11,600
North Lahontan	367	479	543
South Lahontan	274	361	354
Colorado River	3,450	3,650	3,520
Total Agricultural Applied Water Use	**26,600**	**33,800**	**35,400**

Note: All values rounded to three significant figures. Numbers may not add due to rounding.

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.[8] Below we briefly describe each irrigation method and its advantages and disadvantages. See Cooley et al. (2008) for a more detailed description of each method.

Figure 13. Furrow irrigation

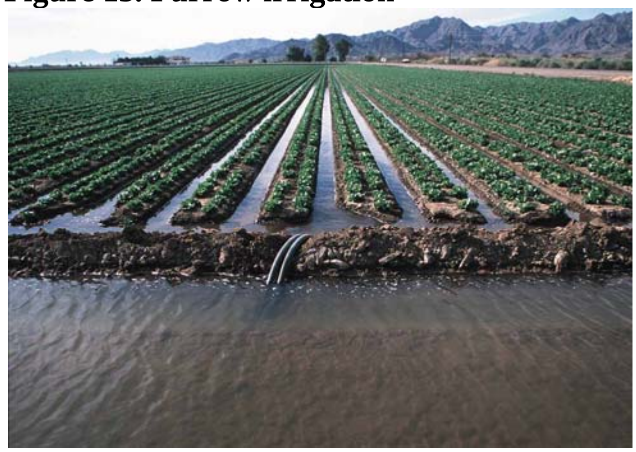


Photo courtesy of USDA NRCS

Flood Irrigation

Flood irrigation is the oldest form of irrigation. It is simply 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 with any crop that is not adversely affected by 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 13).

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 for conveyance and distribution requires that fields be well graded if possible 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. Flood irrigation is also susceptible to high unproductive evaporative losses.

Sprinkler Irrigation Systems

Sprinkler irrigation was introduced in the 1930s. With a sprinkler irrigation system, water is delivered to the field through a pressurized pipe system and is distributed by 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 irregular sized or shaped fields and can be moved between fields (Evans et al. 1998). Low-energy precision application (LEPA) 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. Like LEPA, low-elevation spray applications (LESA) are a variation of center pivots with a nozzle less than 2 feet above the soil surface (Figure 14). LEPA and LESA systems can conserve both water and energy by applying the water

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

at a low-pressure close to the ground, which reduces water loss from evaporation and wind, increases application uniformity, and decreases energy requirements.

Figure 14. Low-Elevation Spray Application Sprinkler

Photo courtesy of USDA NRCS

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

Sprinkler systems also have a number of disadvantages. Installing sprinkler systems requires 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 (I. Bisconer, 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 hindered under windy or extremely hot, dry conditions. In addition, sprinkler systems continuously or periodically wet crop foliage or fruits, which can damage some crops (Jensen and Shock 2001) directly or indirectly through the promotion of plant disease growth.

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 15). 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).

Figure 15. Lateral drip lines in a vineyard

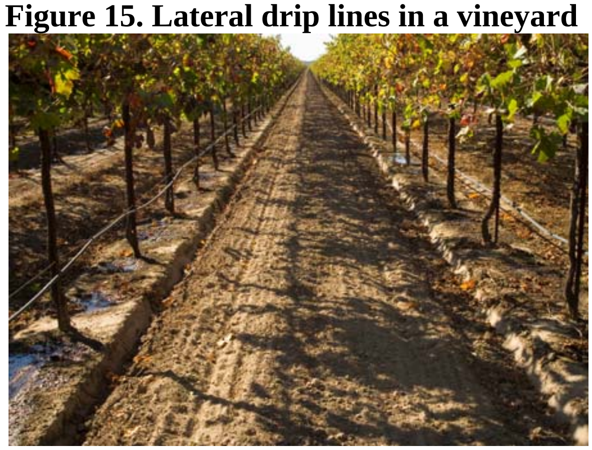


Photo courtesy of USDA NRCS

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 report by the Agricultural Water Management Council, a farmer from the Westlands Water District 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 2006). 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). Growers are becoming more concerned with water run-off, which contains salts, fertilizers, and pesticides, as regulators seek to improve impaired surface waters and address groundwater quality (Ludwig 2009). Drip can also reduce salinity problems; a recent study in the San Joaquin Valley found that "subsurface drip irrigation can be successfully used in commercial fields without increasing root-zone soil salinity, potentially eliminating the need for subsurface drainage-water disposal facilities" (Hanson et al. 2009). With drip systems, diseases are also less likely to develop because water does not come into contact with crop leaves, stems, or fruit (Shock 2006). Finally, drip systems can be used on oddly shaped or hilly terrain.

Table 3. Irrigation systems and associated efficiencies

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 evapotranspiration) divided by the volume of irrigation water applied minus change in storage of irrigation water.
Source: Salas et al. 2006

One of the major disadvantages to converting to drip is the initial investment, which is estimated at $500 to $2,000 per acre (I. Bisconer, Chair of the Drip/Micro Common Interest Group, Irrigation Association, personal communication, 8/6/08). These costs, however, can be offset by a reduction in operation costs and/or increase in crop revenue as a result of targeted, efficient irrigation applications. To achieve these benefits, drip and micro-irrigation systems require management to ensure system integrity, e.g., proper flow and pressure without leaks or clogging. In addition, sufficient water must be applied to leach salts. Typically, irrigation water must be filtered to avoid clogging of the emission devices, and a more reliable, flexible water source may be required than is normally available from water districts. Farmers may switch to using groundwater because of its consistency in quality and availability, which may further exacerbate groundwater overdraft. In addition, insects and rodents can be a problem, especially where the drip line is buried (Shock 2006).

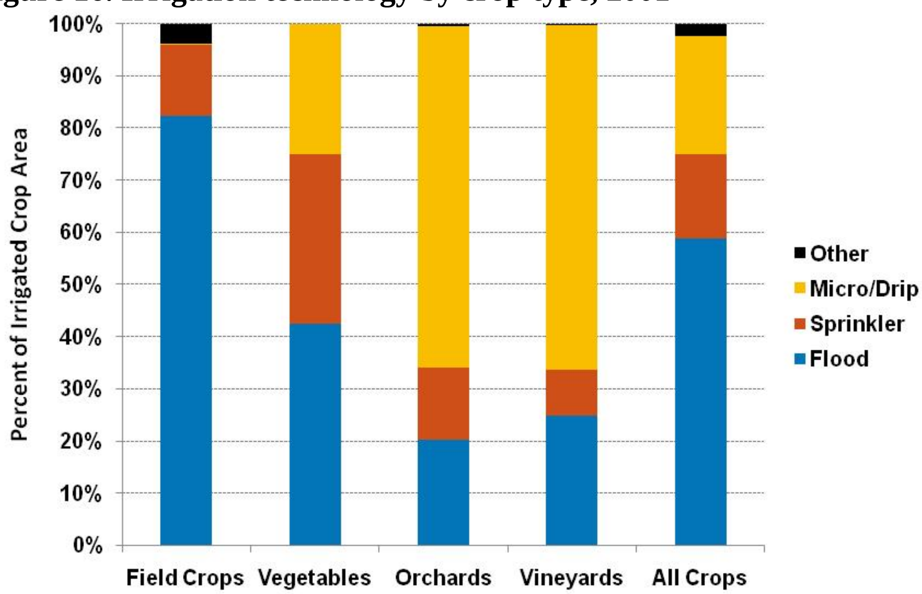
Comparison of Irrigation Technologies

With proper design, installation, operation and maintenance, drip and microirrigation systems 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, water application to non-targeted surface areas, and the propensity for deep percolation since the application rate is somewhat fixed. The potential irrigation efficiencies (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) 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 microirrigation systems are even higher, ranging from 88-90% (Table 3).

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.

The use of irrigation technologies in California varies substantially by crop type (Figure 16). Drip and sprinkler systems are common on orchards and vineyards, accounting for about 80% of the irrigated acreage for these crop types in 2001, though this still means that around 20% of orchards and vineyards are using flood systems. Flood systems are still employed on an even higher percentage of vegetable and field crops, with more than 40% of vegetable and 80% of field crops still using this method. We note that use of drip systems has very likely increased since this survey was conducted in 2001. Farmers, for example, are using drip on a growing number of row and field crops due to the production of drip tape and GPS-guided tractors. Unfortunately, more recent statewide data do not exist. We recommend that more frequent and more comprehensive surveys of irrigation method be conducted.

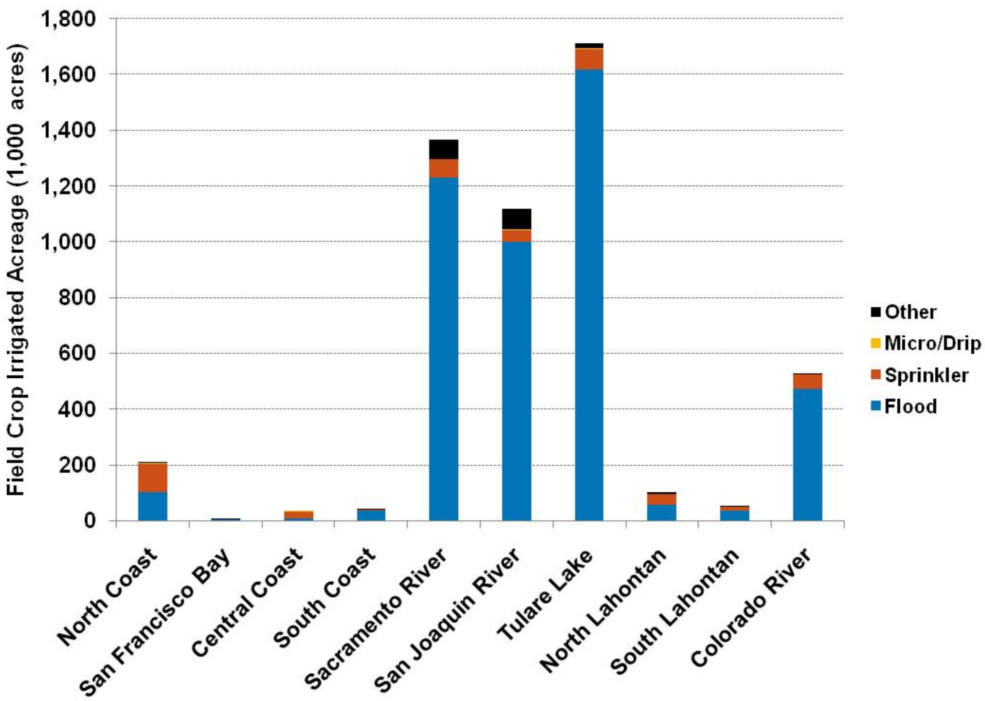
Figure 16. Irrigation technology by crop type, 2001



Note: These data are based on a survey conducted in 2001 and published in 2005. More recent statewide data are not yet available. “Other” includes subsurface irrigation where underground pipes or open ditches are blocked to force water into a crop root zone. Source: Based on data in Orang et al. 2005.

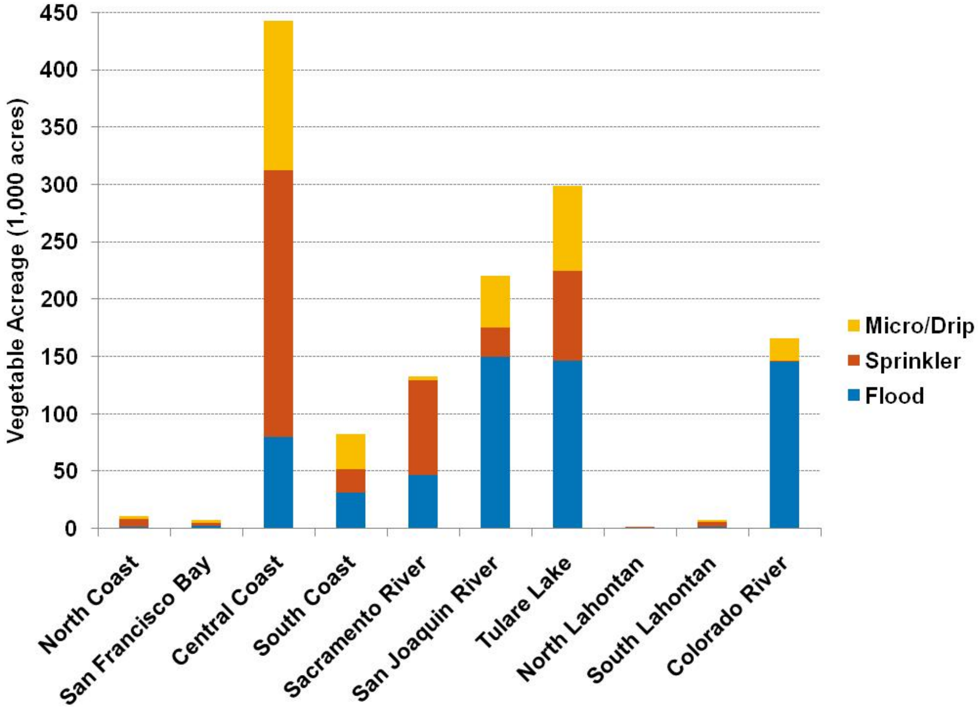
There are also important regional differences in the irrigation methods employed throughout California. Figures 17-20 show crop acreage by irrigation method for each hydrologic region in 2001. Separate figures are shown for field crops, vegetables, orchards, and vineyards. For all crop types, there is more acreage using flood irrigation in the San Joaquin and Tulare hydrologic regions than in any other region throughout the state. Nearly 300,000 acres of vineyards, for example, are still grown using flood irrigation in the San Joaquin and Tulare hydrologic regions. In comparison, less than 4,000 acres of vineyards in the rest of the state are grown using flood irrigation. Of all regions in the state, the Central and South Coast hydrologic regions have the least amount of acreage under flood irrigation. The Colorado River hydrologic region still has a significant amount of field and vegetable acreage under flood irrigation, but has largely converted what little orchard and vineyard acreage they have to drip irrigation.

Figure 17. Irrigated field crop acreage by irrigation method for each hydrologic region, 2001



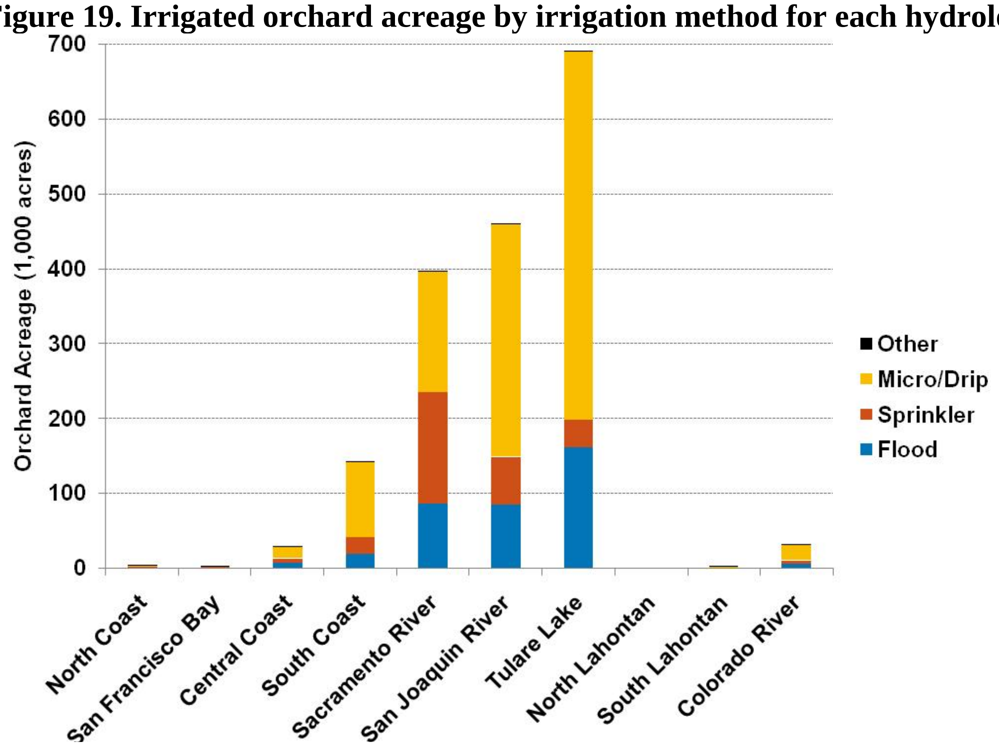
Note: “Other” includes subsurface irrigation where underground pipes or open ditches are blocked to force water into a crop root zone.
Source: Based on data in Orang et al. 2005.

Figure 18. Irrigated vegetable acreage by irrigation method for each hydrologic region, 2001



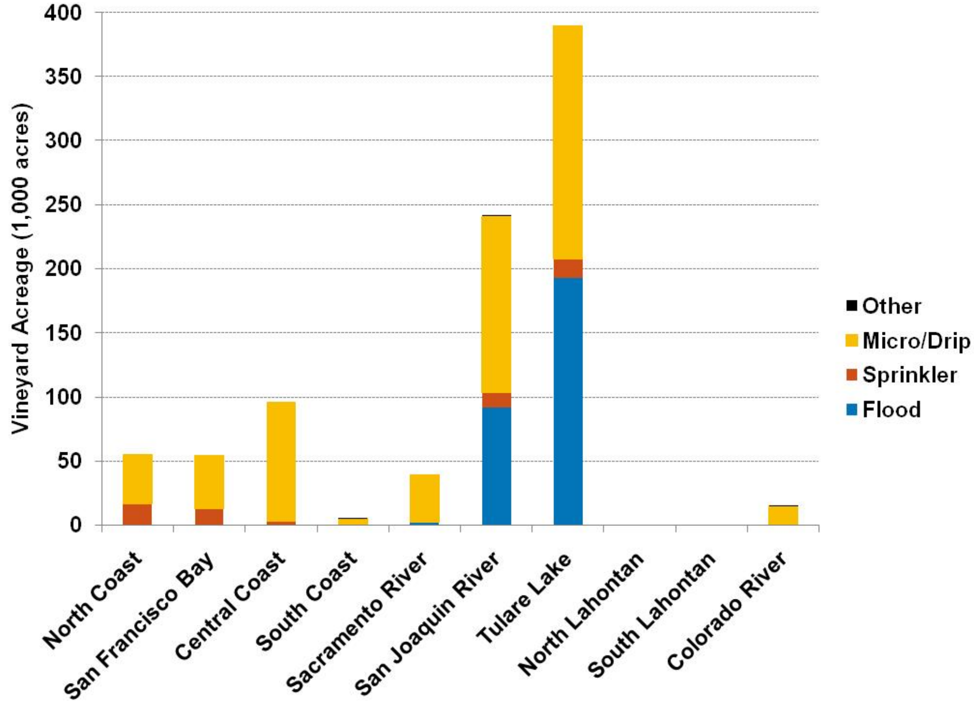
Note: "Other" includes subsurface irrigation where underground pipes or open ditches are blocked to force water into a crop root zone. Source: Based on data in Orang et al. 2005.

Figure 19. Irrigated orchard acreage by irrigation method for each hydrologic region, 2001



Note: "Other" includes subsurface irrigation where underground pipes or open ditches are blocked to force water into a crop root zone. Source: Based on data in Orang et al. 2005.

Figure 20. Irrigated vineyard acreage by irrigation method for each hydrologic region, 2001



Note: "Other" includes subsurface irrigation where underground pipes or open ditches are blocked to force water into a crop root zone. Source: Based on data in Orang et al. 2005.

For the Efficient Irrigation Technology scenario, we assume that 75% of the orchard, vegetable, and vineyard acreage are irrigated using micro-sprinklers and drip, and the remaining 25% is irrigated using sprinklers. Some hydrologic regions already exceed this level of efficiency. Nearly 97% of vineyards in the Central Coast hydrologic region, for example, are irrigated using drip. For these regions, we maintain the existing acreage in drip and convert any area irrigated with flood systems to sprinkler.

As shown in Figure 16, more than 80% of field crops in California are irrigated using flood systems. Sprinklers are used on the remaining acreage. Drip irrigation, however, is increasingly being used on some field crops. For example, Sundance Farms in Arizona has been growing cotton, wheat, and, recently, alfalfa with buried drip. According to the owners, drip has worked well on alfalfa, reducing water use by one-third and increasing yield one-third of a ton per acre per cutting, compared to flood irrigation (Blake 2009). In California, the application of drip irrigation on field crops has been limited. For the Efficient Irrigation Technology scenario, we conservatively assume no drip irrigation on field crops (though we believe that some growers will move in that direction by 2050), but that 50% of field crop acreage is irrigated using sprinklers and the remaining 50% is still irrigated with flood.

Installing sprinkler and drip systems can save a large amount of water, particularly during dry years. Under the Efficient Irrigation Technology scenario, nearly 3.4 million acres of land irrigated by flood was converted to drip (1.1 million acres) and sprinklers (2.2 million acres).[9,10]

[9] Numbers do not add up due to rounding.

This conversion reduces agricultural water use by about 3%, saving 0.9 MAF in a wet year, 1.1 MAF in an average year, and 1.2 MAF in a dry year (Table 4). This scenario assumes that farmers are able to apply water when needed. In reality, there are many irrigation systems that do not provide water on demand, e.g., a rotational irrigation system may provide water once every 16 days. In these situations, district-wide improvements or on-farm ponds would be needed for optimum efficiency. For additional discussion, see the section entitled "Overcoming Barriers to Improving Water Conservation and Efficiency."

Table 4. Results for the Efficient Irrigation Technology Scenario

	Agricultural Water Use (1,000 acre-feet)		
Hydrologic Region	**Wet Year**	**Average Year**	**Dry Year**
North Coast	597	768	714
San Francisco Bay	104	128	139
Central Coast	912	1,020	1,200
South Coast	568	769	662
Sacramento River	6,390	8,320	8,790
San Joaquin River	5,350	6,830	7,280
Tulare Lake	7,860	10,500	11,200
North Lahontan	364	475	539
South Lahontan	268	353	346
Colorado River	3,290	3,500	3,370
Total Agricultural Applied Water Use	**25,700**	**32,700**	**34,200**
Estimated Water Savings (%)	**919 (3.5%)**	**1,130 (3.4%)**	**1,200 (3.4%)**

Note: All values rounded to three significant figures. Numbers may not add due to rounding.

As described above, one of the major disadvantages of converting to drip or sprinklers is the initial investment. For the Efficient Irrigation Technology scenario, nearly 3.4 million acres of land irrigated by flood are converted to drip and sprinklers – a conservative and modest assumption given past trends. If we assume that the average cost of conversion averages $1,250 per acre (I. Bisconer, Chair of the Drip/Micro Common Interest Group, Irrigation Association, personal communication, August 6, 2008), then the initial on-farm investment needed to make this conversion is about $4.2 billion statewide. This estimate does not include the cost of district improvements that may be needed. Although significant, the overall benefits may well exceed this amount due to reductions in operation costs, increases in crop revenue, and the value of more reliable water availability. Additionally, saved water may be applied elsewhere to increase agricultural production, support urban development, or sustain the environment. Additional economic analysis is needed to explore these costs and benefits in greater detail.

[10] While drip irrigation is typically more efficient than sprinklers, a larger area was converted to sprinkler. We assume that field crops, which are the dominant crop type, are only irrigated with flood and sprinkler systems.

Improved 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 (Ortega-Farias et al. 2004, DWR 1997, Dokter 1996, Buchleiter et al. 1996, Rijks and Gbeckor-Kove 1990).[11] Despite the promise of technology-based irrigation scheduling, many California's farmers still primarily rely on visual inspection or personal experience to determine when to irrigate (USDA 2003) (see Table 5). Soil or plant moisture sensors, computer models, daily evapotranspiration (ET) reports, and scheduling services, which have long been proven effective, are still fairly uncommon, suggesting there is significant room for improvement. This conclusion is supported by the experience of individual growers who are increasingly linking their irrigation methods and schedules to real-time information on soil moisture and measured water needs.

Table 5. Method used by California farmers to decide when to irrigate, 2003

Method	California 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 percent.
Source: Table 36 in 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 major crop types for 55 growers across California who used CIMIS to determine water application. Their study concluded that some farmers were under-irrigating while others were over-irrigating their fields. Overall, they found that the use of CIMIS increased yields by 8% and reduced water use by 13% on average (DWR 1997). Again, we urge a new assessment of the use, and value, of CIMIS and related information services in reducing water needs or improving crop yields and quality.

These results are consistent with those reported in other studies. A Kansas study found that irrigation scheduling reduced water use by 20% while also reducing energy, fertilizer, and labor costs. The study found that the benefits of irrigation scheduling exceeded the costs, with a net return of nearly $13 per acre (in year 2007 dollars) (Buchleiter et al. 1996). A second study

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

evaluated AgriMet, a meteorological data collection system operated by the USBR in the Pacific Northwest region. A consulting firm in eastern Oregon that incorporates AgriMet weather data into local crop models found that users of the service reduced their water and energy use by about 15% (Dokter 1996). Kranz et al. (1992) found that irrigation scheduling reduced the applied water by 11% and energy use by 17% while improving yields by 3.5%. Likewise, a consulting firm in Washington using AgriMet to provide irrigation scheduling and soil moisture monitoring services to farmers found that some farmers reduced their water and energy use by as much as 50%, while others farmers were under-irrigating their fields. For those under-irrigating, irrigation scheduling increased both water use and yields (Dokter 1996).

Some farmers are already using irrigation scheduling through either direct access to the CIMIS website or via an irrigation consultant. Based on Eching (2002) and updated United States Department of Agriculture data (USDA 2007a), we assume that 15,000 farmers, or 20% of all California farmers, are already using CIMIS-based services. This scenario examines the potential water savings if all farmers used this technology. Based on the results of the CIMIS analysis, we assume that irrigation scheduling reduces water use by an average of 13 percent. We apply this percentage to total agricultural water use as determined by Efficient Irrigation Technology scenario, thereby taking into account savings already captured in the Efficient Irrigation Technology scenario. The results demonstrate substantial water savings of 2.7 MAF in a wet year, 3.4 MAF in an average year, and 3.6 MAF in a dry year (Table 6). These are the savings from applying irrigation scheduling to those farmers who are not currently using this management practice.

Table 6. Results for Improved Irrigation Scheduling Scenario

	Agricultural Water Use (1,000 acre-feet)		
Hydrologic Region	**Wet Year**	**Average Year**	**Dry Year**
North Coast	535	688	640
San Francisco Bay	93.5	114	125
Central Coast	817	913	1,080
South Coast	509	689	593
Sacramento River	5,720	7,450	7,870
San Joaquin River	4,800	6,120	6,520
Tulare Lake	7,040	9,430	10,000
North Lahontan	326	426	483
South Lahontan	240	316	310
Colorado River	2,950	3,130	3020
Total Agricultural Applied Water Use	**23,000**	**29,300**	**30,700**
Estimated Water Savings (%)	**2,670 (10%)**	**3,400 (10%)**	**3,560 (10%)**

Note: All values rounded to three significant figures. Numbers may not add due to rounding.

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 but work on an inflexible rotational schedule that 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 (FAO), “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 is available from state or federal agencies. The Department of Water Resources, for example, administers loans and grants from various sources, including Propositions 13, 50, and 84, to agricultural water suppliers. These funds are not available to individual farmers. District improvements can also be distributed among all farmers within the area.

The costs for improving irrigation scheduling vary depending on the equipment and amount of automation. A study examining irrigation scheduling on corn coordinated by local Cooperative Extension agents found that costs associated with irrigation scheduling, e.g., irrigation scheduling supplies, labor, and the cost for pumping plant adjustment, totaled around $15 per acre (Kranz et al. 1992). PureSense, and other private irrigation consultants, use probes, sensors, weather instruments and meters, to determine the soil moisture profile and water uptake. This information is collected by satellites, sent to a server, and processed by software that evaluates the amount of water needed. Based on this data, an irrigation schedule designed precisely to match crop water needs is sent directly to the farmer. Costs for these types of services average $20-30 per acre annually (Williamson, PureSense representative, pers.comm. 7/20/08).

Regulated Deficit Irrigation 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 evapotranspiration (ET) requirements throughout the season. However, water scarcity and interest in maximizing crop quality have catalyzed a number of innovative approaches to irrigation management that have been shown to reduce crop water use, including deficit irrigation, tail water recovery, and soil management practices that increase soil moisture retention (Polaris Institute 2008).

Here, we focus on 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. In fact, in some cases, it may improve crop quality. “Deficit irrigation,” defined as the application of water below full crop ET requirements, can be an effective tool to reduce applied water and increase revenue (Chaves et al. 2007, Fereres and Soriano 2006). A recent FAO report presents a number of deficit irrigation studies focused on various crops in semi-arid climates around the world, concluding that substantial water savings can be achieved with little impact on crop yield and quality (Goodwin and Boland 2002). Burt et al. (2003), however, argues that significant crop stress over multiple years can have a negative impact on yield.

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). Because response to water stress can vary considerably by crop, a clear understanding of crop behavior and ecological conditions is required to maintain yields. 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). A summary of benefits associated with regulated deficit irrigation is provided below (Table 7).

Water savings associated with RDI depends on many factors, including the crop type and the sensitivity of growth stages to stress, climatic demand, stored available water at bud break, spring-summer rains, and the particular irrigation method.[12] Cooperative extension specialists have hosted a variety of workshops throughout the state to discuss how to best apply RDI to different crops using local climate data and field-specific information (Bryant 2009, Cline 2009). Thus far, RDI has been more successful with tree crops and vines than with field crops for two reasons (Fereres and Soriano 2006): (1) crop quality, rather than total yield, is an important determinant of economic returns for these crops, and (2) the yield-determining processes in many trees and vines are not as sensitive to water stress during particular growth stages as many field crops. In the 2005 California Water Plan (DWR 2005a), Goldhamer and Fereres (2005) estimate that applying RDI techniques to tree crops and wine grapes in California would provide annual water savings of 1.0 to 1.5 million acre-feet. RDI may also provide benefits for vegetable crops, such as tomatoes, due to an increase in solids, although we do not include this in our scenarios.

Table 7. Benefits associated with regulated deficit irrigation for different crop types

Crop Type	Quality Benefit Associated with Regulated Deficit Irrigation (RDI)
Tomatoes	Increase solids
Almonds	Reduce hull splitting
Stone fruits (peaches, plums, apricots, etc.)	Increases shelf life
Pistachios	Increase shell split
Grapes	Improved quality

Source: Chris Higgins, Netafim USA (California Irrigation Institute annual conference, January 2009, Sacramento, CA).

Based on a literature review and discussion with agricultural experts, we estimate that RDI can reduce water use by 20% for almonds and pistachios, and as much as 47% for vineyards (Table 8). [13] We applied this approach only to wine grapes and raisins as both have been shown to respond positively to RDI (see Prichard 1997, 2000, 2007 and Christensen 2000). We did not apply RDI to table grape acreage. RDI may be appropriate for other deciduous trees, including walnuts, oranges, peaches, plums, apricots, and olives. While RDI may be an effective strategy for these crops, and some vegetable crops, further study is needed and thus we conservatively do not include them in our analysis (Marsal et al. 2008).

[12] Water savings are described in comparison to a control that received full irrigation to meet ET requirements (estimated by the Penman-Monteith method).
[13] The acreage of wine grapes, table grapes, and raisins grown in each region was determined using the 2005 California Grape Acreage Report produced by the California Agricultural Statistics Service. We used grape acreage report data from the same year as the DWR irrigated crop area data used in the model to ensure consistency.

Table 8. Studies on regulated deficit irrigation in the Central Valley, California[14]

Study	Location and 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%	
Prichard 2007	Sacramento Valley 2007	Wine grapes (Syrah)	-49%	-35%
Prichard 2007	Sacramento Valley 2007	Wine grapes (Syrah)	-65%[(b)]	-49%
Prichard 2000	San Joaquin Valley 2000	Wine grapes (Zinfandel)	-38%	-1%
Prichard 2000	San Joaquin Valley 2000	Wine grapes (Zinfandel)	-53%	-20%
Prichard 1997	San Joaquin Valley 1993-1996	Wine grapes (Cabernet sauvignon)	- >30%[(c)]	-19%
Average water savings for wine grapes			-47%	

Note: Almond yield figures are based on dry kernel weight, measured by weight per unit area. Wine grape yield figures are based on fresh grape yield, measured by pounds per vine. 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 "We have observed no negative effects of irrigating at 50% evapotranspiration during the shell hardening stage or post-harvest" (Goldhamer and Beede 2004).
(b): Although there is a significant decrease in yield associated with this reduction in applied water, the wines produced with these grapes were preferred by a panel of experienced wine tasters (Prichard 2007).
(c): This study did not directly measure the reduction in applied water. They applied 70% RDI, or attempted to reduce wine grape water consumption by 30% over the season (monitored by a soil neutron probe). Thus, the reduction of applied water is likely greater than 30% as consumed water does not take into account losses due to evaporation, conveyance, delivery, or distribution by the irrigation system.

[14] 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.

This scenario assumes that no orchards and vineyards are currently grown with these methods. As noted by Burt et al. (2003), there is little information about how many farmers are already practicing RDI, on what acreage or crops, and to what extent. A recent Mendocino County Cooperative Extension survey found that while the vast majority of wine grape growers already practice some degree of 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 and surveys of irrigation practices to demonstrate current levels of efficiency and inform statewide estimates of water use and potential additional water savings.

The Regulated Deficit Irrigation Scenario applies the average savings for vineyards, almonds, and pistachios (shown in Table 7) to the Improved Irrigation Scheduling Scenario, resulting in an estimated water savings ranging from 0.9 MAF in a wet year to 1.2 MAF in a dry year (Table 9). Thus the savings shown in Table 9 take into account the savings captured in the Efficient Irrigation Technology and Improved Irrigation Scheduling Scenario.

Table 9. Results for the Regulated Deficit Irrigation Scenario

	Agricultural Water Use (1,000 acre-feet)		
Hydrologic Region	**Wet Year**	**Average Year**	**Dry Year**
North Coast	519	672	623
San Francisco Bay	71.0	91	99.7
Central Coast	778	874	1,030
South Coast	507	687	591
Sacramento River	5,640	7,340	7,750
San Joaquin River	4,510	5,780	6,160
Tulare Lake	6,590	8,880	9,460
North Lahontan	326	426	482.9
South Lahontan	239	315	309
Colorado River	2,920	3,110	2,990
Total Agricultural Applied Water Use	**22,100**	**28,200**	**29,500**
Estimated Water Savings (%)	**932 (4.0%)**	**1,110 (3.8%)**	**1,190 (3.9%)**

Note: All values rounded to three significant figures. Numbers may not add due to rounding.

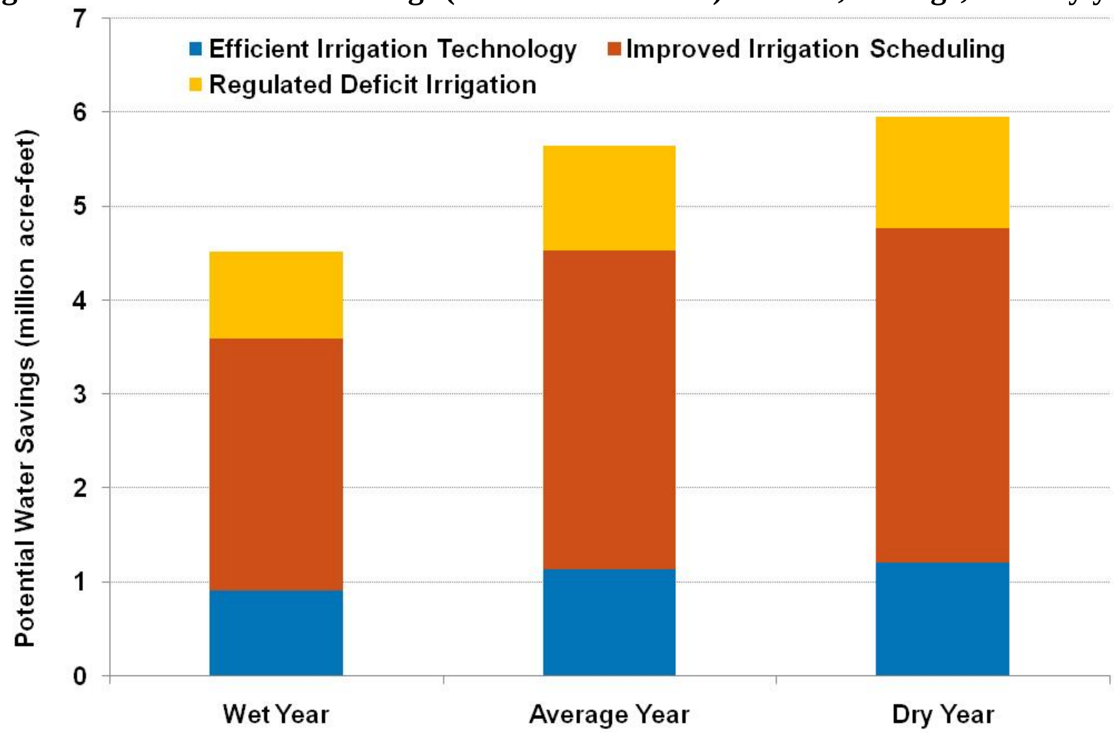
RDI remains an important and feasible efficiency measure that requires no change in the types of crops grown. However, it requires additional infrastructure and/or labor to monitor plant stress using pressure chambers or other plant-based sensors, or by remotely measuring canopy temperature or chemical constituency. Like irrigation scheduling, RDI requires an understanding of crop water needs based on local conditions and crop type. Thus, the costs for implementing RDI are similar to those described above for irrigation scheduling, estimated at about $15-$30 per acre.

Summary of Results

As shown in Extension Service research, academic studies, and the on-the-ground experience of innovative California farmers, many options are available for improving the efficiency of water use in California agriculture. The three scenarios we evaluated here all show the potential for significant water savings based on actual experience. For this analysis, we chose practices where the evidence clearly shows the potential to reduce water use while improving yield and/or quality. These options are not new and, in fact, some farmers have already adopted them. These practices may not be applicable under all conditions, yet there is ample opportunity to further improve water-use efficiency in every region.

The three scenarios we evaluated here all conservatively show the potential for significant water savings. The combined potential savings from the technology and management scenarios are between 4.5 MAF in a wet year and 6.0 MAF in a dry year (Figure 21). In total, these scenarios would reduce agricultural water use by 17 percent. Water savings were substantial for all scenarios but were greatest in the Improved Irrigation Scheduling scenario.

Figure 21. Potential water savings (in million acre-feet) in a wet, average, and dry year



Our results also indicate that water conservation and efficiency improvements are particularly effective in dry years, when agricultural water demand is greater and conflict over scarce water resources is more severe and costly. By investing in "drought-proof" strategies, California farmers can reduce their vulnerability to the kinds of water-supply constraints experienced in the past three years due to drought. Because climate change is expected to increase the frequency and intensity of droughts, these measures can also help California farmers improve their resilience to a changing climate. We must learn from the example of the Murray-Darling basin in Australia, which concentrated primarily on building bigger storage for rains that, in the end, never came. This resulted in the widespread collapse and eventual restructuring of agriculture in the region. Water conservation and efficiency are increasingly important tools that can help California adapt to a drier future and continue to be a world leader in agricultural production.

Overcoming Barriers to Improving Water Conservation and

Efficiency

In some cases, the incentives for water conservation seem clear – lower input costs and increased production value. Yet there are also important 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, extension specialists, water suppliers, and academics. We provide specific recommendations for overcoming information, financial, legal, institutional, and educational barriers.

Data Accuracy and Availability

Challenge

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 region. Different institutions and groups track, record, and report water use in different ways, and no single accepted historical record exists. Further complicating good water policy, many water uses are not measured; thus, reported water use is a combination of measured uses and estimates of uses that are only approximated or modeled.

The Pacific Institute and others, including State agencies, have long lamented these data problems, and we do so again in this study. We have tracked different agricultural water use estimates over the past decade, and we conclude, to our dismay, that no single estimate is either accurate or appropriate. In 2003, an Independent Panel convened by the California Bay-Delta Authority issued a report that described how agricultural water use estimates are currently developed and recommended ways to achieve more "appropriate" measurement of these uses. The definition of "appropriate" was developed based on the consensus of the six panelists along with stakeholder and agency representatives, and sought to balance the costs and benefits of different measurement methods.

Table 10 summarizes the Independent Panel's descriptions of various measurement methods and their costs for surface water diversions, farm-gate deliveries, crop water consumption, and groundwater use. For each, the Panel describes three measurement levels (basic, high, and highest technically practical) and the baseline of existing measurement devices, infrastructure, and capabilities. The Panel then estimates the incremental cost of achieving the next highest measurement level, i.e., moving from the basic to high measurement levels. For example, crop water consumption estimates throughout California are currently developed according to a basic measurement level: a rolling inventory of crop acreage, CIMIS data, and existing crop coefficients. The data quality could be improved by using remotely sensed imagery collected monthly with 30-meter resolution during the growing season (see Box 1). The annual incremental cost of upgrading measurement of crop water consumption would be less than $1 million for the entire state. For all components of the water system, the Panel recommends improving measurement from the basic to the high measurement levels or, in the case of surface water diversion, the highest technically practical.

The information in Table 10 is essential for prioritizing data collection and management activities. In many cases, it is clear that improvements are needed in data collection, particularly for crop consumption and groundwater use. In some cases, however, simply compiling, standardizing, and reporting the data is all that is needed. For example, 90% of farm-gate deliveries are measured at the high or highest technically practical level, although this information is not aggregated or reported to the state. While recent legislation requires agricultural water suppliers to report annual aggregated farm-gate delivery data to the DWR by 2012, implementation of other elements of this legislation are already behind schedule. The Panel also evaluated return flows, water quality, and in-stream flows, but concluded that insufficient data were available to develop specific recommendations. Given the importance of this information for appropriate measurement and management, the Panel recommends that the State undertake a comprehensive review of the measurement needs for developing specific recommendations for return flows, water quality, and in-stream flows.

In the long run, more and better data on agricultural water use must be collected. In a state with such contentious and difficult water challenges as California, the failure to accurately account for 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.

Opportunity
Recent legislation put some of the Independent Panel's recommendations into action but should be applied to all components of the water system identified by the Independent Panel. In 2007, Governor Schwarzenegger signed AB 1404 (Laird), which requires the DWR, State Water Resources Control Board (State Board), and the State Department of Public Health to study the development of a coordinated database for the urban and agricultural water measurement information that is provided to each agency. The law also requires agricultural water suppliers that supply 2,000 acre-feet or more of surface water annually for agricultural purposes or serve 2,000 or more acres of agricultural land to report aggregated farm-gate delivery data to the DWR. Failure to comply would make the water supplier ineligible for certain grants or loans. While this legislation is a step in the right direction, it must be fully implemented in a timely manner. A number of other actions are also needed. Specifically, we should:

- Implement California Assembly Bill 1404 in a timely manner, which would ensure coordinated water use measurement and reporting.
- Use satellite and other technology to improve data collection and analysis, particularly for annual assessments of crop area and evapotranspiration.
- Ensure that the Landsat-7 follow-on mission is equipped with a thermal band to allow for the continued use of satellite imagery for data collection and analysis.
- Design and implement comprehensive local groundwater monitoring and management programs statewide.
- Require the state to evaluate the measurement needs for accurately monitoring return flows.
- Implement a statewide system of data monitoring and data exchange, especially for water use and quality, available to all users.

Table 10. Independent Panel on Water Measurement's analysis of measurement procedures and their associated costs

Measurement	Measurement level	Measurement Procedure Description	Baseline Condition	Annual Incremental Cost ($/acre)
Surface water diversions	Basic	• Estimate flow rates for water delivery structures once per year. • Track delivery duration and use flow estimates to calculate volume delivered.	3%	
	High	• Inventory and rate structures. • Measure flow rates, on average, three times daily per structure use.	13%	< $250,000 (<$0.03)
	Highest Technically Practical	• Inventory and rate structures. • Install flow totaling devices, data loggers, and telemetry where needed.	84%	<$550,000 (<$0.07)
Groundwater use	Basic	• Closure factor after estimating crop water consumption, surface water deliveries, and surface return flows.	72%*	
	High	• Continuous regional characterization of groundwater volume using two methods: detailed sub-basin level hydrologic balance and water table method.		$2-$2.5 million ($0.25-$0.31)
	Highest Technically Practical	• Totalizing flow meters or pump testing coupled with an estimate of the surface runoff or deep percolation of the pumped water.	28%	$20-$25 million ($2.50-$3.10)
Crop water consumption	Basic	• Based on a rolling (every 5 years) inventory of crop acreage, CIMIS, and existing crop coefficients.	100%	
	High	• Remote sensing (Landsat 7) based on a 32-day time step with 30 m resolution during the growing season.	0%	< $1 million (<$0.13)
	Highest Technically Practical	• Remote sensing (Landsat 7) based on a 16-day time step with 30 m resolution during the growing season.	0%	<1.5 million (<$0.19)
Farm-gate deliveries	Basic	• Estimate flow rates for water delivery structures once per year. • Track delivery duration and use flow estimates to calculate volume delivered.	11%	
	High	• Inventory and rate structures. • Measure flow rates, on average, three times daily per structure use.	57%	$25-$30 million ($3.10-$3.80)
	Highest Technically Practical	• Inventory and rate structures. • Install flow totaling devices, data loggers, and telemetry where needed.	32%	$175-$200 million ($22 - $25)

*All wells included in this count are unmetered. The definition of basic and high groundwater relies on regional assessments and assumes no change in measurement at the well.

Note: Cost estimates include capital costs of measurement structures and measurement and data logging equipment annualized over their average useful lives, annual operation and maintenance costs, and annual data management costs.

Source: California Bay-Delta Authority 2003

Box 1: Using Remote Sensing to Measure Crop Water Consumption

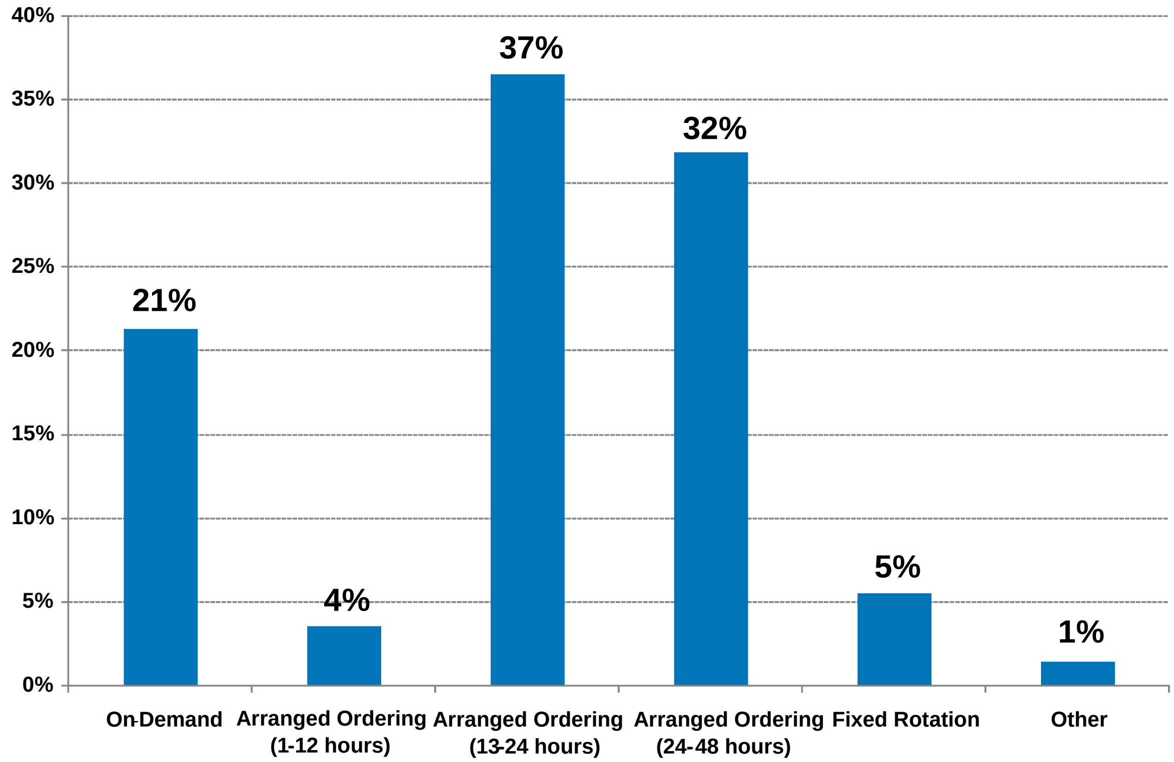
In the last decade remote sensing technology has emerged as a new method to better measure crop water requirements. Field studies indicate that remotely sensed data can be used to provide accurate water consumption estimates and reduce data collection costs. A 2005 study found that the Surface Energy Balance Algorithm for Land (SEBAL), which uses satellite imagery from Landsat 5 and 7 to record thermal infrared, visible, and near-infrared radiation for evapotranspiration measurements, has a typical daily accuracy at the field scale of 85%, and of 95% over an entire growing season (Bastiaanssen et al. 2005). A 2003 study in the Snake River Plain Area in southern Idaho compared SEBAL estimates for water consumption with measurements from highly-accurate precision weighing lysimeters. Despite some error in daily estimates, the difference between the two methods over the growing season was less than 1%, and thus SEBAL demonstrated considerable improvements over standard wide-scale measurement methods (Trezza and Allen 2003). Furthermore, the National Aeronautics and Space Administration reports that traditional monitoring costs in the eastern Snake River Plain region in Idaho are typically $500,000 annually and that using Landsat data would cut costs to $80,000, an 84% reduction (Rocchio 2007). Currently, DWR is using this technique in cooperation with the USBR in the Lower Colorado for Imperial, Palo Verde, and Coachella Valley to get annual estimates of crop acreage and location. They are also working with the USBR to develop a system to be used in the Central Valley. This is an important step toward more frequent, accurate, and consistent data than current crop water measurements.

Water Delivery Systems

Challenge
In California, water is predominantly delivered through gravity-fed canals designed and constructed in the early and middle of the 20th century (AWMC 2008). Nearly 80% of these water systems fail to provide water to farmers on demand (Figure 22). Rather, water is primarily available on an arranged ordering system. Water deliveries for nearly half of those areas subject to an arranged ordering system must place orders 24 to 48 hours in advance, thereby limiting the irrigator's ability to respond to changing weather conditions. About 5% of those surveyed were delivered water based on a fixed rotation and therefore must make water orders up to two weeks in advance of watering (see Box 2 for a description of various water delivery systems).

It should be noted that this survey, conducted by the Agricultural Water Management Council (AWMC), includes agricultural water districts that, while representing a third of California's irrigated acreage, may not be representative of conditions throughout California because those surveyed have voluntarily implemented Efficient Water Management Practices defined by the AWMC. We conclude that distribution system improvements are needed in tandem with on-farm improvements to foster more efficient use of available water resources. To that end, we provide recommendations to enhance the flexibility and accuracy of irrigation water delivery systems in California.

Figure 22. California's water delivery systems



Note: Survey based on members of the Agricultural Water Management Council, representing about one-third of the irrigated acreage in California.
Source: AWMC 2008

Opportunity
It has long been known that flexibility of delivery is a precondition for efficient irrigation scheduling (Goussard 1996, Burt 1996). Thus, the relatively inflexible delivery systems that still characterize many California irrigation districts inhibit effective and efficient water resource management. Flexibility can be enhanced through infrastructure improvements like automation of control structures and regulating reservoirs. Automation of canal and conveyance systems allows the water district to operate control structures in real-time which then “gives farmers more flexibility in when they can receive water” (AWMC 2008). Regulating reservoirs can store excess water from operational spills or from water that was ordered but no longer needed. This water is then available for re-use later.

A recent article in *Water Efficiency* magazine describes an irrigation canal modernization and automation project in the Central California Irrigation District (CCID) service area (Richardson 2008). CCID operates 250 miles of gravity-fed canals and delivers water to 600 customers in Fresno County using a manually-controlled system. Because of its length, the system was characterized by operational spills as well as imprecise water deliveries. As a result, farmers “had a tendency to order water in excess of their actual needs in order to compensate for this level of uncertainty” (Richardson 2008). To improve system performance, project consultants Charles Burt and colleagues from the Irrigation Training and Research Center installed automated canals and weirs as well as a regulatory reservoir at the middle of the system. The regulatory reservoir, which was capable of storing a day’s supply, captured water that was not needed by the farmer, providing the flexibility and reliability needed to manage the water more efficiently. See the following profile of the Panoche Water District for specific examples of irrigation district improvements.

These improvements typically require significant capital investment. Because these improvements can be costly, action is needed to facilitate district water conservation and efficiency improvements.

- State and federal governments should expand efforts to finance district-wide improvements that provide water to farmers when needed, such as lining and automating canals and distribution systems.
- Irrigation districts should implement new water rate structures that encourage efficient use of water. Additional revenue generated from heavy water users can be used to finance district-wide improvements.

Box 2: Irrigation Water Delivery Systems

Most irrigated areas throughout the world are partly or fully supplied from collective delivery systems (Goussard 1996). These systems provide benefits but can also limit the farmer's ability to efficiently manage water resources. Below, we evaluate the three primary methods of delivering water to farmers in California – rotational, arranged ordering, and on-demand – and describe how these systems can present challenges to effective water management.

Fixed Rotation

Rotational deliveries are rigid delivery systems where water is delivered in fixed amounts at fixed intervals (Burt et al. 2000). With fixed rotational deliveries, water is delivered according to a schedule, e.g., once every two weeks, whereby an irrigator must take the whole supply of water available. These systems provide the least flexibility to the farmer, who is not able to schedule irrigations based on crop water demand or changing weather conditions but must apply water when it is delivered.

Arranged ordering

With arranged ordering, the irrigator requests water for a particular date and time. Water is then delivered to the irrigation system within 1 to 48 hours from the time that the order is received, depending on system capacity. Arranged ordering is less rigid than rotational deliveries, although it does not allow the irrigator to adjust deliveries based on short-term changes in weather conditions or soil moisture.

On-demand

With on-demand delivery, irrigators can more precisely schedule irrigations and alter the amount of water applied based on changing conditions. On-demand delivery is the most flexible water delivery system, allowing the irrigator to control the frequency, rate, and duration of irrigation. Because it is user-controlled, it requires little communication between the user and supplier (Burt et al. 2000).

Profile of Panoche Water District and Drainage District

Panoche Water District serves about 38,000 acres and Panoche Drainage District serves approximately 44,000 acres, overlapping Panoche Water District and other nearby lands in and around Firebaugh. Typical crops include almonds, tomatoes, cotton, wheat, asparagus, pistachios and alfalfa.

Conservation Improvements

The District receives water from the Central Valley Project via the Delta Mendota Canal and the San Luis Canal. It is continually making improvements to reduce water losses and increase water delivery reliability and flexibility, improve drainage water management, and implement policies that promote efficient water use. Some of these include: lining irrigation laterals; installing new turnouts on the San Luis Canal to increase water delivery flexibility and reduce energy use; creating a tiered water pricing schedule where the price per-acre foot of water increases substantially as more water is used; establishing a no-tailwater discharge policy for all growers within the District; and providing loans to help growers improve on-farm irrigation systems.

"Approximately 70% of the District has been converted to high efficiency irrigation systems, mostly sub-surface drip and micro-sprinklers. The Water District facilitates low interest loan and grant funding for installation of these systems to increase the conversion rate."
-Marcos Hedrick, District Water Master

According to District Water Master, Marcos Hedrick, "The improved water conveyance systems increase the District's responsiveness to growers' water demands allowing water to be regulated and applied in relation to crop need. These projects have also reduced the volume of subsurface drainage water which must be managed at considerable cost." In addition, the San Joaquin River Improvement Project has greatly reduced subsurface drain water discharges to the San Joaquin River. The project includes 6,000 acres of farmland, of which about 4,300 acres are planted with salt-tolerant crops and irrigated with subsurface drainage water. The salt-tolerant crops uptake and filter the water, the crops are then sold and the profits are re-invested in the project.

"The tiered water pricing program was implemented to encourage water use efficiency, particularly during the pre-irrigation season."
-Marcos Hedrick

The major challenge faced in implementing these programs has been funding. Portions of most of these programs were funded with assistance from the USBR and California Propositions. Hedrick predicts that future implementation and expansion of these programs will continue to be hindered by funding limitations.

Economic Considerations

Challenge

Capital Investment Can be High

While agriculture has social and cultural importance, it is also an economic endeavor and farmers must make choices about investments based on expected costs and returns. Improvements in the measurement of water use and in the delivery of agricultural water can be costly. Conversion to drip irrigation, for example, is estimated to cost between $500 and $2,000 per acre (I. Bisconer, Chair of the Drip/Micro Common Interest Group, Irrigation Association, personal communication, August 6, 2008). In addition to these necessary, first-step improvements, installing new irrigation water delivery systems and changing on-farm management practices can be expensive.

Initial investments in efficiency improvements can be offset by a reduction in operation costs and/or increase in crop revenue. For instance, interviews with practitioners, farmers, and academics indicate that efficient drip irrigation on market tomatoes can increase yields by 20% to 30%, while carrot yields increased by more than 30% in the Imperial Irrigation District (Yolles, Sustainable Conservation, pers.comm. 7/16/09). In addition, growers using the PureSense irrigation management system report yield increases of 20% or more (Gates, PureSense, pers.comm., 7/16/09). Using the "Drip-Micro Irrigation Payback Wizard,"[15] we compared the costs and benefits associated with converting from flood to drip/micro for cotton and almonds in Central California. The Payback Wizard was developed by the Irrigation Association's Drip Micro Common Interest Group and allows farmers to input region, crop type, acreage, and water price to determine the payback period for converting from flood to drip or microirrigation. For example, if the cost of water is $46 per acre-foot (the average cost of water from the SWP in the San Joaquin Valley (DWR 2005b)), the program estimates that the payback period for converting cotton and almonds is 1.9 years and 0.6 years, respectively (Cooley et al. 2008). While these results are site specific, they suggest that investments in water conservation and efficiency can be highly cost effective.

Opportunity

Innovative Funding Mechanisms

Capital costs can be defrayed by a variety of innovative funding mechanisms, including rebates, tax exemptions, and increased funding of existing conservation programs within the federal Farm Bill. Many urban water suppliers offer rebate programs to customers who install water-saving appliances, e.g. front-loading washing machines and low-flow faucet devices. Similarly, agricultural water suppliers could offer rebates to customers who install more efficient irrigation systems or can prove a reduction in water use.

At a federal level, the Environmental Quality Incentives Program (EQIP) provides cost-shares to agricultural producers who make water conservation and efficiency improvements. This program is the only one 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, EQIP funds are fully allocated only days after they become available. Therefore, many

[15] See http://www.dripmicrowizard.com/

promising projects are turned away. The 2008 Farm Bill authorizes EQIP funding at $1.2 billion in 2008, rising to $1.8 billion by 2012, however this only accounts for less than 1% of the overall Farm Bill budget ($618.5 billion). Funding should be increased substantially for this program and more emphasis should be placed on water conservation and efficiency projects.

- Federal funding for conservation programs, especially the Environmental Quality Incentives Program, should be increased.
- State and county governments should provide property tax exemptions for farmers that upgrade to more water-efficient irrigation systems. Exemptions could apply to the value added to a property by the irrigation system and would be valid for 5-10 years.
- The State should 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.

Challenge

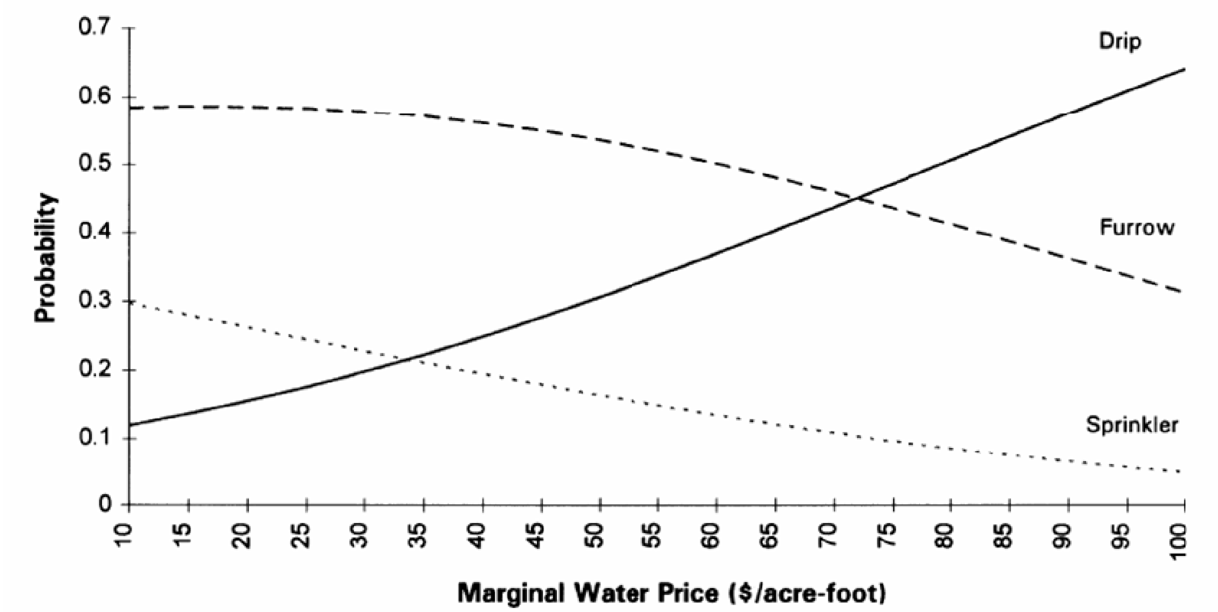
Pricing Policies Fail to Communicate the Value of Water

Our discussions with farmers indicate that many pricing structures fail to provide incentive to conserve water and that this is a source of frustration for those that are making efforts to conserve water. Those farmers who have invested in conservation have indicated they think it would be prudent to develop pricing policies that reward good water stewards and penalize those who waste water. Below, we describe agricultural pricing policies in California and provide recommendations for adopting policies to promote water conservation and efficiency improvements.

The price of water can affect crop choice, irrigation method, management practices, and ultimately, the amount of water applied. Because conserving water often requires capital investment, artificially low water prices may not provide sufficient economic incentive to justify conserving water. Low water prices reduce the likelihood that more efficient irrigation systems will be installed (Figure 23). For example, at $30 per acre-foot, the average price of irrigation water in California in 2003 (USDA 2003), the probability of flood irrigation is about 60%, whereas the probability of sprinklers and drip systems is about 20% each. Interestingly, these estimates match a survey of irrigation technologies in California conducted in 2001. As the price declines, the likelihood of flood and sprinklers increase while that of drip decline. Thus, indirect water subsidies create an artificially inexpensive supply of water and, in so doing, provide a disincentive for water conservation and efficiency.

More than 200 irrigation districts deliver water to farmers in California. In addition, many farmers extract water directly from groundwater or local surface water. There are several different ways that water providers structure water rates: fixed charges, volumetric pricing, and tiered pricing. Because of the sheer number of irrigation districts and differences in water sources, evaluating agricultural water prices, structures, and policies is difficult. Furthermore, few comprehensive surveys have been conducted in California. A recent survey by the AWMC (2008) found that nearly 90% of farmers are subject to volumetric pricing but less than 20% of farmers are subject to tiered pricing.[16] For those subject to tiered pricing, no information is available on the number of tiers and the price of water for each tier; thus, it is not possible to evaluate the effectiveness of these rate structures. Additionally, the survey was based on agencies that are members of the AWMC, which are arguably among the best actors in implementing water conservation and efficiency improvements. Almost no comprehensive pricing data are available for other irrigation districts around the state.

Figure 23. Probability of different irrigation practices in response to marginal water price



Note: Based on empirical data collected from the Arvin Edison Water Storage District located in the southern San Joaquin Valley.
Source: Sunding 2005

Another recent study evaluated the pricing policies of irrigation districts in the Western United States that purchase water from the USBR. USBR policies adopted in the 1990s encourage or require irrigation districts to adopt conservation pricing. Section 3405 (3)(d) of the Central Valley Project Improvement Act (CVPIA), for example, requires irrigation districts to implement tiered pricing.[17] The study, which compared agricultural water pricing policies before and after a series of conservation policies were implemented, found that most pricing policies are ineffective because of loopholes that permit most water to remain in the low-cost tiers: "where price incentive rate structures have been adopted, the common practices has been to set the first tier quantity so that it satisfies typical deliveries and most crop needs. Conservation price incentives were minimal or nonexistent as long as water use remained within these reasonable use allocations" (Michelsen et al. 1999). In other words, if pricing tiers are set up so that almost all water use is encompassed in the first tier, or lowest water rate, then there is very little economic incentive to conserve additional water.

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[16] It is important to note that this survey was based on agencies that are members of the AWMC, which are arguably among the best actors in implementing water conservation and efficiency improvements.
[17] The Central Valley Project Improvement Act only applies to contacts for Central Valley Project water that were entered into, renewed, or amended after October 1992.

Opportunity

Pricing Policies Can Encourage Efficiency

Water prices and pricing structures can be an important tool for communicating the value of water and encouraging efficient use. As noted by the USBR, "Incentive pricing moves away from rate schedules based solely on per-acre fixed charges and toward rate schedules that incorporate both fixed charges and per acre-foot water rates," (USBR 1997) i.e., from fixed to volumetric pricing. While all uniform volumetric rates are a form of conservation pricing, tiered pricing, if designed properly, can provide a stronger incentive to conserve water, as farmers are charged more per unit of water as use increases. However, incentives to conserve surface water must be balanced by incentives to conserve ground water (where it is available) to ensure that conserving one does not lead to over-exploitation of the other.

Properly designed tiered rates would (1) ensure that all water use does not fall within the first tier and (2) include large increases between tiers. In addition to implementing tiered rates to all users, a number of other pricing policies could be implemented to promote water conservation and efficiency. Water suppliers, for example, could provide discounted rates to farmers who can demonstrate a reduction of their total applied water by installing more efficient irrigation systems, implementing improved irrigation scheduling, reusing tailwater, or implementing a variety of other conservation and efficiency improvements.

Implementing new pricing policies can be highly contentious. The USBR notes that acceptance of new polices "can be encouraged by using increased revenues to improve district facilities and to increase district financial stability, improving the situation for all district water users" (USBR 1997). Additional revenue from inclining block rates can also be used to provide rebates, low-interest loans, and grants to farmers to make efficiency improvements. For instance, in the Broadview Water District increased revenue from an inclining block rate was used to help fund a low-interest loan program for farmers wishing to modernize their irrigation systems (Wichelns 2003). Furthermore, process is important for ensuring the success of new pricing policies. New rates should be developed through an open and transparent process. This process must be inclusive, incorporating advice and feedback from a citizen's rate committee that includes farmers as well as local environmental and citizen groups.

Below, we provide specific recommendations on economic opportunities that facilitate water conservation and efficiency improvements.

- Irrigation districts and state and federal water managers should implement new water rate structures that encourage efficient use of water. Additional revenue generated by heavy water users can be used to finance district-wide and on-farm efficiency improvements.

- Irrigation districts and the State should provide sales tax exemptions or rebates on efficient irrigation equipment to help offset capital investments for these systems. Funding for these rebates could be provided by new water rate structures that charge higher rates for those who use more water.

Institutions

Challenge

State and Federal Water Projects have Over-Allocated and Under-Priced Water

Many agricultural water users in California receive water from the CVP (managed by the USBR) and to a lesser degree, the SWP (managed by DWR). Agricultural water suppliers have entered into contracts for water from these two agencies.[18] Yet, these contracts allocate more water than is actually available. The CVP, for example, has only been able to provide 100% of the allocated water to contractors south of the Delta three times since 1990 (USBR 2009).[19] Likewise, the State Water Project has only provided 100% of the allocated contract water to its customers five times since 1996 (Notices to State Water Project Contractors, DWR 1996-2009). In most years, only around 60% of the contracted water is “available” for allocation from both projects (DWR 2008b; B. Cody, Congressional Research Service, personal communication, July 14, 2009). Recently, the ecosystem collapse of the Sacramento-San Joaquin Delta and resulting court-ordered restrictions suggests that even these exports may not be sustainable.

Furthermore, the price of water from these systems is too low, failing to provide an incentive to conserve water. This is particularly true for the CVP. The federal government invested a substantial amount of money to construct the CVP. Under the original contracts, which were negotiated and signed in the late 1940s, the project was to be paid off without interest 50 years after its construction (USBR 1988). However, prices for water from the CVP are low, ranging from $6 to $59 per acre-foot for irrigation (USBR 2008), and as a result, CVP contractors are behind on repaying project costs, which do not include interest. By September 2005, agricultural contractors had repaid only 18% of the original capital investment (USBR 2007). This failure to repay is a subsidy to agricultural users, estimated to be valued at $60 million to $416 million each year (EWG 2004).[20]

Opportunity

Strengthen Water Efficiency Requirements for State and Federal Water Contracts

The USBR has established best management practices for water efficiency, as required by the CVPIA. These include new programs designed to encourage efficiency, e.g., tiered pricing, water measurement, and improvement of pump efficiencies. As described above, tiered pricing can encourage water conservation and efficiency, but average water deliveries from the CVP typically fall within the first tier. Thus in practice, water rates are uniform and are priced at the lowest rate. As described above, the USBR should (1) ensure that all water use does not fall within the first tier and (2) include large increases between tiers.

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[18] For the SWP, additional water (above the maximum annual entitlement) may be purchased if it is available.

[19] It is important to note that shortages from the Central Valley Project are not evenly distributed among contractors. California’s water rights system is based on the principle of “first in time, first in right.” According to this principle, those with senior water rights may receive a 100% of their allocation while those with more junior rights receive nothing. Additionally, the “exchange” and “settlement” contractors, which use nearly 50% of the CVP water dedicated to agriculture, are not subject to CVPIA provisions because, they argue, they are not covered in the language of the act. Thus, despite the fact that CVP allocations totaled 10% in 2009, “settlement” and “exchange” contractors (who have senior water rights) received 100% of their contract water.

[20] According to Public Law 99-546, which was signed in 1986, all facilities built prior to the New Melones Dam and Reservoir in 1980 and all operation and maintenance deficits with interest incurred after 1985 must be fully paid by 2030, suggesting that the price of water from the CVP will have to increase markedly to satisfy this mandate.

The USBR should renegotiate all federal water contracts in light of new biological opinions for salmon and smelt. As part of this process, the required Needs Assessment should be altered to provide a more realistic estimate of future demand. Currently these assessments often over-estimate demand as they fail to take into account whether alternative supplies are available, are based on the contractor's own estimate of future irrigated acreage, and ignore the required retirement of drainage-impaired lands (Wall and Candee 2002 and Stokely, Water Impact Network, 7/7/09, pers. comm.). These assessments should be based on realistic demonstration of reasonable use of existing and future water supplies.

The State should also implement policies to encourage additional efficiency improvements. As a matter of principle, the USBR defers to state law. Thus, the state can take a more active role in strengthening water efficiency requirements. In particular, the state can require that all water deliveries, including the settlement contractors, be measured at the turnout with sufficient accuracy (generally ± 6%) to use for billing purposes and that districts water pricing be based in whole or in part on measured water use. The State can also require that the CVP implement more aggressive tiered pricing.

The DWR, responsible for water deliveries in the SWP, should also encourage efficiency through their contact amendment process. Many contractors ask to amend their original water allotment in order to purchase additional water from the State Water Project. There is no formal process, however, to determine whether contractors are using their existing allocation efficiently. We recommend that the DWR make the water contract amendment process reliant on an evaluation of the efficiency of current water use in the contractor's service area. In particular, contractors should implement the Best Management Practices, at minimum, prior to approval of additional water supply.

Specific policy recommendations include:

- The United States Bureau of Reclamation should revisit its water rate structures, ensuring that all water use does not fall within the first tier and that there are large increases between tiers.
- The United States Bureau of Reclamation should renegotiate all Central Valley Project contracts in light of the new biological opinions issued by the National Marine Fisheries Service and Fish and Wildlife Service.
- The United States Bureau of Reclamation should require all project contractors to provide a valid "Needs Assessment" that conforms to state law by demonstrating reasonable and beneficial use of water and prohibiting the waste of water.
- The State should require that all water deliveries, including the settlement contractors, be measured at the turnout with sufficient accuracy (generally ± 6%) and be subject to tiered pricing.
- California Department of Water Resources should make the water contract amendment process reliant on an evaluation of the efficiency of current water use in the contractor's service area.

Challenge

Lack of Enforcement of "Reasonable and Beneficial Use"

The California Constitution requires that all water is put towards "reasonable and beneficial use" (Article 10, Section 2), and the California Water Code directs the State Water Resources Control Board (the State Board) and Department of Water Resources to take action to prevent the waste, unreasonable use, unreasonable method of use, or unreasonable method of diversion of water (Section 275). The State Board, however, has rarely fulfilled this mandate, and when it has, it has often been under duress. In the last two decades, there have only been a handful of findings of unreasonable use in the state; the most high-profile being the Imperial Irrigation District (Decision 1600) and Mono Lake (Decision 1631). In both of these cases, the State Board was forced to act by court rulings.

The State Board's inaction can be attributed, in large part, to the fact that it does not operate as an independent regulatory body. For example, the Chair serves at the pleasure of the Governor and controls what may be placed on the agenda. The appointment and confirmation processes are politicized. In addition, their funding is tied to the state budget process and can therefore be reduced punitively.

Opportunity

Expand Enforcement of "Reasonable and Beneficial Use"

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. Implementation of the State Board's mandate will be stymied by political forces until the appointment and confirmation processes, and funding of the board are significantly altered. We recommend three critical ways to re-structure the State Board:

- As a regulatory agency, the State Water Resources Control Board should be an independent body with a secure funding source, e.g., fees or regular funding increases consistent with the consumer price index, outside of the political budget process.
- Establish a panel of independent judges, rather than the Governor, to review and recommend candidates for the State Water Resources Control Board.
- Change Water Code Section 275 to eliminate the "and" between the State Water Resources Control Board and the California Department of Water Resources. The State Water Resources Control Board should have independent authority to prohibit waste.

Water Laws

Challenge

Groundwater and Climate Change Impacts are Left Out

Groundwater in California is largely unregulated. With few exceptions, 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.[21] As there is little to no

[21] 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." Additionally, adjudicated basins – where groundwater withdrawals and management are legally reviewed and accepted by all users – are subject to

oversight and measurement of groundwater, there are few incentives for conservation or efficiency. A new study from the USGS estimates that 60 MAF of groundwater has been lost in California's Central Valley since 1961 (Faunt 2009). In some places, groundwater levels have dropped 400 feet or more. Better measurement and management of groundwater is needed immediately to address this problem.

California's failure to regulate groundwater is outdated and out-of-step with the rest of the West. 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. California must address the interconnected nature of its surface and groundwater resources or risk the eventual adjudication of nearly every groundwater basin in the state. Current state law allows local government to address some of these problems through local groundwater management authorities. These efforts can and should be expanded.

In addition, climate change will affect the availability and demand for water resources. Research indicates that climate change impacts are already affecting water resources and that these impacts will intensify in the future. The Western United States is expected to become drier. The snowpack, which acts as our major natural reservoir, is projected to decline by up to 90% by 2100 (Hayhoe et al. 2004). Our existing water rights system is based upon historic conditions. Given that the past is no longer a good predictor of the future, the inflexibility of our existing water rights system increases our vulnerability to climate change.

Opportunity

Improve Management of Water Resources

California's water rights system should be expanded to include groundwater and the potential impacts of climate change. We recommend three measures to promote a more sound and integrated water management system given changing social, economic, hydrologic, and environmental conditions:

- Legislative, regulatory, and administrative support should be given to update the water rights system given future hydrologic uncertainties.
- Current state law, which allows local government to create local groundwater management authorities, should be changed to require such authorities.
- As an immediate stop-gap measure, state and local agencies should establish groundwater management areas in regions where overdraft is most severe.

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monitoring by a court-appointed Water Master. There are presently 19 adjudicated basins in California, most of which are located in Southern California.

Education and Outreach

Challenge

Education and Outreach Programs are Under-funded

The benefits of efficient irrigation technologies and practices are widely acknowledged, yet adoption of these measures in California has been slow. Programs are available but underfunded. For example, the University of California, through its Cooperative Extension program, conducts field-based research on a wide range of topics from animal husbandry, to crop production, to water management, comprising the majority of empirical studies of 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, thus serving as a valuable information source. Nevertheless, statewide there are less than 400 agricultural technicians, Cooperative Extension specialists, and advisors combined; recent state budget short-falls could reduce staff further. Likewise, DWR provides mobile laboratory services to California's farmers that evaluate the performance of irrigation systems and provide farmers with recommendations to improve the efficiency of the irrigation system. Interest in and funding for the program, however, is highly variable, intensifying during a drought but waning during non-drought periods. Lack of institutional and technical support has contributed to the slow adoption of these technologies.

Opportunity

Increase Funding for Education and Outreach Programs

Education and outreach programs typically have built long-term relationships within the agricultural community. These relationships are critical for disseminating new research, information, and technical assistance directly to farmers. These on-the-ground organizations are a key tool for achieving a sustainable agricultural future.

Specific recommendations include:

- Expand water-efficiency information, evaluation programs, and on-site technical assistance provided through Agricultural Extension Services and other agricultural outreach efforts.
- Ensure a stable source of funding for education and outreach programs.
- Expand development and deployment of efficient irrigation technologies and new crop types.
- Fund the Agricultural Water Management Council to update and expand its Efficient Water Management Practices.

Conclusions

California's future is increasingly uncertain. Competition over limited water resources continues and climate change is increasing climate variability. With existing technologies, management practices, and educational and institutional resources, we can reduce agriculture's vulnerability to water supply constraints and improve its long-term sustainability. We conclude with a series of key political, legal, and economic initiatives that would promote more productive and, ultimately, more sustainable water management in California.

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.

- Implement California Assembly Bill 1404 in a timely manner, which would ensure coordinated water use measurement and reporting.
- Use satellite and other technology to improve data collection and analysis, particularly for annual assessments of crop area and evapotranspiration.
- Ensure that the Landsat-7 follow-on mission is equipped with a thermal band to allow for the continued use of satellite imagery for data collection and analysis.
- Design and implement comprehensive local groundwater monitoring and management programs statewide.
- Require the state to evaluate the measurement needs for accurately monitoring return flows.
- Implement a statewide system of data monitoring and data exchange, especially for water use and quality, available to all users.

While agriculture has social and cultural importance, it is also an economic endeavor and farmers must make choices about investments based on expected costs and returns. While investments in on-farm efficiency improvements can be offset by a reduction in operation costs and/or increased crop revenue, the initial investment required can be a significant barrier – policies are needed to overcome this economic barrier.

- Federal funding for conservation programs, especially the Environmental Quality Incentives Program, should be increased.
- State and county governments should provide property tax exemptions for farmers that upgrade to more efficient irrigation systems. Exemptions could apply to the value added to a property by the irrigation system and would be valid for 5-10 years.
- The State should 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.

In California, irrigation water is predominantly delivered through canals designed and constructed in the early and middle of the 20th century. Nearly 80% of these water systems fail to provide water on-demand, which is a necessary precondition for many on-farm water efficiency improvements.

- State and federal governments should expand efforts to finance district-wide improvements that provide water to farmers when needed, such as lining and automating canals and distribution systems.
- Irrigation districts should implement new water rate structures that encourage efficient use of water. This additional revenue generated from large water users can be used to finance on-farm and district-wide 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. Implementation of the State Water Resources Control Board's mandate will be stymied by political forces until the appointment and confirmation processes, and funding of the board are significantly altered.

- As a regulatory agency, the State Water Resources Control Board should be an independent body with a secure funding source, e.g., fees or regular funding increases consistent with the consumer price index, outside of the political budget process.
- Establish a panel of independent judges to review and recommend candidates for the State Water Resources Control Board.
- Change Water Code Section 275 to eliminate the "and" between the State Water Resources Control Board and the California Department of Water Resources. The State Water Resources Control Board should have independent authority to prohibit waste.

A more sound and integrated water management system is needed given changing social, economic, hydrologic, and environmental conditions. In particular, California's water rights system should be expanded to include groundwater and the potential impacts of climate change.

- Legislative, regulatory, and administrative support should be given to update the water rights system given future hydrologic uncertainties.
- Current state law allows local government to create local groundwater management authorities. The law should be changed to require local government to create these authorities.
- The state and local agencies should immediately establish groundwater management authorities in regions where overdraft is most severe.

Many agricultural water users in California receive water from the State Water Project (managed by the California Department of Water Resources) and the Central Valley Project (managed by the United States Bureau of Reclamation). These water projects, however, have over-allocated and under-priced water.

- The United States Bureau of Reclamation should revisit its water rate structures, ensuring that all water use does not fall within the first tier and that there are large increases between tiers.
- The United States Bureau of Reclamation should renegotiate all Central Valley Project contracts in light of the new biological opinions issued by the National Marine Fisheries Service and Fish and Wildlife Service.
- The United States Bureau of Reclamation should require all project contractors to provide a valid "Needs Assessment" that conforms to state law by demonstrating reasonable and beneficial use of water and prohibiting the waste of water.
- The State should require that all water deliveries, including the settlement contractors, be measured at the turnout with sufficient accuracy (generally ± 6%) and be subject to tiered pricing.
- The California Department of Water Resources should make the water contract amendment process reliant on an evaluation of the efficiency of current water use in the contractor's service area.

Education and outreach programs are critical for disseminating new research, information, and technical assistance directly to farmers. Programs are available but underfunded. These on-the-ground efforts are central to achieving a sustainable agricultural future.

- Expand water-efficiency information, evaluation programs, and on-site technical assistance provided through Agricultural Extension Services and other agricultural outreach efforts.
- Ensure a stable source of funding for education and outreach programs.
- Expand development and deployment of efficient irrigation technologies and new crop types.
- Fund the Agricultural Water Management Council to update and expand its Efficient Water Management Practices.

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