California's Next Million Acre-Feet: *Saving Water, Energy, and Money*

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Acronyms and Abbreviations

AF – acre-feet

CEC – California Energy Commission

CIMIS – California Irrigation Management Information System

DWR – California Department of Water Resources

EPA – U.S. Environmental Protection Agency

GWh – gigawatt-hour

gpcd – gallons per capita per day

gpf – gallons per flush

gpm – gallons per minute

IID – Imperial Irrigation District

kWh – kilowatt-hour

MELASI – Mothers of East Los Angeles Santa Isabel

MWD – Metropolitan Water District of Southern California

RDI – regulated deficit irrigation

USBR – United States Bureau of Reclamation

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)

1 gigawatt-hour (GWh) = 1,000,000,000 watt-hours = 1,000,000 kilowatt-hours (kWh)

California's Next Million Acre-Feet: Saving Water, Energy, and Money

Introduction

Water is vital to the health of our economy and natural ecosystems. California's cities and agricultural communities depend upon reliable supplies of clean and adequate freshwater. As California's population and economy grow, there is mounting concern about our ability to meet future water demand amidst pressure on our complex water systems. In the 20th century, our approach to meeting this demand was to develop new supply by tapping our rivers, streams, and groundwater aquifers. While this approach brought tremendous benefits to the state, it also came at enormous environmental cost. We are reaching the economic, ecological, and social limits of traditional supply options: continuing to rely solely on building new infrastructure will fail to solve our impending crisis. We must expand our thinking about supply, away from costly new dams and toward other options for expanding supply (e.g., recycled water, stormwater capture, and integrated groundwater banking and management) and reducing statewide water demand. There is no "silver bullet" solution to our water problems, as all rational observers acknowledge. Instead, we need a diverse portfolio of solutions. But the need to do many things does not mean we must, or can afford, to do everything. We must do the most effective things first.

In particular, there are tremendous opportunities to improve the efficiency with which we use water at lower economic and ecological cost than developing new supply. There is vast potential to reduce our demand for water without affecting the services and benefits that water provides. Improving efficiency offers many benefits. Conserved water can be reallocated to other uses by the same user, such as growing more food on a farm. It can be left (or returned to) ecosystems to help restore natural water flow levels. It can be moved from one user to another as part of an economic arrangement or transfer. In addition, reducing the application of unnecessary water can save energy, reduce wastewater and associated treatment costs, and eliminate or delay the need for new water supply and treatment infrastructure. Water management efforts and programs should explicitly work to assure such co-benefits.

We have improved the efficiency of our water use substantially over the past 25 years. Without these past efforts, our current challenges would be much worse, demands on limited water supply would be much higher, and ecosystem destruction would be far more widespread. Despite these improvements, however, our current water use remains wasteful. The Pacific Institute has completed a series of independent reports on urban and agricultural water efficiency that provide a comprehensive statewide analysis of the conservation potential (Gleick et al. 2003, 2005; Cooley et al. 2006, 2008, 2009; Christian-Smith et al. 2010). Our findings have been confirmed by other independent assessments and adopted by the California Department of Water Resources in the California Water Plan (CALFED 2006; DWR 2005). These studies find that existing, cost-effective technologies and practices can reduce current state demand for water by six-to-eight million acre-feet per year, or around 20% statewide.

Widespread conservation and efficiency improvements are possible in every sector – in our homes, businesses, and farms. These water savings can be achieved for much less than the cost of building new, or expanding existing, supply. These savings represent a tremendous amount of untapped potential. Even today, after California's conservation efforts, millions of old inefficient toilets and household fixtures remain in use. California businesses are still relying on wasteful equipment and practices. Nearly 60% of all crop acreage in California still uses inefficient flood irrigation systems (Orang et al., 2005). Water savings are possible if farmers continue their efforts to shift to more efficient irrigation technologies and practices, such as drip systems, and improved management practices, such as better irrigation scheduling and soil-moisture monitoring, all of which can reduce water use while also improving agricultural yields and/or crop quality.

In this report, we identify ways that Californians can capture a fraction of the potential water conservation and efficiency savings, and quantify these potential savings within the urban and agricultural sectors. Overall, we recommend technologies and strategies that will let California quickly save 1 million acre-feet of water at lower cost than current proposals to develop new supply, and with far fewer social and environmental impacts. All together, the efficiency improvements we identify require an upfront investment of $1.87 billion. The cost of the conserved water is $185 per acre-foot for the agricultural sector and a net *savings* of $99 per acre-foot for the urban sector, over the lifetime of the efficiency improvement.

These conservation and efficiency improvements are much cheaper than many proposed new surface storage projects. Sites Reservoir, for example, is estimated to require a capital investment of $3.0 billion while providing only 184,000 acre-feet of water per year; the

How much is an acre-foot?

-An acre-foot is a quantity of water that would flood an acre of land one foot deep, or 325,851 gallons.

A *million* acre-feet is:

- nearly 12 times the city of San Francisco's annual water use; 4.5 times the city of San Diego's annual water use; and 1.6 times the city of Los Angeles' annual water use.

- equivalent to a flow of 890 million gallons per day – 37% of the American River's annual discharge.

- approximately enough water to irrigate all the grain produced in California annually.*

- enough water to satisfy the household needs of 6.7 million new Californians (more than the growth that demographers predict will occur within the next 10 years).

- almost three times the amount of water that would be yielded annually by the proposed Sites Reservoir and Temperance Flat Reservoir – combined.

- the amount of water that would be produced annually by 18 large desalination plants (the size of the proposed Carlsbad desalination plant, which would be the largest in the northern hemisphere).

*Grain acreage and applied water estimates based on data from the California Department of Water Resources; DWR defines grain as "wheat, barley, oats, miscellaneous grain and hay, and mixed grain and hay."

cost of water from Sites Reservoir is estimated at $520 per acre-foot[1] plus an additional $140 to $150 per acre-foot to pump that water over the Tehachapi Mountains (DWR 2007). The economic justification for Temperance Flat Reservoir, located on the San Joaquin River, is even weaker. In 2008 the US Bureau of Reclamation estimated that building a new dam at Temperance Flat would require a capital investment of $3.4 billion and yield only 158,000 acre-feet per year; the cost of water from Temperance Flat Reservoir is $720 per acre-foot.[2] And these costs are already rising. Additional cost would be required to actually deliver water to homes, farms, and businesses throughout California.

Unlike proposed new water storage projects, the efficiency improvements recommended here often pay for themselves as a result of the many co-benefits that water conservation and efficiency provides, including reductions in wastewater and energy bills and improvements in crop quality and yield. Reducing water demand also delays or eliminates the need to develop expensive water and wastewater treatment and energy infrastructure, thereby producing additional long-term financial savings for future generations. We note that these infrastructure savings are not included in this analysis, although they can be substantial.

Where will the water savings come from?

Water savings are available through a wide variety of water-efficient practices in the urban and agricultural sectors. In the urban sector this includes replacing old, inefficient devices with high-efficiency models, as well as lawn conversion, residential metering, and rate structures that better communicate the value of water. In the agricultural sector, best water management practices include weather-based irrigation scheduling, regulated deficit irrigation, and switching from gravity or flood irrigation to sprinkler or drip irrigation systems. Here, we focus on well-documented, cost-effective approaches that are already being used in California. We emphasize efficiency improvements rather than behavioral changes because the latter are less easily quantified. Nonetheless, experience in Australia, Colorado, and California in recent years shows that changing water use behavior can also provide very fast and inexpensive savings in emergencies, with long-term benefits.

This analysis explores how to capture one million acre-feet of potential water savings (only a fraction of the conservation potential statewide). We divide these savings between agriculture and urban uses, with approximately 70% of the savings derived from the agricultural sector and 30% from the urban sector. Our assessment could have identified one million acre-feet of water

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[1] Cost estimate based on the best alternative identified in USBR 2008a. Note that the Bureau of Reclamation annualizes the cost over a 100-year period at a 4 7/8% interest rate. These unusually generous assumptions deflate the cost of water from this project.

[2] Cost estimated based on alternatives identified in USBR 2008b. Note that the Bureau of Reclamation annualizes the cost over a 100-year period at a 4 7/8% interest rate. These unusually generous assumptions deflate the cost of water from this project.

savings in either the agricultural or urban sectors alone, but here we demonstrate how even small changes in cities and on farms can relatively quickly and inexpensively produce large water savings.

These water savings are a combination of "consumptive" and "non-consumptive" uses (see box below). Both kinds of savings are valuable, despite claims by some water analysts of the need to focus solely on reducing "consumptive" water uses. In particular, saving non-consumptive uses may be especially cost-effective and helpful for restoring instream flows for certain highly damaged aquatic ecosystems and for reducing energy use associated with on-farm or urban water systems.

Consumptive and non-consumptive water use

The water literature is rife with confusing and often misleading terminology to describe water use, e.g., water withdrawal, consumptive use, non-consumptive use, etc. It is important to clarify these terms, as different meanings can lead to different or conflicting conclusions about the water conservation potential. To be clear, water withdrawals refer to water taken from a source and used for human needs. These withdrawals can be divided into two water-use categories: consumptive and non-consumptive. Consumptive use is sometimes referred to as irretrievable or irrecoverable loss. According to Gleick (2003), "The term *consumptive use* or *consumption* typically refers to water withdrawn from a source and made unavailable for reuse in the same basin, such as through conversion to steam, losses to evaporation, seepage to a saline sink, or contamination." Additionally, water that is incorporated into products or plant and animal tissue is typically exported out of the basin of origin, and thus is also a consumptive use.

Confusion about consumptive and non-consumptive water use has led many planners to grossly underestimate the value of conserving non-consumptive water use and, consequently, overall water-conservation potential. Some water planners believe that conservation measures that produce savings in non-consumptive water uses are less important than that from consumptive water uses. They argue that water that is used non-consumptively is available for reuse by downstream users and thus conserving this water does not produce any new water. These planners, however, fail to realize that *any* demand reductions reduce the amount of water taken from ecosystems and the need for new infrastructure investments to capture, store, treat, and distribute water. It can also allow for greater flexibility in managing water deliveries. Furthermore, reductions in water withdrawals can improve the timing and maximize the amount of water left in the natural environment, providing benefits to downstream water quality, the environment, recreational uses, and even upstream use.

Urban water use: how much can we save?

In California's urban areas, water is used for residential, commercial, and industrial uses, outdoor landscaping, and other miscellaneous uses. Official estimates from California's Department of Water Resources indicate that urban water use was 9.3 million acre-feet in 2005, although significant uncertainties are associated with these numbers (DWR 2009). Some urban areas have been able to maintain or even reduce water demand while supporting population and economic growth: statewide per-capita demand between 1995 and 2005 remained fairly constant, averaging 192 gallons per person per day (DWR 2010). While many water agencies invested in water conservation and efficiency programs during this period, these savings were essentially cancelled out by urban growth in hot, inland areas where outdoor water demand is particularly high.

A wide variety of efficient devices and fixtures are available to reduce urban water demand. Our analysis shows that residents of California could reduce water use by more than 160,000 acre-feet each year by (1) replacing 3.5 million toilets with high-efficiency models, (2) installing faucet aerators and showerheads in 3.5 million homes, and (3) putting in 425,000 high-efficiency clothes washers. California businesses could save an additional 123,000 acre-feet each year by installing efficient devices in commercial and industrial kitchens, bathrooms, and laundries, and upgrading cooling towers. And nearly 35,000 acre-feet of water could be saved outdoors by using pressurized water brooms instead of hoses to wash sidewalks and by replacing just 2,000 acres of lawn with low-water-use plants in each of six counties: San Diego, Orange, Riverside, Ventura, Fresno, and Sacramento. In combination, these thirteen conservation measures alone would reduce urban demand by more than 320,000 acre-feet each year.

In addition to saving water, these water conservation and efficiency devices save energy. We estimate that these water-saving measures would reduce California's electricity use by 2,300 gigawatt-hours (GWh) and its natural gas use by 87 million therms each year. The annual electricity savings are equivalent to the electricity use of 309,000 average households in California.[3]

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[3] According to EIA (2010), the average California household uses 7,440 kWh per year.

Table 1. Water and energy savings for selected water conservation and efficiency measures.

Efficiency Measure	Number Installed	Water Savings (AF)	Electricity Savings (GWh)	Natural Gas Savings (million therms)
Residential toilet (1.28 gpf)	3,500,000	93,500	306	-
Showerhead (1.5 gpm)	3,500,000	47,500	985	59.3
Residential front-loading clothes washer	425,000	13,300	188	8.86
Faucet aerator (1.5 gpm)	3,500,000	6,750	74.5	3.75
Pre-rinse spray valve (1.0 gpm)	20,000	3,070	76.9	3.70
Connectionless food steamer	7,000	3,440	24.9	1.31
Commercial dishwasher	8,500	1,300	56.4	2.90
Commercial front-loading clothes washer	90,000	10,500	148	6.98
Commercial urinal (0.5 gpf)	750,000	51,800	170	-
Commercial toilet (1.28 gpf)	750,000	31,300	103	-
Cooling tower pH controller	5,500	21,900	71.8	-
Pressurized water broom	50,000	7,670	20.3	-
Replace lawn with low-water-use plants	12,000 acres	28,400	75.4	-
Total		**320,000**	**2,300**	**86.8**

Notes: All numbers rounded to three significant figures. Energy savings include both end use and embedded energy savings. End use savings result from reductions in volume of water that must be heated prior to use. Embedded energy savings are due to reductions in the energy used to deliver drinking water to homes and businesses and treat wastewater before discharge into the environment. See Appendix A for a more detailed discussion of the assumptions and approach used in this analysis.

How do we capture the urban water savings?

Identifying potential savings is just the first step in tackling California's water problems. Equally, or even more, important is developing programs for achieving those savings. There are many tools available for this, including incentives, pricing policies, regulations, and education. In this section, we recommend strategies for moving forward quickly to reduce wasteful and inefficient uses of water.

Financial incentives

Even when energy or water savings are clearly cost-effective, up-front costs sometimes pose barriers to water users. Many approaches can help overcome these barriers. Rebate programs are among the most common ways to encourage customers to make investments in water conservation and efficiency improvements. Residents and business owners purchase new devices as the old devices wear out. While most new standard devices use less water than older models, there are many new high-efficiency devices available that use even less water. For example, an old clothes washer uses about 60 gallons per load. New, standard top-loading clothes washers use 30 gallons per load and cost $500. New, efficient front-loading clothes washers, however, use only 15 gallons per load, although the average cost is slightly higher, at about $750. While the efficient devices are cheaper over their lifetimes due to lower water, energy, and wastewater bills, users may be put off by the higher up-front costs. Many water agencies provide their customers with a rebate to defray the additional cost of the more efficient device. In the case of clothes washers, some water agencies partner with local energy utilities to provide rebates to their customers ranging from $200 to $300. Additionally, utilities may partner with retailers to offer rebates at the point of sale, giving customers an immediate incentive to purchase the more efficient device.

Another approach that may be effective is a "Cash for Water Wasters" program where old, inefficient devices would be replaced with more efficient models. Such a program would be similar to the Cash for Clunkers program implemented in the summer of 2009 to get old cars off the road and provide a boost to the automotive industry. A similar program focused on energy efficiency was launched by the federal government in 2010 with funding from the American Recovery and Reinvestment Act. Consumers across the country were provided a total of $300 million in rebates to purchase energy-efficient household appliances. To ensure the inefficient devices are taken off the market, the old appliances must be recycled. A "Cash for Water Wasters" program would operate in a similar matter but would target devices and fixtures that use water in residences and businesses. In addition to helping ensure the long-term sustainability of California's water resources, a "Cash for Water Wasters" Program would save money and reduce energy use and associated greenhouse gas emissions. It would also create jobs and promote a green economy benefiting product manufacturers, suppliers, plumbers, and contractors.

There are strong and successful precedents for such programs. In the mid-1990s, the New York City Department of Environmental Protection launched a massive toilet rebate program to replace one-third of all water-wasting toilets in New York City with low-flow models using no more than 1.6 gallons per flush. For this program, property owners contracted directly with private licensed plumbers for the installation of a low-flow toilet. After completion of the work, the City provided the property owner with a $240 rebate for the first toilet and $150 for the second toilet. Where possible, the plumber would also install low-flow showerheads and faucet aerators. The program was a huge success. Between 1994 and 1997, 1.3 million low-flow toilets were installed, saving 70 - 90 million gallons per day. Customers saw their water and wastewater bills drop 20 to 40% (EPA 2002). The City was able to defer the need to identify new supply sources and expand wastewater treatment capacity, thereby saving the community even more money.

Similarly, a successful toilet direct install program was implemented in Southern California in the 1990s. In 1992, a pilot partnership to install low-flow toilets was created between the community non-profit group Madres del Este de Los Angeles Santa Isabel (Mothers of East Los Angeles Santa Isabel - MELASI) and the Metropolitan Water District of Southern California, Los Angeles Department of Water and Power, Central Municipal Water District, and California Water Service Company. Toilets were installed in low-income households free of charge, and MELASI was paid $25 for every toilet replaced (Lerner 1997). The program provided employment opportunities to community residents, creating twenty-five full-time and three part-time jobs (Lerner 1997). The community-based approach was also a success in terms of water conservation, with one-in-three households contacted participating, and a total of 8,000 toilets replaced in the first year and 50,000 replaced by the end of 1997 (Hamilton 1992, Hamilton and Craft undated, Lerner 1997). Such a successful model could have been, but was not, expanded statewide. We recommend reinstituting and expanding this kind of community-based effort.

Regulations

In addition to financial incentives, regulations can facilitate water conservation and efficiency improvements. Recent standard state and federal regulations for appliance standards have greatly improved the efficiency of residential water-using fixtures. Other kinds of regulatory approaches are becoming increasingly common and can further reduce the burden on the water provider. In late 2009, for example, California enacted SB 407 (Padilla), which requires the replacement of all inefficient plumbing fixtures in commercial and residential properties with efficient models by 2017 for single-family homes and 2019 for multi-family homes and commercial properties.[4] While initial versions of the bill required these retrofits as a condition of sale or transfer of property, watered-down language of the final bill significantly reduced the enforceability and water conservation function of the law. Opposition from the California Association of Realtors and the California Business Properties Association, in particular, led to the elimination of the "replacement-on-resale" language and significant delays in the target compliance dates. The law makes compliance a condition for some – but not all – building permits after 2017, but otherwise, the law as written does not provide for any penalties or fines or any other mechanisms to ensure compliance. Strengthening this law by including some mechanism for ensuring compliance would result in even greater savings.

In addition, Governor Schwarzenegger recently signed SBx7-7, which requires urban water suppliers to reduce per-capita water use by 20% by 2020. Early versions of the bill set numeric water use reduction targets for agriculture, although this language was removed. The law still requires agricultural water suppliers to improve water use monitoring and reporting, establish

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[4] Specifically, the law requires replacement of toilets using more than 1.6 gallons per flush; urinals using more than 1.0 gallons per flush; showerheads with a flow capacity of more than 2.5 gallons per minute; and faucets with a flow capacity of more than 2.2 gallons per minute.

pricing structures that reflect the volume of water used, and develops agricultural water management plans. This bill, if successfully implemented, is an important step to help California achieve more effective and efficient use of its water resources.

Pricing policies and metering

Pricing policies can also promote water conservation and efficiency improvements. Many water agencies are moving beyond simple volumetric pricing and are beginning to adopt inclining block rates. Through an increasing block rate design, the unit price for water increases as water use increases, with prices set for each block of water use. Customers who use low or moderate volumes of water are charged a modest unit price and rewarded for conservation; those using significantly higher volumes pay higher unit prices. When designed properly, this approach can provide a strong financial incentive to conserve while ensuring that lower-income consumers are able to meet their basic water needs at a reduced cost. A 2003 survey of water rate structures in the southwest United States found that per-capita water use is typically lower in cities with dramatically increasing block rates, such as Tucson and El Paso (WRA 2003).

Pricing policies that promote water conservation and efficiency are predicated on meters that measure actual water use. Water bills for unmetered residents are based on a flat fee that is independent of the volume of water that is actually used, eliminating information that could encourage residents to reduce their water use. Unfortunately, at a time of chronic water crises and calls for new water-supply expenditures, several major cities in California still do not measure water deliveries to residences. Although meters will be required on all water connections by 2025, many water utilities in the San Joaquin Valley and even much of Sacramento remain unmetered (Black and Veatch 2006). In addition, an estimated 96% of multi-family residents are not sub-metered nationwide (Mayer et al. 2004).

Studies show that metering customers and charging them for the water they use substantially reduces water use. The City of Davis, for example, installed meters on nearly 10,000 homes and began a metered billing rate, effectively reducing per-capita water use by 18% (Maddaus 2001). The City of Clovis, which uses water meters, has an average per-capita use nearly 40% lower than the neighboring city of Fresno, which does not use water meters (Hanak 2005, citing *Fresno Bee* 2004). In Denver, metering reduced water use by 28% (Bishop and Weber 1995). In addition to reducing household water use, meters are also critical for effective management of the water system. Water providers can use this information to target water conservation and efficiency programs to particular customer classes and determine the program's effectiveness. Meter data is also an extremely valuable audit tool that can help locate leaks within the distribution system and at the customer's homes. We recommend an accelerated effort to meter all water uses.

Education and outreach

Education programs can also be effective for promoting water conservation and efficiency. The U.S. Environmental Protection Agency (EPA), for example, launched the WaterSense labeling program in 2006 to promote water-conserving devices that are 20% more efficient than average products and meet rigorous performance criteria. Additionally, the State, in partnership with the Association of California Water Agencies, recently launched the "Save Our Water" program to develop a consistent statewide message on the importance of water conservation and efficiency and to disseminate consumer-oriented information and tools to help Californians reduce their water use.

Although not included in this analysis, behavioral changes can generate tremendous water savings very quickly and at very little cost. In South East Queensland, Australia, for example, residents responded to drought restrictions by decreasing water use from the already low 70 gallons per person per day (gpcd) to 34 gpcd. Even after restrictions were eased, water use rose only to 43 gpcd (Queensland Water Commission 2009). In Denver, water use dropped from 211 gpcd to 165 gpcd during drought restrictions imposed in 2002, then rose very slightly to 170 gpcd after those restrictions were removed (Denver Water 2009). Denver Water's public campaign expenditures in 2009 were only $735,000, yet the campaign contributed to the 6,000 acre-feet reduction in water use in the service area that year (A. Muniz, Denver Water, pers. comm. Dec. 2009). Consistent information on how to achieve efficiency improvements – and their benefits – should be prepared and disseminated throughout the state.

Agricultural water use: how much can we save?

Agriculture accounts for the vast majority of applied water use in California (DWR 2005). The agricultural sector uses 80% of California's developed water supply, or about 34 million acre-feet per year, thus even small improvements in irrigation efficiency can produce tremendous water savings. Yet, while recent legislation set a 20% water conservation target by 2020 for urban water suppliers, there are no quantitative savings required for agricultural water suppliers. Nonetheless, there is great potential for water savings in the agricultural sector. These savings are more cost-effective than most other water supply options and provide many co-benefits associated with improved agricultural water management, including increased crop quality and yield and water quality improvements (Cooley et al. 2009, Christian-Smith et al. 2010).

For this analysis, we chose among the simplest, proven agricultural water-use efficiency measures available, which include: (1) weather-based irrigation scheduling, (2) regulated deficit irrigation, and (3) efficient irrigation technologies, e.g., drip and sprinkler systems. First, weather-based irrigation scheduling uses data about local weather conditions to determine how much water a crop needs. The California Department of Water Resources maintains the California Irrigation Management Information System (CIMIS) to provide this information to growers. This service is free and available online to the public, but other kinds of weather-based systems are also available from irrigation consultants who may set up additional weather stations on-farm to provide even more precise local information.

Second, regulated deficit irrigation imposes water stress on certain crops that have drought-tolerant life stages, e.g., wine grapes and some nuts. This approach is widely practiced in many

Mediterranean and semi-arid climates around the world, including more and more efforts in California, providing improvements in crop quality and/or yield along with significant water savings (Cooley et al. 2009). Third, certain irrigation technologies, such as sprinkler and drip irrigation systems, tend to have higher distribution uniformities and water-use efficiencies than traditional flood, or gravity, irrigation systems. As we note elsewhere, however, realizing the full water savings from any irrigation technology requires proper management and maintenance (Cooley et al. 2008, 2009).

We applied these three measures to only a fraction of California's nearly 9.5 million acres of irrigated land. For instance, in our analysis, irrigation scheduling was applied to 20% of vegetable, orchard, and vineyard acreage in California, or about 811,000 acres. Regulated deficit irrigation was applied to 30% of almonds and pistachios in the state, or about 205,000 acres. We also calculated the water savings associated with converting a small portion of vegetable, orchard, and vineyard acreage from flood irrigation to sprinkler or drip irrigation systems in the Central Valley.[5] Altogether, these three measures were applied to only 15% of the irrigated agricultural acreage in California but produced nearly 700,000 acre-feet of water savings each year (Table 2).

Table 2. Agricultural water conservation and efficiency savings.

Measure	Annual Water Savings (AF)	Area Affected (acres)
Irrigation scheduling	291,000	811,000
Regulated deficit irrigation	170,000	205,000
Drip/sprinkler irrigation	238,000	424,000
Total	**699,000**	**1,440,000**

Notes: All numbers are rounded to three significant figures. Energy savings are not included as the embedded energy of agricultural water varies greatly based on the water source (e.g., groundwater vs. surface water, local supply vs. State Water Project). Adequate data are not available to estimate these savings but they make the recommended improvements even more attractive.

It is important to note that these savings are a combination of consumptive and non-consumptive water uses, and therefore they are not necessarily available for re-allocation or use elsewhere. However, as noted above, reductions in water demand often provide important co-benefits, including:

- **Improved 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 reduces these water-quality problems.

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[5] We used the Analytica model described in Groves et al. (2005) to calculate the water savings from changing from flood to sprinkler and drip irrigation systems.

- **Increased 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. Reducing unproductive uses of water in selected locations permits less water to be taken from vulnerable stretches of natural systems. Instream flows serve many purposes (see, for example, Postel and Richter 2003, Maunder and Hindley 2005), including
    - removing fine sediments that cement river substrate and 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; and
    - allowing and supporting fish passages and migrations.

- **Improved 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. This factor is important because the natural 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, and support, anadramous fish migration (Maunder and Hindley 2005).

- **Benefits to 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, the large pumps for the State Water Project and Central Valley Project kill fish on the intake screens and at the fish diversion facility, leading to expensive infrastructure retrofits, legal challenges, and controversial environmental restrictions on water withdrawals.

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

- **Improvements in Crop Quality and Yield.** More precise application of water to meet crop needs has been shown to improve crop quality and/or yield. In addition, slightly stressing drought-tolerant crops has been shown to increase solids (tomatoes), reduce hull split (almonds), increase shelf life (stone fruit), increase shell split (pistachios), and increase sugar content (wine grapes).

- **Reduced Energy Use.** Capturing and conveying water to agricultural users often requires an input of energy. For example, conveying surface water to farmers in the Tulare Lake hydrologic region requires up to 970 kWh per acre-foot.[6] Likewise, pumping groundwater requires between 175 kWh and 740 kWh per acre-foot or even more, depending on pumping depth (Wolff et al. 2004). As a result, reducing water withdrawals can save energy and reduce related greenhouse-gas emissions.[7]

- **Decreased Soil Salinity.** 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. This works both ways, however, and at times, farmers may wish to increase water use to remove salts from soils. Careful soil and water management are required to balance these competing interests.

How do we capture the agricultural water savings?

Although financial incentives and regulations to promote water-use efficiency are less often applied to the agricultural sector, a transformation in agricultural water use could generate significant savings in water and energy and potentially create more and better rural jobs. There is an urgent need to modernize California's on-farm water infrastructure to become more efficient and resilient to drought and long-term climate changes by implementing water district upgrades (e.g., lining irrigation canals, implementing technologies to accurately measure water use, automating delivery structures, recycling drainage water, and providing pressurized water for farmers) and on-farm improvements (e.g., conversion to higher efficiency sprinkler and drip irrigation systems, shifting to conservation tillage practices, and other methods to conserve soil moisture). This would require substantial investment in new infrastructure and labor for up-front installation and ongoing maintenance. This work could potentially extend some seasonal farm jobs to year-round employment, increase wages for existing workers, and/or increase the number of jobs in the agricultural sector, though the employment opportunities have not yet been

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

[7] 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" in Cooley et al., 2008 for a more detailed discussion.

comprehensively analyzed. The costs for this transition could be defrayed by establishing new and expanding existing rebate programs,[8] low-interest loans (e.g., the state has provided low-interest loans to irrigation districts to finance district and on-farm water infrastructure improvements), and grant programs (e.g., the federal Farm Bill conservation programs). Additional revenue generated from tiered pricing could also be used to finance district-wide improvements.

Well-designed pricing policies have also been shown to be effective for reducing agricultural water use. For example, the Broadview Water District, a small district in the southern San Joaquin Valley, implemented increasing block rates in 1988 to reduce the volume of contaminated drainage water flowing into the San Joaquin River. The rate was set at $16 per acre-foot for the first 90% of the 1986 to 1988 average water use and $40 per acre-foot for any additional water. Careful monitoring ensured an accurate accounting of water use. By 1991, the district's average applied water declined by 19%, from 2.8 acre-feet per acre to less than 2.3 acre-feet per acre as a result of efficiency improvements and crop shifting (MacDougall et al. 1992). In addition to the rate changes, discussions and workshops with farmers facilitated the exchange of information and contributed to the program's success (Wichelns and Cone 1992).

Municipal water agencies may also provide another potential funding source for agricultural efficiency improvements. In1988, the Imperial Irrigation District (IID) entered into a 35-year agreement with the Metropolitan Water District of Southern California (MWD) in which MWD would pay for water conservation measures within the IID service area in exchange for more than 100,000 acre-feet of the conserved water each year. In 2003, IID entered into a similar agreement with the San Diego County Water Authority. These transfer offer examples of municipal water agencies funding system and on-farm efficiency projects in exchange for a portion of the water conserved. If the adverse environmental and social impacts of such efficiency projects are appropriately mitigated by the transfer parties, such projects can be clear examples of the "beneficiary pays" principle and provide irrigators with the capital they need to improve water delivery systems, without impairing agricultural productivity.

How much will conserving 1 million acre-feet cost?

When developing water conservation and efficiency programs, a key question is "how much will it cost?" Cost depends on how the program is structured and the assumptions about who pays and when. The program adopted in this analysis is modeled on a rebate program. For most devices, we assume that the customer was in the market for a new device, and thus the cost is the cost difference between a new standard and new efficient device. For some devices, including faucet aerators, cooling tower pH controllers, water brooms, replacing lawn with low-water-use plants, and all of the agricultural measures, however, we assume that the customer would not have made

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[8] Pacific Gas and Electric offered a rebate program for installing drip irrigation systems in some areas of the state.

the investment otherwise, and thus the cost is the full cost of the device. We also include the administrative cost for running a rebate program, which typically varies from about 10% to 30% of the rebate cost, depending on the measure under consideration (Table 3).

Table 3. Cost data for selected urban water conservation and efficiency measures.

Conservation Measure	Device Cost ($/device)		Incremental Cost	Incremental Plus Administrative Cost
	Efficient	Standard		
Residential toilet (1.28 gpf)	$ 200	$ 150	$ 50	$ 63
Showerhead (1.5 gpm)	$ 40	$ 20	$ 20	$ 25
Residential front-loading clothes washer	$ 750	$ 492	$ 258	$ 323
Faucet aerator (1.5 gpm)	$ 8	$ -	$ 8	$ 10
Restaurant pre-rinse spray valve (1.0 gpm)	$ 70	$ 50	$ 20	$ 25
Connectionless food steamer	$ 6,000	$2,500 (elec.); $3,800 (natural gas)	$ 3,230	$ 4,040
Commercial dishwasher	$ 9,000	$ 6,950	$ 2,050	$ 2,560
Commercial front-loading clothes washer	$ 750	$ 492	$ 258	$ 323
Commercial urinal (0.5 gpf)	$ 550	$ 540	$ 10	$ 13
Commercial toilet (1.28 gpf)	$ 200	$ 150	$ 50	$ 63
Cooling tower pH controller	$ 2,250	$ -	$ 2,250	$ 2,810
Pressurized water broom	$ 250	$ -	$ 250	$ 313
Replace 1 acre of lawn with low-water-use plants	$ 43,600	$ -	$ 43,600	$ 54,500

Notes: gpf = gallons per flush; gpm = gallons per minute. All numbers rounded to three significant figures. See Appendix A for a more detailed discussion of the assumptions and approach used in this analysis. Cost of landscape conversion is based on a rebate level of $1 per square foot, which does not account for economies of scale with larger installations, which can have a unit cost of less than half this rate.

We estimate that, together, the urban water conservation and efficiency measures save more than 320,000 acre-feet per year and require an initial investment of $1.3 billion (Table 4). These measures save additional money over their lifetime through lower water, wastewater, and in some cases, energy bills. We estimate that these devices would have a "negative cost" over their lifetime,[9] saving an average of around $99 per acre-foot of water conserved. Although not included here, there are additional savings from the deferral or downsizing of capital-intensive

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[9] A "negative cost" means that these technologies and approaches save more money over their lifetime than they cost to implement.

water supply and treatment facilities, which would further increase the financial savings from these measures. These additional savings accrue to the water distributors rather than the end users, though ultimately the end user saves by avoiding rate increases associated with capital programs.

Table 4. Initial investment and cost of conserved water for urban water conservation and efficiency measures.

	Number of Devices	Incremental Plus Administrative Cost	Initial Investment ($ millions)	Cost of Conserved Water ($/AF)
Residential toilet (1.28 gpf)	3,500,000	$ 63	$ 219	$ 1,580
Showerhead (1.5 gpm)	3,500,000	$25	$ 87.5	$ - 3,140
Residential front-loading clothes washer	425,000	$ 323	$ 137	$ - 1,510
Faucet aerator (1.5 gpm)	3,500,000	$ 10	$ 35.0	$ - 1,200
Restaurant pre-rinse spray valve (1.0 gpm)	20,000	$ 25	$ 0.500	$ - 5,550
Connectionless food steamer	7,000	$ 4,040	$ 28.2	$ - 523
Commercial dishwasher	8,500	$ 2,560	$ 21.8	$ - 7,060
Commercial front-loading clothes washer	90,000	$ 323	$ 29.0	$ - 231
Commercial urinal (0.5 gpf)	750,000	$ 13	$ 9.38	$ - 214
Commercial toilet (1.28 gpf)	750,000	$ 63	$ 46.9	$ - 229
Cooling tower pH controller	5,500	$ 2,810	$ 15.5	$ - 188
Pressurized water broom	50,000	$ 313	$ 15.6	$ 387
Replace lawn with low-water-use plants	12,000 acres	$ 54,500	$ 653	$ 1,680
Total			**$ 1,300**	**$ - 99.3**

Note: All numbers are rounded to three significant figures. Water savings from lawn replacements are based on replacing 2,000 acres of lawn with low-water-use plants in each of six California counties: San Diego, Orange, Riverside, Ventura, Fresno, or Sacramento Counties. Cost of landscape conversion is based on a rebate level of $1 per square foot, which does not account for economies of scale with larger installations and reduce the unit cost to less than half this rate.

We assume that the cost of installing precision irrigation systems is $1,200 per acre (Cooley et al. 2009; AWMC and CFWC 2010). The costs for improving irrigation management practices (regulated deficit irrigation and irrigation scheduling) vary depending on the equipment and amount of automation. A study coordinated by local Cooperative Extension agents in Nebraska found that costs to implement irrigation scheduling, including irrigation scheduling supplies, labor, and the cost for pumping plant adjustment, totaled around $15 per acre in 1990 U.S. dollars, or $25 per acre in 2010 U.S. dollars (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).

In total, we estimate that these agricultural water efficiency measures require an initial investment of $575 million (Table 5), including $530 million in initial capital costs for installing efficient irrigation technologies and $45.7 million in weather and soil moisture monitoring equipment for irrigation scheduling and deficit irrigation. Annual operation and maintenance costs associated with these improved irrigation management practices would cost $47 million per year. The cost of conserved water would be of $185 per acre-foot over the lifetime of the measure, significantly cheaper than most sources of new water supply. Furthermore, these cost estimates do not include the many co-benefits of water-efficiency improvements, e.g., improvements in crop quality, water quality, and crop yield.

Table 5. Initial investment and cost of conserved water for agricultural water conservation and efficiency measures.

	Area Effected (acres)	Capital Cost ($/acre)	O&M Cost ($/acre)	Initial Investment ($ millions)	Annual O&M ($ millions)	Cost of Conserved Water ($/AF)
Irrigation scheduling	811,000	$ 45.0	$ 25.0	$ 36.5	$ 20.3	$ 100
Regulated deficit irrigation	205,000	$ 45.0	$ 25.0	$ 9.21	$ 5.12	$ 43.0
Drip/sprinkler irrigation	424,000	$ 1,250	$ 50.0	$ 530	$ 21.2	$ 391
Total	1,440,000			$ 575	$ 46.6	$ 185

How does the cost compare to other water supply options?

Applying the water conservation and efficiency measures described here to only a small fraction of the homes, businesses, and farmland in the state would deliver valuable water savings far below the cost of new infrastructure currently proposed. As in the earlier example of Sites Reservoir, a capital investment of $3.0 billion yields water at an estimated cost of $520 per acre-foot[10] plus an additional $140 to $150 per acre-foot to pump that water over the Tehachapi Mountains (DWR 2007), for an expected long-term annual yield of 184,000 acre-feet. And the

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[10] Cost estimate based on the best alternative identified in USBR 2008a.

proposed dam at Temperance Flat requires a capital investment of $3.4 billion to yield water at an estimated cost of $720 per acre-foot, for an expected annual yield of 158,000 acre-feet per year.[11]

Like most projects, infrastructure project proponents minimize the actual costs and exaggerate the benefits. Project costs and benefits are spread out over an unusually long 100-year lifetime, making the annual costs lower and the project water yield higher than if the project lifetime were more realistic. Environmental benefits are included in the cost estimates, making the projects appear more economically favorable. Yet, the environmental cost of building these facilities, including riverine habitat losses, is ignored. Recreational benefits are typically included, although the cost of destroying existing recreational sites is ignored.

Furthermore, the costs for building Sites and Temperance Flat Reservoirs do not capture the cost of actually providing this water to Californians. Additional infrastructure would be required to deliver that water to communities throughout the state. In addition, local communities would need to build new or expand existing water and wastewater treatment plants. Furthermore, the customer would bear additional cost to use that water, e.g., heating and, in some cases, treating this water in their homes and businesses. By reducing the volume of water needed to take showers and clean clothes, water conservation and efficiency reduces the volume of water that must be moved, treated, heated, and treated again as wastewater, reducing the need and cost to develop additional water and wastewater treatment infrastructure.

How do we pay for it?

While the water savings we identified are far cheaper than most other supply options, they are not free. Capturing these savings requires an initial investment. These efficiency improvements, however, often pay for themselves as a result of the many co-benefits that water conservation and efficiency provides, including reductions in wastewater and energy bills and improvements in crop quality and yield. The distribution of benefits among the customer; general public; water, wastewater, and energy utilities; and irrigation districts suggest that the costs should be shared among these beneficiaries. Energy and wastewater utilities benefiting from these programs could partner with water agencies and irrigation districts to provide their customers with rebates and other financial incentives. Water agencies and irrigation districts could adopt pricing structures whereby revenue generated from higher charges on water wasters could fund conservation programs. The State could provide money through grants and low-interest loans to utilities and irrigation districts to increase customer incentives. Many of these programs are in use to some degree throughout California, but they can and must be expanded. In addition, the State could institute a public goods charge, as was done for energy in 2000, to provide a steady stream of

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[11] Cost estimated based on alternatives identified in USBR 2008b. Note that the Bureau of Reclamation annualizes the cost over a 100-year period at a 4 7/8% interest. These unusually generous assumptions deflate the cost of water from this project.

funding for water conservation and efficiency programs. Depending on the fee schedule, a public goods charge could generate $100 million to $500 million annually (DWR 2010). These approaches have the added benefit of reducing pressure on the state's general fund by ensuring that the beneficiaries pay the costs.

Conclusions

Water conservation and efficiency must be a central component of a portfolio of solutions for California's water problems. Improved efficiency can help meet California's water needs for decades to come while still satisfying a growing population, maintaining a vibrant agricultural and industrial sector, and restoring the health of the Sacramento-San Joaquin Delta and other threatened ecosystems. This assessment identifies 1 million acre-feet per year of potential water savings, split between the agricultural and urban sectors, which can be achieved with existing technology, and we recommend strategies for moving forward quickly to capture these savings. All together, the efficiency improvements require an upfront investment of $1.87 billion – far lower than many other water supply options. The cost of these efficiency improvements is $185 per acre-foot for the agricultural sector and a net *savings* of $99 per acre-foot for the urban sector. The net savings in the urban sector conservation measures means that the customer saves money over the lifetime of the device through lower energy and wastewater bills.

Water conservation and efficiency measures can be captured more quickly than traditional water supply options. In addition, savings from these measures are incremental. This is a key benefit of water conservation and efficiency measures. Conservation programs can be expanded when demand pressures are high and relaxed as demand pressures wane. With most water supply projects, however, the community is committed to maintain demand to ensure that the new supplies are fully utilized.

The cost for water conservation and efficiency measures can be defrayed through a combination of financial incentives, regulations, education, and pricing policies. Various financial incentives, including rebates, low-interest loans, and grants, can help reduce the upfront cost associated with these efficiency improvements. In addition, existing legislation requires that Californians install water meters, more efficient devices in their homes and businesses, and implement efficient water management practices on their farms. A combination of financial incentives, regulation, and education may mean that we can capture these savings at even lower costs and at a faster rate.

References

Bishop, W. J., and J.A. Weber. (1995). Impacts of Metering: A Case Study at Denver Water. Prepared for the 20th Congress IWSA, Durban, South Africa.

Black & Veatch. (2006). 2006 California Water Rate Survey. Los Angeles, California.

CALFED. (2006). Water Use Efficiency Comprehensive Evaluation: Final Report. California: CALFED Bay-Delta Program Water Use Efficiency Element. Sacramento, CA.

Christian-Smith, J., L. Allen, M. Cohen, P. Schulte, C. Smith, and P. H. Gleick. (2010). California Farm Water Success Stories. Pacific Institute, Oakland, California.

Cooley, H., P.H. Gleick, G. Wolff. (2006). Desalination: With a Grain of Salt. A California Perspective. Pacific Institute, Oakland, California.

Cooley, H., J. Christian-Smith, P.H. Gleick. (2008). More with Less: Agricultural Water Conservation and Efficiency in California: A Special Focus on the Delta. Pacific Institute, Oakland, California.

Cooley, H., J. Christian-Smith, P.H. Gleick. (2009). Sustaining California Agriculture in an Uncertain Future. Pacific Institute, Oakland, California.

Denver Water. (2009). Solutions: Saving Water for the Future. Retrieved on August 25, 2010, from http://www.denverwater.org/docs/assets/DD81F7B9-BCDF-1B42-DBDA3139A0A3D32D/solutions1.pdf.

Department of Water Resources (DWR). (2005). California Water Plan. Bulletin 160-05, Sacramento, California.

Department of Water Resources (DWR). (2007). Sites Reservoir: Frequently Asked Questions. Sacramento, California.

Department of Water Resources (DWR). (2009). California Water Plan. Bulletin 160-09, Sacramento, California.

Department of Water Resources (DWR). (2010). 20x2020 Water Conservation Plan. Additional authors include State Water Resources Control Board, California Bay-Delta Authority, California Energy Commission, California Department of Public Health, California Public Utilities Commission, and California Air Resources Board. Assistance also provided by California Urban Water Conservation Council and U.S. Bureau of Reclamation. Sacramento, California.

Energy Information Administration (EIA). (2010). Table 5: Average Monthly Bill By Census Division, and State 2008. Retrieved on August 24, 2010 from http://www.eia.doe.gov/cneaf/electricity/esr/table5.html.

Environmental Protection Agency (EPA). (2002). Cases in Water Conservation: How Efficiency Programs Help Water Utilities Save Water and Avoid Costs. Washington, D.C.

Gleick, P.H. (2003). Water Use. *Annu. Rev. Environ. Resour.*, 28: 275-314.

Gleick, P.H., H. Cooley, D. Groves. (2005). California Water 2030: An Efficient Future. Pacific Institute, Oakland, California.

Gleick, P.H., D. Haasz, C. Henges-Jeck, V. Srinivasan, G. Wolff, K.K. Cushing, A. Mann. (2003). Waste Not, Want Not: The Potential for Urban Water Conservation in California. Pacific Institute, Oakland, California.

Groves, D., S. Matyac, and T. Hawkins. (2005). Quantified Scenarios of 2030 Demand. In California Department of Water Resources (DWR). The California Water Plan Update. Bulletin 160-05, Sacramento, California.

Hanak, E. (2005). Water for Growth: California's New Frontier. Public Policy Institute of California, San Francisco, California.

Hamilton, F. 1992. Saving Water & Making Jobs. *Water Conservation News*. Department of Water Resources, Sacramento, California.

Hamilton, F. and J.P. Craft. (undated). CTSI Corporation. Dynamic Community Programming for Water Efficiency. San Rafael, California.

Kranz, W.L., D.E. Eisenhauer, and M.T. Retka. (1992). Water and Energy Conservation Using Irrigation Scheduling with Center-Pivot Irrigation Systems. *Agricultural Water Management*, 22(4): 325-334.

Lerner, S. (1997). Eco-Pioneers, Practical Visionaries Solving Today's Environmental Problems. Cambridge, MA: MIT Press.

MacDougall, N., M. Hanemann, and D. Zilberman. (1992). The Economics of Agricultural Drainage. Submitted to Central Valley Regional Water Quality Control Board, October 1992, Department of Agricultural and Resource Economics, U.C. Berkeley.

Maddaus, L. (2001). Effects of Metering on Residential Water Demand for Davis, California. Brown and Caldwell. Sacramento, California.

Maunder, D. and B. Hindley. (2005). Establishing Environmental Flow Requirements: Synthesis Report. Conservation Ontario. Retrieved July 11, 2008, from http://conservation-ontario.on.ca/projects/flow.html.

Mayer, P.W., E. Towler, W.B. DeOreo, E. Caldwell, T. Miller, E.R. Osann, E. Brown, P.J. Bickel, and S.B. Fisher. (2004). National Multiple Family Submetering and Allocation Billing Program Study. Boulder, CO.

Postel, S. and B. Richter. (2003). Rivers for Life: Managing for People and the Environment. Island Press. Covelo, California.

Queensland Water Commission. (2009). The 2008 Water Report. Retrieved on August 25, 2010, from www.qwc.qld.gov.au.

United States Bureau of Reclamation (USBR). (2008a). Plan Formulation Report: North-of-the-Delta Offstream Storage Investigation.

United States Bureau of Reclamation (USBR). (2008b). Plan Formulation Report: Upper San Joaquin River Basin Storage Investigation.

Western Resource Advocates (WRA). (2003). Smart Water: A Comparative Study of Urban Water Use Efficiency Across the Southwest. Boulder, Colorado.

Wichelns, D., and D. Cone. (1992). Tiered Pricing Motivates Californians to Conserve Water. *Journal of Soil and Water Conservation*, 47(2): 139-144.