ENERGY DOWN THE DRAIN

The Hidden Costs of California's Water Supply

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August 2004

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California has been through its share of scorching droughts and energy shortages, but many residents of the western United States may not realize the close connections between water and power resources. Water utilities use large amounts of energy to treat and deliver water. Even after utilities deliver water, consumers burn more energy to heat, cool, and use the water.

▸ The California State Water Project is the largest single user of energy in California. In the process of delivering water from the San Francisco Bay-Delta to Southern California, the project uses 2 to 3 percent of all electricity consumed in the state.

▸ The State Water Project burns energy pumping water 2,000 feet over the Tehachapi Mountains—the highest lift of any water system in the world. The amount of energy used to deliver that water to residential customers in Southern California is equivalent to approximately one-third of the total average household electric use in the region.

▸ Ninety percent of all electricity used on farms is devoted to pumping groundwater for irrigation.

Despite these connections, water planners at the federal, state, and local levels have largely failed to consider the energy implications of their decisions. Water agencies select water sources without assessing the energy costs of transporting the water over great distances to its users. Likewise, they fail to consider the energy savings of using less water. This kind of disregard for the energy implications of water leads to high costs for consumers and wasteful water-supply decisions.

A proper understanding of water and energy, however, can save both money and resources. Our report presents a model for how policymakers can calculate the amount of energy consumed in water use. We applied this model to three case studies in the western United States, and our analysis shows that integrating energy use into water planning can save money, reduce waste, protect our environment, and strengthen our economy. Water planners can use this model in their own regions to find similar solutions that will benefit consumers and the environment alike.

KEY FINDINGS

We quantitatively evaluated the connections between energy and water in three case studies. We used San Diego County's search for future water supply options to highlight energy use in urban water systems. Our examinations of the Westlands Water District and the Columbia River Basin illustrate energy use in agricultural settings. Our research found the following.

Water conservation lowers energy use and energy bills. The San Diego case study revealed that end use of water—especially energy intensive uses like washing clothes and taking showers—consumes more energy that any other part of the urban water conveyance and treatment cycle. This is a rather striking finding since conveyance is a much more obvious energy consumer, particularly in Southern California. Therefore, reducing water use can save significant amounts of energy. For instance, if

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San Diego relied on conservation instead of additional water from Northern California to provide the next 100,000 acre-feet of water, it would save enough energy to provide electricity for 25 percent of all of the households in San Diego.

Water recycling is a highly energy efficient water source. In both urban and agricultural settings, reusing water is far less energy intensive than any physical source of water other than local surface water. For example, Orange County is constructing a water recycling system that will use only half the amount of energy required to import the same amount of water from Northern California. Even groundwater pumping is more energy intensive in San Diego and the Westlands Water District than water recycling from urban wastewater; and the depth to groundwater in these locations is not atypical for western settings.

Orange County is constructing a water recycling system that will use only half the amount of energy required to import the same amount of water from Northern California.

Retiring agricultural land may increase energy use if the water is transferred to other agricultural or urban uses. Transferring water from retired, drainage-impaired Westlands land to urban settings would dramatically increase energy use because urban water use is typically more energy intensive. For example, we estimate that transferring the conserved water to San Diego would require an additional 1.3 billion kWh/yr compared to leaving that water in the delta. Allowing water to remain in Westlands would likely result in an increase in permanent crops and a significant increase in embedded energy ranging from 16 percent to 48 percent depending on assumptions.

Retiring agricultural land can save energy if the water is dedicated to the environment. Using data from the Westlands Water District—one of the largest agricultural users of water in the West—we concluded that ending irrigation to retired farmlands could generate large energy savings if the water remains instream. Retiring 100,000 acres of drainage-impaired farmland in Westlands, with corresponding reductions in Central Valley Project deliveries, could save at least 71 million kWh from reduced Central Valley Project pumping. This is enough to meet the residential energy needs for the city of Modesto for two months. Retiring this land could also save an additional 50 million equivalent kilowatt-hours used for cultivation and harvest.

Diverting water above dams costs power and money. Our Columbia case study demonstrates that when water is diverted for irrigation before it reaches a dam, an enormous amount of energy—the foregone energy production—is lost. For example, the foregone energy production in the Columbia Basin Project is the equivalent of 30 percent of the total energy use for the city of Seattle. This loss may be large enough, in dry years, to make it possible to pay farmers more than they could earn growing low-value crops and still have enough money to purchase environmental flows when they are most valuable.

RECOMMENDATIONS

All three of our case studies demonstrate that including energy considerations in water management decisions can lead to significant energy—and money—savings.

The case study analysis supports two primary recommendations for how policy makers can begin to achieve these savings.

Decision makers should better integrate energy issues into water policy decision making.
Looking at energy use and water use simultaneously generates valuable insights that do not arise from separate policy analyses of water and energy issues. We therefore recommend:

▶ Modifying state planning tools, such as the Urban Water Management Planning Act and Bulletin 160, among others, to require inclusion of energy use and costs;

▶ Improving coordination among resource management agencies to better identify and address the energy implications of water policy decisions;

▶ Conducting an energy intensity analysis of the United States Bureau of Reclamation's distribution systems and identifying regions and districts where large amounts of power are required to deliver water;

▶ Exploring the retirement of drainage-impaired lands in the Central Valley in order to reduce energy use and generate water to help restore the delta;

▶ Developing partnerships designed to produce energy, economic, and environmental benefits through voluntary water transfers in the Columbia River Basin and elsewhere, with a focus on dry-year transfers where large water diversions reduce downstream flows and hydropower generation.

Both water and energy policymakers should give water conservation higher priority.
Surprisingly, policy actions that affect end uses of water may have much larger energy implications than policy actions that affect the mix of physical water sources. We conclude that conservation has much greater potential, and stronger energy-related economic and environmental benefits, than has been recognized to date. In addition, the energy benefits of conservation can generate air quality and climate change benefits. Given this strong finding, we recommend:

▶ Prioritizing conservation funding;
▶ Enforcing existing conservation requirements;
▶ Requiring water measurement;
▶ Promoting conservation through conservation pricing;
▶ Offering conservation incentives;
▶ Implementing measures to ensure conservation savings.

CHAPTER 1

THE HIGH COST OF ENERGY USE IN WESTERN WATER SYSTEMS

Water use and energy use are closely linked. Providing and using water consume large amounts of energy. Energy production frequently uses or pollutes water.[1] Most electricity production also contributes to global climate change, which is likely to have tremendous impacts on water availability and management. Yet energy and water issues are rarely considered together. This is as true at the policy level as it is at the personal level. Most consumers certainly do not realize that saving water is an excellent way to save energy and, indirectly, to reduce air pollution.

The California Water Code notes that wasting water is an unreasonable use of energy.[2] Yet none of the existing resource planning efforts meaningfully addresses the interplay between the two issues, let alone their relationship with climate change. Even the California Energy Commission (CEC) has noted this failure. A CEC report to the state legislature noted: "The State appears to not be consciously managing its rapidly evolving water and energy policies in a coherent manner."[3] Integration of energy considerations into water policy and planning is long overdue.

This report explores the energy implications of water use and presents a methodology for incorporating energy impacts into water resource decisions. It relies heavily on data and examples from California but includes a case study from the Northwest.

THE LINKS IN THE WATER-ENERGY CHAIN

The more than 60,000 water systems and 15,000 wastewater systems in the United States are among the country's largest energy consumers, using about 75 billion kWh/yr nationally—3 percent of annual U.S. electricity consumption.[4] This demand is equivalent to the entire residential demand for the state of California and does not even include energy for what is called end use: the energy required to further treat, circulate, heat, or cool water at the consumer level.[5] Even if all of this power came from relatively clean modern natural-gas-fired power plants, producing the energy used by water systems would release approximately 30 million tons of carbon dioxide—the equivalent of more than 4 million cars.[6]

Many of the peak demands for water and the energy required to treat and transport that water coincide with the peak seasonal energy demands experienced by the electrical utilities, particularly in areas with hot summers like Southern California.[7] Thus, reducing the energy required to move, use, and treat water could help avoid power outages and avoid or delay the need for new power facilities.

This report divides the water supply-use-disposal chain into five stages.[8]

Source and conveyance ▶ **Treatment** ▶ **Distribution** ▶ **End use** ▶ **Wastewater treatment**

▸ *Source and conveyance:* Significant amounts of energy may be required to create a usable source of water and bring it to where it will be treated or consumed. Most water used in the United States is diverted from surface sources such as rivers and streams or pumped from groundwater aquifers. Smaller amounts of freshwater are produced from salt water, brackish water, or wastewater using desalination or water-recycling technologies. Desalination requires energy to remove salts from water using reverse osmosis or other processes. Water recycling requires energy to remove pollutants from wastewater.

Water is either used near its source or transported for storage and use elsewhere. Conveying water often requires pumping the water over hills and mountains or into storage facilities—a process that can require large amounts of energy. Such systems

FROM SOURCE TO TAP: THE HIGH ENERGY COST OF MOVING WATER

Moving large quantities of water over long distances and significant elevations is a highly energy intensive task. For this reason, water systems in the West are particularly energy intensive. According to the Association of California Water Agencies, water agencies account for 7 percent of California's energy consumption and 5 percent of the summer peak demand.

The State Water Project (SWP) is the largest single user of energy in California. It consumes an average of 5 billion kWh/yr, more than 25 percent of the total electricity consumption for the entire state of New Mexico. The California Energy Commission reports that SWP energy use accounts for 2 to 3 percent of all electricity consumed in California.

The SWP consumes so much energy because of where it sends its water. To convey water to Southern California from the Sacramento–San Joaquin Delta, the SWP must pump it 2,000 feet over the Tehachapi Mountains, the highest lift of any water system in the world. Pumping one acre-foot of SWP water to the region requires approximately 3,000 kWh. Southern California's other major source of imported water is also energy intensive: pumping one acre-foot of Colorado River Aqueduct water to Southern California requires about 2,000 kWh.

In fact, according to an estimate from the Metropolitan Water District of Southern California, the amount of electricity used to deliver water to residential customers in Southern California is equal to one-third of the total average household electric use in Southern California.

usually also have hydroelectric generators that recover some of this energy as the water falls down the other side of those hills and mountains.

▸ *Water treatment:* Water treatment facilities use energy to pump and process water. The amount of energy required for treatment depends on source-water quality. High-quality groundwater may require little treatment; surface water taken from rivers that have upstream discharges of wastewater may require significant treatment. The energy required for water treatment is expected to increase over the next decade as treatment capacity expands, new water quality standards are put in place, and new treatments are developed to improve drinking water taste and color.[9] Agricultural water generally is not treated before use.

▸ *Local water distribution:* Energy is typically required for local pumping and pressurization, but gravity pressurization and distribution are also possible when reservoirs are sufficiently higher than residences and businesses.

▸ *End uses:* Water users consume energy by further treating water (e.g. with softeners or filters), circulating and pressurizing it (e.g. with building circulation pumps or irrigation systems), and heating and cooling it.

▸ *Wastewater collection and treatment:* Treating wastewater consumes energy in pumping, aeration, and other processes. In 1995, wastewater treatment in California used approximately 1.6 billion kWh of electricity.[10]

ENERGY AND WATER USE: A CYCLE OF ENVIRONMENTAL DAMAGE

The development of the American West was facilitated by the construction of large water projects to convey water for municipal and agricultural uses. These water projects have brought important benefits, but they have also had well-documented and devastating impacts on rivers and landscapes throughout the West. Many once abundant species are now threatened or endangered due in part to these projects. When you include the massive energy production needed to operate these water projects, their environmental impacts are even greater. As one of the largest consumers of energy in the state, California's water system significantly contributes to the state's energy-related pollution.

Energy production has a wide range of damaging environmental and health effects, depending on how and where that energy is produced. Electric power plants, for instance, release dangerous levels of soot and smog, causing thousands of premature deaths, hundreds of thousands of asthma attacks, and other illnesses each year. In addition to the frequently noted air quality impacts of electric power plants, many power plants have once-through cooling systems that can significantly harm ocean and river environments. According to the Hudson Riverkeeper, a typical power plant using once-through cooling technology can kill billions of fish each year by trapping fish against intake screens or drawing fish into the facility.[11] Hydroelectric power production has far less impact on air quality, but far more negative effects on rivers and the aquatic species they support.[12]

THE WATER-ENERGY-CLIMATE-CHANGE FEEDBACK LOOP

Energy production also leads to climate change. Power plants emit 40 percent of U.S. carbon dioxide pollution, the primary cause of climate change. Unless emissions are reduced, average U.S. temperatures could be 5 to 10 degrees Fahrenheit higher by the end of the century. Climate change has the potential to greatly affect water supply and water management. In California, climate change is likely to lead to greater risk of drought or water shortages in the summer months. At the same time, winter runoff may increase and cause a greater risk of flooding. [13]

All of these changes could have serious consequences for hydroelectric power generation. Changes in runoff have a direct impact on the amount of hydropower generated both because hydropower production decreases with lower flows and because higher flows often must be spilled past dams without producing any power. During droughts, there are two types of hydroelectric losses: less water runs through the turbines in powerhouses, and the lower reservoir level reduces the “head,” thereby reducing the power produced by a given amount of water. In the Colorado River’s lower basin, a 10 percent decrease in runoff reduces hydropower production by 36 percent.[14] As hydropower generation decreases, energy users are likely to turn toward fossil fuels, thereby increasing emissions that contribute to climate change. During the first five years of the 1987 to 1992 California drought, hydropower losses cost California ratepayers $3 billion and led to an increase in greenhouse gas emissions of 25 percent over normal levels.[15]

ENERGY AND WATER SUBSIDIES: THE DRIVING FORCE BEHIND INEFFICIENCY

Despite the significant environmental and health concerns caused by energy intensive water use, many current policies actually encourage this wasteful practice. Energy and water subsidies in particular help drive the cycle of inefficient and energy intensive water use by hiding the true resource costs.[16] Water subsidies increase demand for water (thereby increasing energy use) and discourage conservation. Energy subsidies encourage transporting water over distances and pumping groundwater from depths that would not be economically feasible if the water users had to pay all the costs of energy and water. Policies aimed at reducing the energy used in water supply should address these inappropriate financial signals.

Subsidies exist when prices charged do not cover the government’s cost or when the price does not equal comparable market price. A 1992 report from the Department of Energy’s Energy Information Administration calculated the estimated subsidy value from these two different perspectives on federal hydropower sales nationwide. The report concluded that the annual subsidy at historic cost with full cost recovery was $1.232 billion for the Bonneville Power Administration (BPA) and $505 million for the Western Area Power Administration (WAPA) in 1990. The subsidy at estimated market price of electricity was $213 million for the BPA and $1.2 billion for the WAPA.[17]

Federal power remains close to the cheapest power in any region of the country.[18] Users of federally supplied irrigation water with access to this cheap power are getting

POWER ARBITRAGE: MAKING A PROFIT OFF SUBSIDIES

The schemes enabled by subsidized power rates can be seen in the Bureau of Reclamation's Columbia Basin Project. The project sells power to irrigators for less than 4 percent of the market rate. To take advantage of this cheap power, some water districts in the CBP have added low-head hydropower generators to their water canals. The cheap energy used to pump water into the canals is then used to help generate hydropower that the irrigators sell at a substantial profit on the open market. According to a report by the Committee on Natural Resources, this practice reduces water conservation incentives even further because every drop of water added to the canals provides more hydropower profits for the district. By allowing what is essentially a power arbitrage scheme, the Bureau of Reclamation has created an incentive for intensive pumping, leading to excess water and energy use and unnecessary environmental impacts, all at the taxpayers' expense.

a double subsidy and are receiving a distorted price signal about the value of that energy. For the Central Valley Project, energy charges vary widely from contractor to contractor. A charge of 1 cent per kWh—which a Central Valley Project representative estimated was the average for the project—is equivalent to $10 per MWh.[19] In comparison to market rate, California has long-term energy contracts for $86 per MWh.

It is difficult to calculate the full value of the subsidies given to users of federally supplied irrigation water. This difficulty helps keep the energy costs of water systems buried. Many California farmers still pay the government $2 to $20 per acre-foot for water, which represents as little as 10 percent of the "full cost" of the water, although some farmers are paying more as contracts are revised (e.g., $35 per acre-foot).[20] For new projects built or proposed by the Bureau of Reclamation, water costs are between $250 and $500 per acre-foot.[21] These water and power subsidies can have perverse results, as illustrated in the box on power arbitrage.

Including energy considerations might eliminate some of the water supply projects currently being considered in California and would more accurately show the benefits of conservation as an alternative.

MISSED OPPORTUNITIES: WATER POLICY OVERLOOKS ENERGY USE

Resource management could improve if water planning and policy reflected the critical link between water and energy. Despite a few recent efforts, however, water planning at the federal, state, and local levels has largely failed to consider energy implications. CALFED, California's Bulletin 160 series, the California Urban Water Management Planning Act, and the Memorandum of Understanding Concerning Urban Water Conservation in California (MOU) all give inadequate attention to the connections between water and energy use and policy. Although CALFED and other agencies have completed many studies that compare the costs of different water supply options, few of these studies have taken into account the energy benefits and costs of different water supply options. This is unfortunate because energy cost is a critical factor in the cost of various water management alternatives. Including energy considerations might eliminate some of the water supply projects currently being considered in California and would more accurately show the benefits of conservation as an alternative.

Water planners at the state level also have done a very limited job of addressing energy considerations. The California Water Plan, known as Bulletin 160, updates information about current and future water supplies and water uses for all regions of the state, including an evaluation of possible options for meeting California's future water needs. The California Water Code requires that the Department of Water Resources update Bulletin 160 every five years. As recently as 1998, Bulletin 160 did not include energy considerations.

A draft of the 2003 California Water Plan was released in November 2003. For the first time, the water plan included a discussion of the impacts of global climate change on California water resources and policy. It also qualitatively considered energy prices as a factor that could affect future water use, supply, or management. Significant quantitative evaluation of energy issues was not included in the 2003 draft. Phases 2 and 3 of the update (scheduled for 2004 and 2005, respectively) might address energy issues in more detail, with quantification or modeling possible in Phase 3 (2005).

Water planning at the local level generally fails to integrate energy considerations. Under California's Urban Water Management Planning Act, every supplier of urban water to more than 3,000 customers or in quantities greater than 3,000 af/yr must adopt an Urban Water Management Plan and must update it at least every five years. The law requires that the plans contain fairly specific projections of supply, demand, and potential water conservation measures across a 20-year planning horizon. Completed plans are filed with the Department of Water Resources. The Urban Water Management Planning Act does not require water suppliers to consider the energy implications of their water management options or to factor in related energy costs and benefits when considering water conservation measures.

Most major urban water suppliers in California have committed to implementing a series of water conservation practices outlined in an MOU. The cost-benefit analysis required in the MOU does not require consideration of energy, so water suppliers may fail to implement conservation practices that are clearly cost-effective when energy is included (see Table 5 in Chapter 2 for some residential examples of this problem).

Finally, the California Environmental Quality Act requires suppliers to evaluate the potential environmental impacts of all projects, including water transfers such as the recent arrangement between the Imperial Irrigation District and the San Diego County Water Authority. But the energy implications of water decisions are so far below the radar of decision makers that the significant energy impacts of the transfer are not mentioned in the environmental impact report for the project.[22]

CHAPTER 2

The Connections Between Water and Energy

As water works its way from source to tap, it typically requires many infusions of energy. We need energy to move it from its source, treat it, pipe it into businesses, consume it in our homes, and treat it before disposal. While one step in this process might not require a lot of energy—using a low-flow toilet in Los Angeles, for instance—another step may consume a great deal of energy—transporting water 2,000 feet over the Tehachapi Mountains to Southern California.[23] It is only when we look at the energy consumed in the entire water cycle that we get a clear sense of how much energy is really at stake.

This kind of whole-system calculation is called energy intensity. Energy intensity is defined as the total amount of energy required to use a specific amount of water in a specific location.[24] Energy intensity takes into account each site-specific step in the water supply-use-disposal cycle: source and conveyance, treatment, distribution, end use, and wastewater treatment.

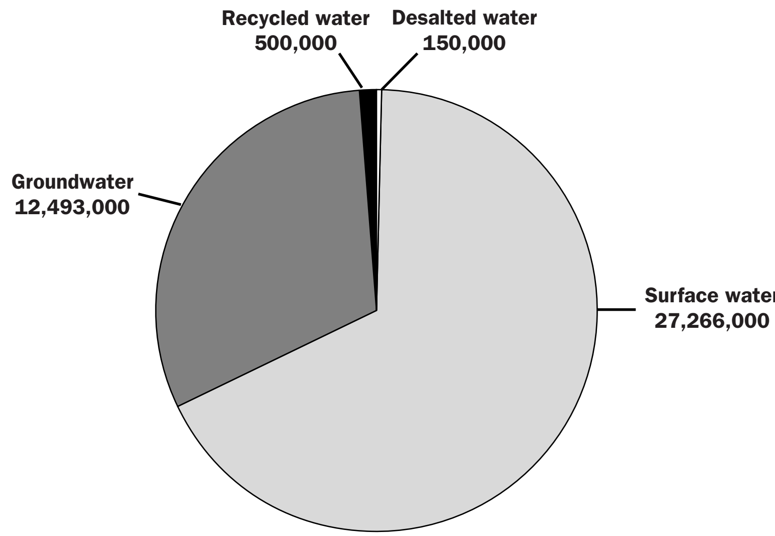
Looking at energy intensity reveals that not all water use requires the same amount of energy. For example, since it often takes more energy to convey a gallon of water from outside the region to Southern California than it does to Northern California, saving water in Southern California can achieve greater energy savings. This in turn means that water supply options appropriate for one region of California may not be appropriate for another. To determine appropriate strategies, water planners need to understand and quantify the five components of energy intensity presented below.

SOURCE AND CONVEYANCE

Source and conveyance ▶ Treatment ▶ Distribution ▶ End use ▶ Wastewater treatment

California gets its water from a great variety of sources and locations, and each one relies upon a different method of transport and a different amount of energy use. California's water supply mix is illustrated in Figure 1.[25] At present, surface water and groundwater provide the primary sources of water supply in California. Use of

FIGURE 1
Primary Sources of Water in California in Acre-Feet per Year



desalination and water recycling is expanding and could impact the energy used for water supply in some regions.

Surface Water

Surface water makes up about 70 percent, or about 27.3 million acre-feet per year, of water use in California. The majority of precipitation falls in the northern part of the state, while the majority of the population and the majority of water use is in the southern part of the state. Table 1 lists the major projects that transport water from one region to another in California.

These water delivery systems also generate hydroelectric power as water flows through power-generating turbines. Major water conveyance systems are either net energy producers (e.g., Central Valley Project, San Francisco, and Los Angeles aqueducts) or net energy consumers (e.g., State Water Project, Colorado River Aqueduct).

TABLE 1
Major Water Projects and Water Deliveries in California

Project	Average Annual Deliveries (million acre-feet)
Central Valley Project	7
All American and Coachella Canals	3
State Water Project	2.3
Colorado River Aqueduct	1.2
Mokolumne Aqueduct	0.36
Hetch Hetchy Aqueduct	0.33
Los Angeles Aqueduct	0.2
Potter Valley Project	0.154

Source: Association of California Water Agencies and Potter Valley Project Overview

The State Water Project and the Central Valley Project

The State Water Project (SWP) and the Central Valley Project (CVP) are two of the largest water projects in California and convey water the longest distances. The single largest user of energy in California, the SWP consumes an average of 5 billion kWh/yr, accounting for 2 to 3 percent of all electricity consumed in California.[26] On average, pumping one acre-foot of SWP water to Southern California requires approximately 3,000 kWh (this is an average net energy use figure; actual energy use varies for different Southern California communities).[27]

State and federal operations staff for the SWP and the CVP are well aware of the energy used to move water and have long worked to minimize it. The large energy requirements of the SWP were recognized even prior to its construction. Early SWP plans called for a dedicated nuclear power plant to provide electricity for the lift over the Tehachapi Mountains. Since then, some activities, including operational changes at the Oroville Dam and the Thermalito Afterbay, have been designed to reduce power use.

Both the SWP and the CVP have large financial incentives to reduce energy use. For example, the average SWP annual operating budget is about $900 million, of which at least a third is related to power costs.[28] Efficiency measures implemented by facility operators include:

- *Early water projections and energy purchases:* Each water year, the SWP makes projections for its water deliveries and develops its energy portfolios to ensure it has enough power to make these projected deliveries. Buying the power early in the water year is critical: the SWP makes advance purchases (days, weeks, or months ahead) on the power market because they are much more economical than buying on the spot market.

- *Optimizing pump scheduling:* The energy costs for water systems depend heavily on whether energy is consumed during on-peak or off-peak periods. On-peak energy is significantly more expensive than off-peak energy. Within system constraints, the SWP and the CVP try to take advantage of the price difference by pumping off-peak and generating on-peak.

- *Engineering, repairs, and maintenance:* CVP and SWP representatives say that their projects are constantly refurbishing the system to maximize power generation and minimize power use. This includes evaluating the efficiency of pumps and generators and upgrading technology.[29]

Despite these efforts at energy savings, the CVP and the SWP may become even bigger energy consumers, since both are now considering building new and expanded dams. Our analysis indicates that these new or expanded facilities are likely to be net energy consumers (see the "Can Building New Hydroelectric Dams Consume Energy?" box on page 10 for further discussion of this issue).

Conveyance and Evaporative Water Loss

Water is lost throughout the storage and conveyance process, often through evaporation and seepage as it sits in reservoirs and then travels through canals to water users.

CAN BUILDING NEW HYDROELECTRIC DAMS CONSUME ENERGY?

The Department of Water Resources and the Bureau of Reclamation are currently investigating five proposed new and expanded surface storage facilities to determine if they are feasible water supply projects. Proponents have cited hydropower production as an additional benefit for some of these projects. Careful analysis, however, reveals that these proposed dams might in fact be net consumers of energy.

Planning agencies often overlook two important energy-related issues regarding new and expanded dam projects: the first is off-stream location. Several of the facilities under consideration (Sites, Los Vaqueros, and some of the proposed sites on the Upper San Joaquin River) are off-stream facilities—constructed not on major streams, but in side canyons. These projects would require pumping water uphill into the reservoir. Energy would be generated when water is released from storage, but each of these facilities would be a net consumer of energy. Another of these proposed projects, the Delta Wetlands project, would be constructed on subsided delta islands. In this case, gravity would fill the reservoir, but energy would be required to pump water back into delta channels and deliver it to the SWP or other users. This facility would also be a net energy consumer.

The second often-overlooked issue is the amount of energy required to deliver the water generated by these new storage facilities. The water generated by new surface storage facilities could go to many water users. The closest potential user, Central Valley agriculture, however, will not be able to afford water from these facilities unless it is highly subsidized.

The other biggest market opportunity for the water is Southern California. But SWP water delivered to Southern California is very energy intensive, with a weighted average requirement for delivery of 2,947 kWh/af.[30] This energy requirement is so great that the energy required to convey this water would exceed the energy generated at the new dam. For example, one of the proposed expansions includes raising Shasta Dam. This is the best-case scenario since it would generate more new energy per acre-foot of additional storage than any other surface storage facility under consideration, both because Shasta is an on-stream reservoir that does not require pumping to fill the reservoir and because raising an existing reservoir generates more hydraulic head than a similarly sized new reservoir. Nevertheless, our analysis suggests that if the yield were delivered to Southern California, this project would result in a net consumption of 380 kWh/af.* In summary, all of the surface storage facilities under consideration by CALFED would be net consumers of energy if the water they generate were delivered to Southern California.

* See Larry Dale, et. al., *The Impact of Electricity Prices on the Cost of Five Options to Increase Southern California's Urban Water Supplies*, prepared for NRDC, 2003.

These losses increase the effective amount of energy required per usable gallon of water. Reservoir losses are not critical from an energy perspective when the reservoir is filled by gravity. But they may be critical if pumping takes place upstream of the reservoir (e.g., the Eastside Reservoir in Southern California) or if pumping is required to fill the reservoir, as in many of the current proposals for off-stream storage in California.

Reducing losses from reservoirs and conveyance systems could add to the available water supply and could generate additional hydroelectric energy. Reducing these losses would also lower the energy intensity of water supplies because it would decrease the amount of energy used to transport water that is eventually lost (carriage water). The SWP has not done an analysis of conveyance losses but estimates these losses to be 5 percent.

The CVP has not done an analysis of its evaporative losses either. Instead, its models use assumed conveyance losses for evaporation and seepage south of the delta. CVP operations assume a loss of 150,000 acre-feet out of 3 million acre-feet delivered, or approximately 5 percent.

When comparing imported water to other sources, such as recycling or desalination, a full energy accounting would include the energy required to move water to the point where it evaporates or seeps out of the conveyance system. This energy would be added to the energy required to transport the water actually delivered.

Groundwater

Groundwater represents about 30 percent of the water used in California, or approximately 12.5 million af/yr. This is 1.5 million acre-feet more than is naturally replenished, a pattern referred to as overdraft. Agriculture uses 85 percent of the withdrawn groundwater, and municipal areas use 15 percent. Most is used locally in the area overlying the aquifer.

California does not measure or regulate groundwater withdrawals, so groundwater data are incomplete. Therefore, it is not possible to calculate exactly how much energy is used in pumping groundwater. The California Department of Water Resources has estimated groundwater use and well depths in three areas that represent two-thirds of the groundwater used in the state. In the Tulare Lake Basin, with an average well depth of 120 feet, groundwater pumping requires 175 kWh/af. In parts of the San Joaquin River Basin and the Central Coast region where groundwater depth is closer to 200 feet, pumping requires approximately 292 kWh/af. Based on these estimates, electricity used for pumping groundwater in these areas would average 2.25 billion kWh/yr at a 70 percent pumping efficiency.[31] If this represents two-thirds of the state's groundwater use—and if all groundwater were pumped with electricity—then statewide electrical energy use for groundwater pumping would be approximately 3.4 billion kWh/yr.

In some areas, greater depth to groundwater requires even greater energy use. For example, pumping in Los Angeles requires 580 kWh/af.[32] Staff of the Sweetwater Authority and the Yuima Muncipal Water District in San Diego County report 467 and 661 kWh/af, respectively, are used on average to pump groundwater in their service areas (see Chapter 3). Staff of the Westlands Water District report that groundwater pumping in the district requires an average of 740 kWh/af (see Chapter 4).

Groundwater overdraft is a growing issue in some agricultural areas, like the Central Valley. As groundwater levels decline, an increasing amount of energy is needed to lift that groundwater to the surface. Jointly managing surface and groundwater resources, known as conjunctive use, holds promise as an approach to increasing water supplies in the West. Any analysis of conjunctive use projects must recognize and include the energy costs of retrieving the stored water from groundwater basins. However, if conjunctive use helps to recharge overdrafted groundwater basins, it could decrease the average use of energy for pumping groundwater. The California Energy Commission has expressed serious concerns about the CALFED conjunctive use proposals and CALFED's inattention to their energy implications.[33]

Desalination

Ninety-seven percent of the earth's water is too salty to drink or grow crops. However, salt water can be converted to freshwater through a process called desalination. Desalination has been limited in the United States because of its high cost: less than 1 percent of California's current water supply comes from desalination. However, it is a topic of growing interest as technological advances are reducing desalination costs.

The economics of desalination are directly tied to the cost of energy: energy constitutes approximately 40 percent of total costs. There are various methods of desalination, each requiring different amounts of energy. Energy use can vary within methods as well, depending on source water quality and design details.

The most common choice for new desalination plants today is reverse osmosis, in which salty water is filtered under high pressure through a semipermeable membrane. This method accounts for 90 percent of California's current desalination capacity. In 1999, desalination capacity in California was estimated at approximately 150,000 af/yr in more than 150 plants, the majority of which are small industrial plants. The 30 plants that are used for municipal purposes total about 80,000 af/yr.[34]

There are currently about two dozen desalination facilities proposed for along the California coast, with a total output of about 220,000 acre-feet.[35] The California Energy Commission is compiling data to determine how the energy demands of these proposed facilities could affect the state's power grid.

Current energy requirements and total costs for desalination vary widely depending on project specifics. For a seawater desalination plant under investigation by the Municipal Water District of Orange County, energy requirements are estimated at 5,500 kWh/af. The Carslbad seawater desalination project in San Diego County is estimated to use 5,400 kWh/af (see Chapter 3). Even lower energy use may be possible. Staff of Ionics Corporation report the new Trinidad seawater desalting plant will use about 4,800 kWh/af.[36] A proposed seawater desalting plant serving the Inland Empire Utilities Agency would use approximately 4,400 kWh/af.[37]

One of the models for lowering energy costs for desalination is colocating facilities with coastal power plants. Many of these power plants have destructive once-through cooling systems, however, and desalination should not be used to justify extending the life of these harmful facilities. In order for desalination projects—including colocated facilities—to gain acceptance, they will need to demonstrate a net reduction of environmental impacts.

Another opportunity for reducing energy requirements is to use desalination to treat brackish groundwater, which can produce water at a lower total cost and a lower energy cost than ocean desalination. Brackish groundwater treatment has enormously varying energy requirements depending on source water quality. Desalting brackish groundwater at the Chino Desalter Facility requires 1,700 kWh/af, while

CAN DESALINATION REDUCE ENERGY USE?

While desalination is very energy intensive on a per-unit basis, in some cases the flexibility it allows may result in lower total energy use.

The Marin Municipal Water District faces such an opportunity. The district is considering a desalination facility that would replace part of its contract with the Sonoma County Water Agency. The agency contract requires the district to purchase Russian River water at times of the year in which the water is not needed, in a classic "use it or lose it" arrangement. While the pumping needed to import Russian River water consumes less energy than desalination on a per-unit basis, the district would be forced to buy much more of it than it would need to produce with desalination.

With desalination, the district could shift more to its domestic reservoir supply—the least energy intensive source—in most year types, with desalination available as a dry-year supplement. The district's use of desalination to address peak demands could reduce its overall energy use.

In a dramatically different approach, private companies can also cover the cost of building and operating desalination plants in return for long-term contracts that require water agencies to purchase large volumes of desalinated water. Many Southern California projects are taking this approach. This could require desalination plants to operate at maximum capacity in order to drive down the unit cost, which could increase energy and air quality impacts.

the Reynolds water treatment plant in San Diego County reports only 405 kWh/af for treating brackish groundwater (see Chapter 3).[38] The same technology can be used to clean up groundwater impaired by other contaminants.

While the process of desalination remains expensive as a water supply option, it can have a variety of potential benefits relative to other sources of supply, including:

- *Local supply:* Desalination is typically done close to the place of use, so energy requirements for conveyance are likely to be lower than they would be for imported water supplies.
- *Reliability:* Desalination makes water available in all water years, while surface water and groundwater supplies may be limited in dry years. This reliability is extremely valuable to urban water users.[39]
- *Operational flexibility:* If the water is not needed, a desalination facility can be turned off. This is in contrast to the take-or-pay provisions of some water contracts. For the advantages and potential pitfalls of this approach, see the box on desalination above.
- *Water quality:* Desalination can produce very high-quality water, required by some water districts for blending with some of their lower-quality water supplies.
- *Potential ecosystem benefits:* Leaving surface water supplies instream and using desalinated water as a partial replacement can generate substantial ecosystem benefits.

Desalination may be a reasonable part of a water supply plan in areas where the energy costs of importing more supplies are high and where alternative water

Desalination makes water available in all water years, while surface water and groundwater supplies may be limited in dry years. This reliability is extremely valuable to urban water users.

sources could be environmentally damaging. This is particularly true when full life-cycle energy costs are considered along with the benefits of desalination, such as reliability, ecosystem restoration, and water quality.

However, before moving forward with desalination on a large scale, districts must recognize that very little is known about its impact on marine and coastal environments. Few, if any, studies have been conducted on marine resource impacts from the large-scale desalination facilities in the Middle East and Caribbean. The range of potential adverse environmental impacts that may arise from desalination facilities include siting and construction, waste discharge, energy consumption, coastal development, and injury and death of aquatic life from water intakes.[40] These must all be explored and adequately addressed before development of desalination facilities begins. In most cases, conservation or water recycling may offer better, cheaper, and less environmentally damaging alternatives.

Water Recycling

The California Water Code defines recycled water as "water which, as a result of treatment of waste, is suitable for a direct beneficial use or controlled use that would not otherwise occur."[41] By 2020 more than 3 million acre-feet of wastewater will be generated annually by California's urban coastal areas; much of this could be recycled.

In most cases, conservation or water recycling may offer a better, cheaper, and less environmentally damaging alternative to desalination.

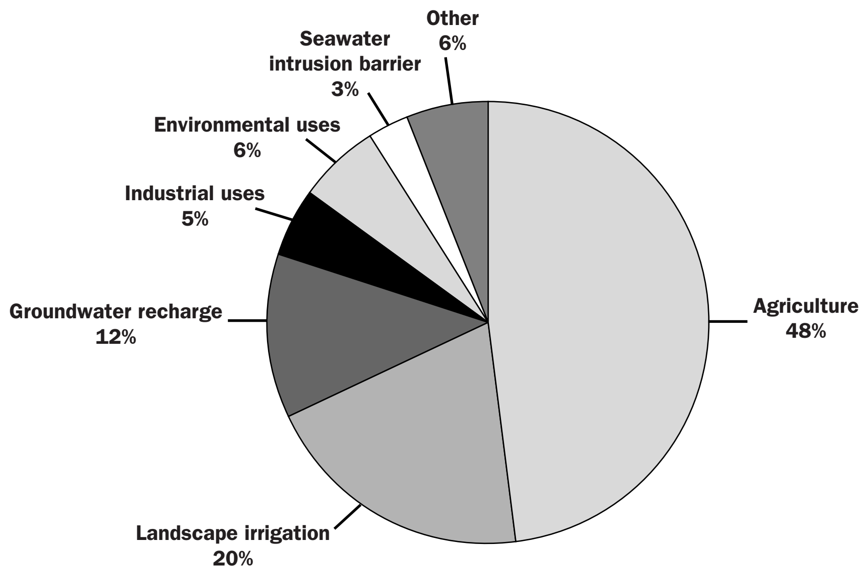
Recycled water is most commonly used for groundwater recharge or for landscape or irrigation purposes. While there have been some proposals for direct potable reuse of recycled water, these projects have not been implemented in the United States. Figure 2 shows municipal recycled water use in California in 2000.[42] Recycled water use is currently estimated to be within a range of 450,000 to 580,000 af/yr.[43] In addition to this officially recycled water, hundreds of thousands of acre-feet of treated wastewater are released into rivers and become part of the downstream water supply.

The energy costs for water recycling are the incremental treatment costs required to treat wastewater to the standard necessary for its intended use, and any energy required to convey the water to its place of use. Costs vary depending on the type of project being developed, the degree of treatment required, and the proximity of the water treatment plant to the location where the recycled water will be used.

In 2001, California legislation created a recycled water task force within the Department of Water Resources. The task force was assigned the responsibility of identifying impediments to using more recycled water in California, along with possible solutions. The task force's report was completed in June 2003 and asserts that California could recycle 1.5 million af/yr by 2030, with an investment of nearly $11 billion for additional infrastructure.[44]

Recycled water is already serving as an important element of water supply for many communities. As with desalination, water recycling offers reliability benefits, since it is available even in drought years. The energy costs for recycled water are likely to be lower than the costs for most other supply-side options, including desalination.

FIGURE 2
Recycled Water Use in California in 2000



The energy costs for recycled water are likely to be lower than the costs for most other supply-side options, including desalination.

The Orange County Water District is constructing a groundwater replenishment system—a water-recycling system that will replace an existing Orange County water recycling facility and will provide a new water supply for the area. Water from the system will be used as a seawater intrusion barrier as well as to augment groundwater supplies. Water costs for that component of the district's supply will be reduced by nearly half, since it will be less expensive to treat as well as produce the water locally than to import water.[45] In particular, producing the recycled water will require only half the energy it takes to bring water to Orange County from Northern California.[46] The system is expected to begin delivering water in 2007.

A few other examples of the many water recycling projects in California include:

▸ A joint project of the Dublin San Ramon Services District and the East Bay Municipal Utility District, in which 2,800 acre-feet of recycled wastewater are used to recharge the aquifer annually;

▸ South Bay and Long Beach, where recycled water is injected into formations that are part of the basin's aquifers to prevent seawater intrusion;

▸ Los Angeles County, where the Central Basin Recycled Water Project delivers approximately 4,000 acre-feet annually to more than 150 industrial, commercial, and landscape irrigation sites;

▸ South Bay Water Recycling in San Jose, which delivers around 16,000 af/yr to landscape irrigation customers;

▸ Monterey County Water recycling projects that provide recycled water for agricultural irrigation.

TREATMENT

Source and conveyance ▶ **Treatment** ▶ **Distribution** ▶ **End use** ▶ **Wastewater treatment**

Treatment is the second stage in the water use cycle, and generally applies only to urban water. The average direct electricity requirement for surface-water treatment plants is 450 kWh/af, with the bulk of that energy going to pump treated water.[47] Since pumping costs are directly related to the volume of water that must be pumped, reductions in demand for treated water will directly reduce this energy use. Energy efficient pumping systems can also make a significant difference in power bills and can reduce demand on energy infrastructure. Opportunities include installing premium efficiency motors and adjustable speed drives, selecting efficient pumps, using effective instrumentation and controls, and managing pumping operations by the efficient use of available storage and highly efficient pumping units.[48]

Data from the San Diego case study (see Chapter 3) confirm that energy for treatment is quite small. The Perdue Water Treatment plant reports using only 41 kWh/af; the Escondido-Vista plant reports 48 kWh/af; and the Levy Water Treatment Plant reports 68 kWh/af.

By reducing peak demand, water conservation can eliminate or delay the need for expanding treatment facilities or decrease the size of the expansion needed.

Most surface water sources require treatment, usually consisting of chemical additions, coagulation and settling, filtration, and disinfection. Urban water suppliers are moving in the direction of more energy intensive treatment methods of disinfection such as ozonation and ultraviolet radiation for health and safety reasons.[49] In many groundwater systems, disinfection is the only treatment required. Physical-chemical processes are used only in those cases where excessive concentrations of specific constituents have to be reduced.

Water treatment facilities are sized to meet peak demands. The lowest demand for water occurs in winter months when the requirements for outside water use are greatly reduced. Peak demand occurs in the summer when consumers irrigate for crops and landscaping. As mentioned in Chapter 1, many of the peak demands for water coincide with the peak seasonal demands experienced by the electrical utilities.[50] By reducing peak demand, water conservation can eliminate or delay the need for expanding treatment facilities or decrease the size of the expansion needed. By decreasing peak demands on the electrical utilities, water conservation can also help avoid power shortages.

LOCAL DISTRIBUTION

Source and conveyance ▶ **Treatment** ▶ **Distribution** ▶ **End use** ▶ **Wastewater treatment**

Water systems must transport water from the intake source to treatment facilities, then to local storage facilities, and finally to the customer. Most of the energy involved in municipal water systems is used for pumping. For a city of 50,000 people, approximately 2 million kWh/yr are required for all plant operations, with more than 1.6 million kWh of that amount needed for the pumping alone.[51] Assuming 2.6 persons per household and 0.5 acre-foot per household per year of water consumption, this pumping-only estimate converts to about 170 kWh/af delivered to customers.

These are average figures. In many cases, energy for pumping is much higher. According to members of the San Diego County Water Authority staff, there is enormous variation in the energy used to distribute water from their treatment plants to customers. Limited data from the San Diego case study support this belief. The Levy-Helix Water District, for example, reports an average of 215 kWh/af to deliver water to its customers; however, half the distribution grid is pressurized by gravity since some treatment plants are significantly elevated above end use locations. The electrically pressurized portion of their distribution system reportedly uses about 430 kWh/af. The distribution system for the North City (San Diego) water recycling facility reportedly uses about 940 kWh/af.

Many urban water distribution systems were placed underground more than 50 years ago, and leaks caused by corrosion of pipe material or other problems can lead to the loss of significant amounts of potable water. Distribution system losses increase the energy intensity of water supply by requiring utilities to treat and convey water that will be lost. Losses vary significantly among urban suppliers: typically from 6 to 15 percent, but as high as 30 percent.[52] Approximately 2 percent of this lost water goes to unmetered use for firefighting, construction, and flushing drains and hydrants.

One approach to improving management of local distribution and reducing energy costs involves using a supervisory control and data acquisition (SCADA) system. The SCADA system consists of a central computer that integrates the operation of water-system control points, such as pumps, reservoirs, and metering stations, even when located far away from one another.

Fresno installed a SCADA system in 1988. The SCADA system saves Fresno $725,000 per year in energy and water costs by doing the following:[53]

- Continuously monitoring the pumping energy required for each gallon of water that every well produces;
- Turning on the pumps at the most cost-effective wells first;
- Selecting wells according to optimum time-of-day electrical rates;
- Providing better control of water-line pressure, which reduces leakage.

With the SCADA system continuously monitoring and managing the pumps, Fresno saves energy and money both by reducing the energy consumed by the pumps and by saving water that previously was lost to leakage. While many urban districts use SCADA systems, not all systems are being operated to reduce energy use. Some agricultural districts are also installing SCADA systems and variable frequency motor drives that are more efficient under partial loads, allowing them to save both water and energy.[54]

THE END USE OF WATER

Once a customer receives water, additional energy may be needed to heat, cool, purify, or pump that water in preparation for its intended use. Changes in the amount or quality of water needed for some of these uses can further increase the amount of energy consumed in the process. The literature on water use contains little information on energy use integral to water end use beyond domestic fixtures and appliances. The San Diego case study (Chapter 3) and to lesser extent the Westlands and Columbia case studies (Chapters 4 and 5) evaluate this issue to the extent possible given the resources available for this report. This is an area of great significance for future research and energy and water policy.

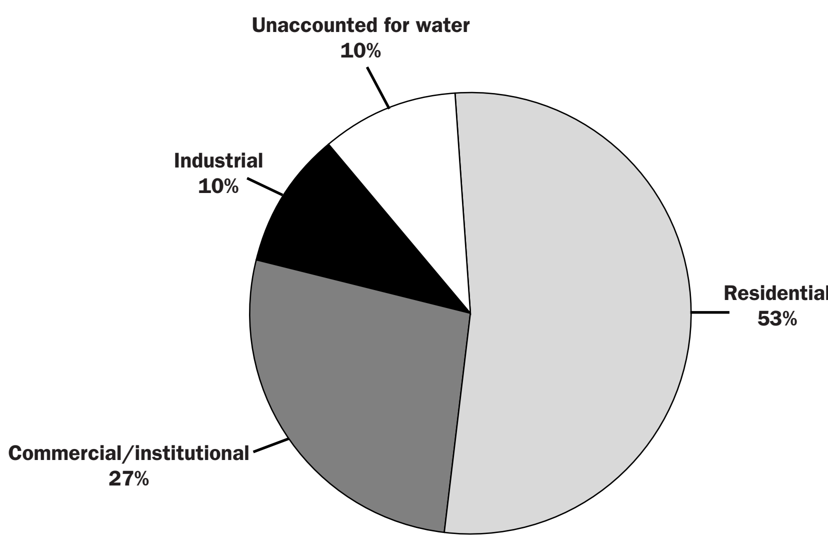
While there are efficiency improvements that can reduce the energy inputs required at each stage of the water use cycle, the greatest energy and water savings come from reducing water consumed by various end uses. Conservation at the end use stage eliminates all of the "upstream" energy required to bring the water to the point of end use, as well as all of the "downstream" energy that would otherwise be spent to treat and dispose of this water.

Conservation at the end use stage eliminates all of the "upstream" energy required to bring the water to the point of end use.

Urban Water Use

California urban water use in 2000 was approximately 7 million acre-feet.[55] Urban use is typically divided into residential and nonresidential use, with nonresidential use further divided into commercial, industrial, and institutional uses (CII). The breakdown of urban water use in California is illustrated in Figure 3.

FIGURE 3
Urban Water Use in California



Residential Water Use

California's residential sector uses almost 4 million af/yr. A new study found that approximately 1.4 million acre-feet of this use could be saved with existing cost-effective technologies.[56] These water savings would also provide substantial energy savings from avoided conveyance, treatment, distribution, end use, and wastewater treatment.

Hot Water Use

A study of 1,200 homes in 14 cities looking at residential water use found that the top four indoor uses were:[57]

- Toilet (26.7 percent);
- Clothes washer (21.7 percent);
- Shower (16.8 percent);
- Faucet (15.7 percent).

Energy use and savings from the latter three items on this list, which all use hot water, are presented in Tables 2 through 4.[58] Savings from toilets are discussed separately below.

Conserving water from some hot-water-using devices may not be cost-effective when water savings are considered alone. But as Table 5 demonstrates, the measures are very cost-effective when energy savings are included.[59] Where the table indicates

TABLE 2
Estimated Energy Use by Showerheads

	Rated Flow (gallons per minute)	Actual Flow (gallons per minute)	Estimated Energy Use per Household* (kWh/yr)	Estimated Savings per Household with a 2.5 gpm showerhead (kWh/yr)
1994–present	2.5	1.7	1,128	
1980–1994	3.0	2.0	1,328	200
1980–1994	4.0	2.7	1,793	665
Pre-1980	5.0–8.0	4.3	2,855	1,727

*Assumes 5.3 minutes per person per day; 2.64 persons per household; 0.13 kWh of electricity per gallon of water at 106 degrees.

TABLE 3
Estimated Energy Use by Faucets

	Rated Flow (gallons per minute)	Actual Flow (gallons per minute)	Estimated Energy Use per Household* (kWh/yr)	Estimated Savings per Household with a 1.5 gpm Faucet or Aerator (kWh/yr)
1994–present	1.5	1.0	445	N/A
1994–present	2.5	1.7	756	311
1980–1994	3.0	2.0	890	445
Pre-1980	3.0–7.0	3.3	1,468	1,023

*Assumes 8.1 minutes per person per day; 2.64 persons per household; 0.057 kWh per gallon of water at 80 degrees.

TABLE 4
Estimated Energy Use by Clothes Washers

	Water Use (gallons per minute)	Energy Use (kWh per load)	Estimated Energy Use per Household* (kWh/yr)	Estimated Savings per Household with a 27 gpm Clothes Washer (kWh/yr)
1998–present	27	1.6	632	N/A
1990–present	39	3.0	1,185	553
1980–1990	51	3.9	1,540	908

*Assumes 0.41 loads per person per day; 2.64 persons per household. Applies only to households with clothes washers.

TABLE 5
Accounting for Energy Benefits from Indoor Residential Water Conservation

	Cost of Conserved Water (Dollars per Acre-Foot Conserved)	
Device Installed (natural replacement)	**Without Energy Benefit**	**With Energy Benefit**
2.5 gallon-per-minute showerhead	$324	–$736
Average high-efficiency clothes washer (includes vertical and horizontal axis machines)	$865	–$177
Average high-efficiency dishwasher	$862	–$102

negative costs of conserved water, energy savings alone more than pay for the conservation investment.

Federal and state programs to promote market transformation, along with state and local rebate programs, can accelerate the adoption of these technologies.[60]

Cold Water Savings

Toilets and landscaping account for the two largest residential uses of water. Both use cold water and do not require significant end use energy. However, conservation of cold water can still save upstream and downstream energy inputs. Pacific Gas & Electric estimates that conveyance, treatment, distribution, and disposal energy requirements average 1,788 kWh/af statewide.[61] These requirements are much higher in Southern California, where conveyance alone averages close to 3,000 kWh/af.

Toilet flushing represents the largest single use of water inside the home. While older toilets use as much as 6 gallons per flush, federal and state water-efficiency laws now standardize flush volumes at a maximum of 1.6 gallons per foot for all new toilets. Many water utilities in California have conserved significant quantities of water by installing ultra low-flow toilets. Statewide, however, there are significant additional savings still available from ultra low-flow toilet retrofits.[62] Ultra low-flow toilets do not save end use energy because toilets don't use hot water, but they can save conveyance, distribution, and treatment energy.

Landscape water use represents approximately 40 percent of residential use in California. A recent study estimates that California residents could save from

25 to 40 percent of their landscape water use by improving management practices and applying already existing technology, such as rainwater cisterns and gray-water systems that reuse household wastewater for irrigation. These savings could be achieved relatively quickly and would reduce water use by 360,000 to 580,000 per year.[63]

One potentially effective way to target landscape water use is through rates. More than 2 million California residents are charged a fixed rate for water usage. This system fails to reward those who conserve and punish those who waste. Fixed rates are usually used when meters have not been installed. Lack of meters in turn allows leaks to go undetected. Data show that per-capita water use is about one-third less in areas where water users are billed based on volumetric rates rather than fixed rates. Metering is one of the most basic and effective water conservation tools. Recent legislation requires some unmetered cities in California to install water meters and bill water users on the basis of water use, and proposed legislation (AB 2572, Kehoe) would address the remaining unmetered cities.

Commercial/Industrial/Institutional Water Use

California's commercial, industrial, and institutional (CII) sector accounts for more than 30 percent of urban water demand, or around 2.5 million acre-feet.[64] More than 50 percent of the total CII water use is for cooling and heating, which requires energy inputs.[65] Recent studies estimate that cost-effective conservation could reduce CII water use by 15 to 50 percent.[66] In California, a recent study estimates that the CII sector could save 39 percent of the water it uses, which would correspond to state-wide savings of 1 million acre-feet.[67]

Data show that per-capita water use is about one-third less in areas where water users are billed based on volumetric rates rather than fixed rates.

Commercial customers often have the same water needs as residential users, e.g., toilets, sinks, laundries, kitchens, and landscaping. The most frequently used commercial conservation measures include plumbing fixtures and appliance retrofits or replacement and more efficient landscaping. Institutional customers, such as schools and universities, hospitals, government buildings, prisons, and military installations, primarily use water for heating and cooling, domestic uses, and landscape irrigation.

Industrial water use primarily falls into five categories:

- Cooling and heating
- Industrial processing
- Washing
- Adding as a direct ingredient
- Landscaping

Data on water-related energy use in industry are scant. The Department of Energy asks manufacturers to report energy information on many end uses, but water treatment (e.g., heating, cooling, treating water) is not one of the end uses. Instead it gets embedded into broader end use categories. This makes it difficult to estimate industrial water-related energy use.

The most common conservation measures used in the industrial sector include site-specific engineering modifications of water-using equipment and processes.[68] Despite the potential for large savings in the CII sector, a study done for the American

DISHWASHERS AND WASHING MACHINES: HOW AN INCREASE IN ENERGY INTENSITY CAN STILL LEAD TO OVERALL ENERGY SAVINGS

Energy intensity measures the amount of energy used per unit of water. Some water sources are more energy intensive than others; for instance, desalination requires more energy than wastewater recycling. Water conservation technology may either increase or decrease energy intensity.

Yet when water planners make decisions, they should look not just at energy intensity, but also at the total energy used from source to tap. In the case of water conservation, some programs may consume a lot of energy at one stage in the energy-water-use cycle, but still decrease the amount of energy used overall. The following three examples illustrate the interplay between energy intensity and total energy use.

Water conservation may increase energy intensity and increase total energy use. A particular irrigation technology could reduce water use by 5 percent, but require so much energy to operate that it increases the energy intensity per acre-foot of water by 10 percent. This could increase total energy use by 4.5 percent.

Water conservation may increase energy intensity and decrease total energy use. The average high-efficiency dishwasher increases the energy intensity of dishwashing by 30 percent, but it reduces water use by 34 percent. As a result of using less water—and therefore less energy to convey water from the source to the dishwater—the net total energy needed to wash dishes would decline by 14 percent.

Water conservation may decrease energy intensity and decrease total energy use. The average high-efficiency clothes washer reduces water use by 29 percent, as compared with average low-efficiency machines, and simultaneously lowers energy intensity by 27 percent. Energy intensity declines because mechanical aspects of the machines (agitators, etc.) are also improved. By reducing total water use and energy intensity, total energy use is reduced by 48 percent.

Water Works Association Research Foundation found that certain types of large water-using facilities such as correctional facilities, military bases, and utility systems have been ignored by many audit programs and have thus not received recommendations for conservation measures. The study further noted: "improved coordination and cooperation among water, wastewater, and energy utilities are needed to realize the water efficiency potential in the CII sector."[69]

Landscape water use represents the single greatest use in the CII sector. In 2000, 38 percent of CII water use in California was used for landscape irrigation.[70] A recent study estimates that it is possible to reduce this water use by 50 percent.[71] One important tool for achieving these savings is better management of landscape water use. Frequently, the same meter is used to measure a property's indoor and outdoor water use. In these complex mixed-use situations, it may be difficult to even know how much water is being applied to the landscape. Proposed legislation (AB 2298, Plescia) would require a dedicated landscape meter for new construction with more than 10,000 square feet of irrigated acreage and for existing properties with more than one acre of irrigated landscape. This would enable water agencies to establish water budgets for these large landscapes and to target landscape water waste with appropriate rate structures. Dedicated landscape meters would also enable landscape managers to better ensure the efficiency and proper functioning of irrigation systems.

Urban Conservation

Since end use appears to consume the most energy in the water-supply-use chain, water conservation programs hold enormous energy conservation potential. Much of the urban water conservation occurring in California is driven by national and state efficiency standards for certain water appliances and by the Memorandum of Understanding Regarding Urban Water Conservation in California (MOU)—an agreement signed by most of the large urban water suppliers in California outlining a series of water conservation best management practices. The MOU and the California Urban Water Conservation Council (composed of signatories to the MOU) deserve much credit for advancing urban water conservation in California.

Nevertheless, significant conservation potential remains beyond what the MOU requires.

▸ The MOU does not require agencies to implement all cost-effective conservation strategies, but rather specifies levels of implementation (i.e., percentage of customers to be audited or number of toilets to be replaced).

▸ The Urban MOU has minimal requirements for CII water use, demanding only that utilities survey and offer incentives to 10 percent of their CII customers, and to achieve 3 percent CII water savings through implementation of a CII ultra low-flow toilet program by 2004.

▸ Because the Urban MOU targets a limited number of customers for landscape audits, even full implementation of the MOU will probably generate only a small portion of these total potential landscape water savings.

▸ The MOU pays scant attention to energy. For example, MOU signatories are not required to include energy savings when determining if a best management practice is cost-effective.

The neglect is mirrored by the energy utilities, which pay little attention to saving water. The only water-saving elements typically included in energy conservation programs are those that save hot water. This is unfortunate because, as noted throughout this report, saving even cold water can save significant amounts of energy, depending on the source of that water.

Some energy utilities have noted the link between water and energy use and have targeted their public messages accordingly. Public education materials from the Sacramento Municipal Utility District note: "a tremendous amount of electricity is used to run the pumps that obtain, purify, and bring water to your house and then transport wastes to your regional wastewater utility. To help reduce this energy use, the Sacramento Municipal Utility District and the Sacramento Area Water Works Association ask that you avoid using large amounts of water during the peak energy demand hours of 11 A.M. to 7 P.M."[72] Unfortunately, this approach is still the exception.

In sum, while energy savings are possible at all stages of the water supply cycle, water conservation programs may be the most cost-effective way of reducing the total energy involved in urban water use. In particular, programs aimed at reducing water use in areas with energy intensive supplies may yield the most cost-effective water and energy savings.

Agricultural Water Use

Agriculture uses approximately 80 percent of the developed water supply in California. In 1995, this amounted to almost 34 million acre-feet.[73] In 1995, California agriculture used approximately 4.4 billion kWh of electricity for groundwater pumping and irrigation purposes, and more than 11 billion kWh for all purposes.[74] Ninety percent of all electricity used on farms is used for groundwater pumping.[75]

For agriculture south of the delta, significant energy may be required for conveying surface water supplies, and reducing water use can translate into energy savings. For agriculture in some other regions of California, such as the Sacramento Valley, surface supplies are gravity fed and reducing surface water use will not translate into saving conveyance energy. Yet even in these areas, improving water use efficiency may save energy by decreasing groundwater pumping and reducing energy required for local distribution. However, in some cases, energy savings from reduced surface water deliveries or reduced groundwater pumping may be partially or fully offset by increased energy requirements of some water-efficiency technology.

Given the proper price signals—especially elimination of subsidies—farmers may shift to lower-water-use/higher-value crops.

Improving the efficiency of irrigation systems through better water measurement and irrigation scheduling, installation of micro-irrigation systems, tailwater recovery systems, and other measures can reduce agricultural water use on farms. [76] In addition to improving irrigation efficiency, farmers can also reduce water use by shifting to lower-water-use crops. While crop choice is made based on a wide variety of factors, resource costs play a significant role. Given the proper price signals—especially elimination of subsidies—farmers may shift to lower-water-use/higher-value crops. For example, a 1992 California Energy Commission report to the state legislature found that agriculture's response to the seven-year drought and changes in energy rates "was to shift production from low-value to high-value crops (e.g., from alfalfa to tomatoes). Even with higher costs, the agricultural economy was robust and these high-value crops were able to absorb those costs."[77]

Dry years present a particular challenge for both water and energy systems: demands are greater while supplies are reduced. In dry years, water systems generate less power. Not only does less water run through the turbines in powerhouses, but also the lower reservoir levels reduce the water pressure and thus reduce the power produced by a given amount of water. Unfortunately, dry years tend to result in increased power demand. During dry years, water systems will need to pump more water—and therefore consume more energy—because irrigators (and other consumers) are getting less water from rainfall. Also, in low water years, farmers are more likely to rely on groundwater pumping, which increases the demand for power.

A voluntary program of compensated dry-year fallowing of agricultural lands could generate a substantial dry-year water supply. However, depending on the source and disposition of the transferred water, these programs may not save energy. Quantified examples of the potential energy and water benefits or costs of permanent or dry-year land-retirement programs are provided in the Westlands Water District (Chapter 4) and Columbia Basin (Chapter 5) case studies. As discussed in the Columbia River Basin case study, such programs can provide significant benefits to the agricultural economy.

Agricultural Water Conservation

California currently lacks a comprehensive program for agricultural water use efficiency. Agricultural water users established the Agricultural Water Management Council, which developed a list of best management practices, but environmental groups have been critical of the council's process because it fails to adequately address water measurement, and it relies on a purely voluntary approach. Only four water management plans were submitted to the council last year.

CALFED's efforts to develop an agricultural water-use efficiency program have also been a disappointment. CALFED staff worked with environmental and agricultural stakeholders and agency representatives to identify specific benefits related to water flow, timing, and quality that can be achieved through agricultural water use efficiency, and to establish quantifiable objectives for the portion those benefits for which agriculture should be responsible. This program could allow for inclusion of energy costs and benefits, although inclusion of energy costs is not currently required in the cost-benefit analysis that must be submitted with project proposals.

Unfortunately, the task of implementing the CALFED Agricultural Water-Use Efficiency Program has been passed on to the Department of Water Resources, where it languishes. Updating quantifiable objectives is supposed to be an ongoing process, yet no additional objectives have been developed or refined since the program was given to the department. There is no process in place for evaluating progress toward meeting quantifiable objectives. CALFED has not even initiated its required three-year evaluation of progress toward meeting quantifiable objectives. The program never adopted any enforcement mechanisms or consequences for not meeting the program objectives.

WASTEWATER TREATMENT

Source and conveyance ▶ **Treatment** ▶ **Distribution** ▶ **End use** ▶ **Wastewater treatment**

Wastewater systems generally include three components: collection systems (sewers and pumping stations), treatment facilities, and effluent disposal or reuse. Collection and disposal or reuse require energy for pumping, while treatment requires energy for pumping, running treatment operations, and processing solids. In 1995, wastewater treatment in California used approximately 1.6 billion kWh of electricity.[78] Given California's continued growth, current energy use for wastewater treatment is likely to be significantly higher.

TABLE 6
Energy Use in Wastewater Treatment

Treatment	1-mgd facility (kWh/af)	100-mgd facility (kWh/af)	100-mgd facility with energy recovery (kWh/af)
Trickling filter	580	225	130
Activated sludge treatment	750	340	225
Advanced treatment	865	400	280
Advanced treatment with nitrification	980	520	400

Estimates of the energy used in water treatment depend on facility size, type of processing, and efficiency. Some facilities (typically larger facilities) recover energy from biogas combustion, which reduces their net consumption. Average energy use is illustrated in Table 6.[79]

Frank Burton conducted a study computing a weighted average over the range of facility sizes and estimates the following net energy requirements: 440 kWh/af for activated sludge, 501 kWh/af for advanced wastewater treatment without nitrification, and 640 kWh/af for advanced wastewater treatment with nitrification. The study estimated that by 2008, 50 percent of U.S. wastewater treatment capacity would include nitrification.

Energy used for wastewater plants in the San Diego case study (see Chapter 3) ranged from 816 kWh/af for the Santee Basin plant to 1,272 kWh/af for the North City (San Diego) plant. Variation may be wider than these numbers suggest since all water from the Santee Basin plant is reused either in recreational lakes or for irrigation after treatment to tertiary standards.

Water conservation can reduce the energy required for treating wastewater and can eliminate the need for new or expanded facilities. The 1996 Clean Water Needs Survey submitted to Congress by the Environmental Protection Agency identified more than $139 billion in capital costs for water quality projects and other related work eligible for funding through state revolving funds established under the Clean Water Act. Close to $100 billion of this amount is flow-related and could be delayed or reduced through water conservation.

Water conservation can also reduce wastewater treatment operating costs. In Orange County, California, conservation-induced reductions in wastewater flows generated energy savings in collection systems pumping, influent pumping, aeration, and outfall pumping. Taken together, these energy savings amounted to $11,047 per year for each million gallons per day of reduced flow. These savings are equivalent to about $10 per acre-foot of reduced flow. Capital costs savings were estimated to be worth more than 10 times this amount for the Orange County system.[80]

ADDITIONAL ENERGY IMPLICATIONS OF WATER POLICY

This chapter has focused on the energy embedded in water use—the energy directly applied during the five stages of the water use cycle through activities such as pumping, heating, and cooling. However, the energy implications of water policy extend far beyond the energy embedded in water. For example, if a water allocation decision results in a factory closure, the factory would save both the energy embedded in water use and any other energy required for operating the facilities, such as heating, lighting, and industrial processing. The implications of a water policy decision may include changes in embedded energy use, as well as changes in other types of energy use.

In agriculture, water policy decisions may affect the amount of water applied to a field, and the energy required to obtain and apply that water. Savings from these changes represent the embedded energy component. In addition, water policy decisions that result in altered crop patterns may affect the amount of energy required for harvest, cultivation, and processing. These changes represent additional energy implications of the policy.

In situations where water for irrigation is diverted upstream of hydropower generation facilities, deciding to irrigate means deciding to forego hydropower generation. This lost hydropower generation is not included when calculating the amount of energy embedded in water, yet these hydropower opportunity costs are also energy implications of water resource decisions. (Chapter 5 explores these additional energy implications in the Columbia River setting.)

Where water for irrigation is diverted upstream of hydropower generation facilities, deciding to irrigate means deciding to forego hydropower generation.

This report has focused so far on energy embedded in water. But additional energy implications can be quite significant. While a complete analysis of the full energy implications of water policy decisions is beyond the scope of this report, for illustration purposes, we do analyze some of the additional energy implications of the specific water policy decisions discussed in the case studies.

CHAPTER 3

San Diego County—Energy and Urban Water

Like many California water agencies, the San Diego County Water Authority (SDCWA) is attempting to find additional water sources to meet its current and projected water demands. SDCWA staff estimate that at least an additional 100,000 af/yr of end use water will be required in 2020. Efforts to develop these supplies are well under way. However, analysis of supply alternatives historically has neglected consideration of energy implications. This chapter illustrates the type of results SDCWA would obtain if they analyzed supply choices from an energy perspective.

The preliminary results of our San Diego analysis indicate that:

- End use constitutes the largest component of energy embedded in the urban water-use cycle.
- Conservation and recycling appear to be the most energy efficient sources of water if local surface supplies are not available.
- Water supply decisions can significantly affect energy use. These energy implications warrant inclusion in water supply planning and other water management policy decisions.

A MODEL FOR QUANTIFYING ENERGY IN WATER USE

This chapter introduces a spreadsheet model systematically quantifying the energy use implications of water management decisions in an urban setting. This tool can help policymakers throughout the western United States to better understand the energy implications of their water demand management and water supply decisions. Chapters 4 and 5 apply the model in two agricultural settings: the Westlands Water District in California's Central Valley and Washington's Columbia Basin Project.

The model tracks the energy inputs for the five stages of the water use cycle.[81] This allows planners and policymakers to manipulate these inputs and predict the energy impacts of different water policy choices, such as constructing a desalination facility or implementing a water conservation program. A discussion of the methodological issues involved in constructing this model is presented in the box below. The full model is presented in Appendix A.

The case studies include enough specific data to reach some policy conclusions. They also help to identify areas where future research would be most worthwhile. Readers are cautioned that the case studies are illustrations of our methods, not full implementations of them. The methods require more location-specific information than could be assembled with the resources available during preparation of this report.

The San Diego case study illustrates how one can evaluate the energy implications of water policy decisions in an urban setting. The data sources, and assumptions used

METHODOLOGICAL ISSUES

As in all modeling efforts, there is a boundary question about which energy inputs should be included or excluded from the energy intensity estimates. We include energy used directly in managing water, e.g., pumping, heating, cooling, pressurization, and treatment. The method in this report is not a life-cycle analysis that accounts for indirect energy use such as the energy needed to manufacture and install a water pipeline.

For simplicity, the analysis only lists energy inputs that would change across water policy decisions. For example, the method does not quantify hydroelectric production in the State Water Project or Central Valley Project facilities prior to water intakes in the San Joaquin Delta, and it does not quantify gasoline or diesel fuel used to service these facilities. The policy decisions analyzed in this report would have little impact on these energy uses, so they are excluded.

The method uses water delivered to customers as the denominator of our energy intensity ratios. A qualitative definition of energy intensity is the amount of energy used per unit of water. Because water losses occur in the supply-use-disposal chain, however, there is more than one way to quantitatively define energy intensity. An acre-foot of water diverted by the State Water Project might yield only 0.95 acre-feet of water delivered to a water treatment plant because water evaporates and leaks from aqueducts and canals. If moving that amount of water were to take 100 kWh of energy, one could say that the energy intensity is either 100 kWh/af or 105.3 kWh/af (100/0.95). This same logic applies throughout the supply-use-disposal chain. One must choose water quantities at some point in the chain to use as the denominator in all of the energy intensity calculations in the chain in order to have consistent and meaningful results.

The method treats energy use as linear in the quantity of water transported or used. This is clearly not true at the scale of individual pumps because pumps are more efficient when operating near full capacity. They will use more energy per acre-foot lifted if they are running at half capacity. The linear assumption is often accurate, however, at larger scales because one of several pumps in a bank of pumps can be turned off or on in order to pump less or more water.

Not all energy used to pump or transport water is electric energy. For example, diesel fuel is increasingly used to pump water on farms, and natural gas is typically used to heat water in urban settings. The energy measure in this report is equivalent kilowatt-hours, which is the sum of actual kilowatt-hours and fossil-fuel use converted to kilowatt-hours. The conversion assumes that the fuels were used in thermal power plants to produce electricity.

in the San Diego case study, are listed in Appendix B. The data, however, may not be representative enough of the entire SDCWA service area to support final policy decisions on some issues.

THE SAN DIEGO CONTEXT

We chose San Diego County for our urban-water-supply case study because it involves a wide range of actual and potential water sources and conservation opportunities. The SDCWA is a regional water wholesaler that has been operating since 1944. It purchases water from the Metropolitan Water District of Southern California to sell to 23 member agencies located within the western third of San Diego County (920,000 acres; 1,437.5 square miles) and serves nearly 3 million residents. The water needs of the member agencies and their retail customers are diverse since the agencies consist of six cities, four water districts, eight municipal water districts, three irrigation districts, a public utility district, and a federal military reservation.

The average annual raw water supply in the SDCWA service area for 1996 through 2000 was approximately 685,000 acre-feet. Average annual raw water supplied by the SDCWA in 2020 is predicted to increase to about 810,000 acre-feet. Because water is lost in conveyance, treatment, and distribution, water currently delivered to customers is around 610,000 af/yr, while projected deliveries in 2020 are about 710,000 af/yr.

Key Water Supply Facts

▶ The Metropolitan Water District obtains water for the SDCWA from the Colorado River Aqueduct (about 470,000 af/yr) and the State Water Project (about 83,000 af/yr) and delivers it to the SDCWA at the boundary of Riverside and San Diego counties.

▶ Water is delivered from the SDCWA to its member agencies through two gravity-fed aqueducts containing five large-diameter pipelines (274 miles total).

▶ Water is delivered from the member agencies to retail customers via approximately 7,800 miles of pipeline.

▶ The local groundwater provides about 30,000 af/yr. One groundwater source is brackish and is treated to potable standards.

▶ Wastewater recycling provides about 18,000 af/yr.

▶ Surface water reservoirs are primarily used as terminal storage for imported water.

▶ The local surface water supply is about 86,000 af/yr.

Water in three of the five principal SDCWA pipelines is treated outside the county at the Metropolitan Water District's Skinner Water Treatment Plant in Riverside County. The SDCWA member agencies also operate 10 raw water treatment plants. Most water delivered by member agencies is treated potable water. The exceptions are recycled wastewater and untreated—raw—water provided for agricultural purposes. Member agencies operate 14 wastewater treatment plants and 24 water recycling facilities.

The SDCWA has encouraged water conservation and investments in end use efficiency, both directly and through membership in the California Urban Water Conservation Council—the implementing agency for the Memorandum of Understanding for Urban Water Conservation in California. The SDCWA also recognized that energy and water savings can occur together and began a successful partnership with San Diego Gas and Electric, the regional energy supplier, over 10 years ago. Since the collaboration began, more than 550,000 low-flow showerheads have been installed. Over five years ago, SDCWA partnered with San Diego Gas & Electric to offer financial incentives for installing horizontal-axis clothes washers.

THE SEARCH FOR ADDITIONAL WATER SOURCES

To supplement its current water supplies and plan for the future, the SDCWA has been working for years to arrange a 75-year water transfer agreement with the Imperial Irrigation District, located in southeastern California. The final transfer agreement, signed on October 16, 2003, calls for the SDCWA to receive up to 200,000 af/yr of water. Deliveries will ramp upward during the term of the agreement, providing an average of about 143,000 af/yr over the life of the agreement. The SDCWA will provide the Imperial Irrigation District with up-front payments of $20 million and payments for the transferred water starting at $258 per acre-foot and increasing each year, according to a set price schedule. Additional costs will be incurred to “wheel” this water to San Diego.

The SDCWA also recognized that energy and water savings can occur together and began a successful partnership with San Diego Gas and Electric, the regional energy supplier, over 10 years ago.

In its Regional Water Facilities Master Plan of 2000, the SDCWA identified reducing its dependence on imported water in general and its dependence on water imported from the Colorado River in particular as critical to making its water supplies more stable and reliable. Toward this end, the SDCWA has attempted to diversify and expand its local sources of water, specifically targeting seawater desalination as the preferred alternative.

The SDCWA has considered developing a seawater desalination facility at Encina, which would be constructed adjacent to the Encina Power Station. This project would be the largest seawater desalination plant in the Western Hemisphere, producing 50 million gallons per day (56,000 acre-feet annually) of fresh water. The project is similar to other reverse-osmosis facilities being constructed around the world, including new operating plants in Florida and Trinidad. This new water source would supply up to 8 percent of the region’s water needs.

In addition to developing the Encina facility, the SDCWA is evaluating other coastal locations that may be suitable for a regional seawater desalination facility. For example, the SDCWA is currently evaluating the feasibility of a desalination plant adjacent to the South Bay Power Plant in Chula Vista. Other coastal sites being evaluated include the San Onofre Nuclear Generating Station at the north end of San Diego County and sites as far south as the Mexican border.

SDCWA is not investigating or supporting any project to import water via ocean-going water bags towed by tug from Northern California or other points north. Nonetheless, the analysis includes an evaluation of water-bag supply to San Diego County as an interesting point of comparison with long-distance transport in canals and pipes. Readers should not construe inclusion of an alternative in this report as an endorsement by the authors or as a comment on the feasibility or appropriateness of any alternative.

RESULTS OF THE CASE STUDY

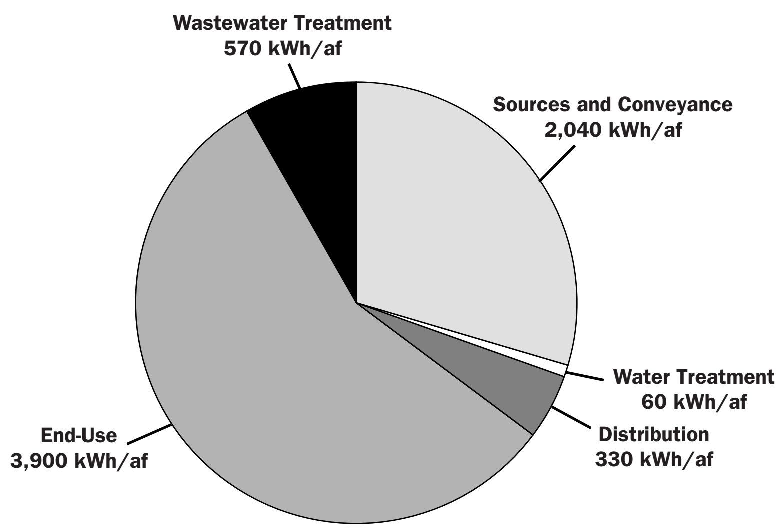
The SDCWA was able to provide some data for all five steps in the water-supply-use-disposal chain. Data from other locations were then used to supplement the analysis when San Diego data were not available. Consequently, the results of the case study analysis should be interpreted cautiously. Remember that the case studies demonstrate the methods and the importance of applying them, but they are based on limited data. Care should be taken in relying on this case study for final decision making until the data sources and assumptions are verified or modified appropriately.

End Use Energy Dominates the Water Use Cycle

Our research revealed that the end use of San Diego's water—heating it for showers, for instance, or pressurizing it for car washes—consumes by far the most energy in the whole water delivery chain. This is a rather striking result given that San Diego County imports most of its water from long distances, requiring large amounts of energy for conveyance.

Figure 4 describes the distribution of estimated total energy use per acre-foot (6,900 kWh) among the five components of the supply-use-disposal chain. Energy use that is integral to end use of water dominates the total.

FIGURE 4
Estimated Energy Intensity Components of Water in San Diego County



The relatively large amount of energy associated with end use is composed of three types. First, water is sometimes heated for use—for example, for taking showers in homes, for washing dishes in restaurants, or for manufacturing in some industrial facilities. Second, water is sometimes recirculated, pressurized, or lifted in use. Examples include cooling towers, recirculating hot water loops in newer residences, additional pressurization in high-rise buildings, and irrigation pipe pressurization or lifts from canals on farms. Finally, some energy use comes in close conjunction with water use, and may increase or decrease when water is conserved, but is not directly embedded in water. For example, energy is used to run air conditioning compressors that are water-cooled.

The summary number for estimated energy use integral to water end use shown in Figure 4 is presented in more detail in Table 7.[82] The energy intensity estimates are based on the data and assumptions listed in the table notes and are more fully described in Appendix B. Zeros are used when energy use is implausible. "Not Estimated" means data were inadequate to support a credible estimate. The numbers in the table are not significant to the digits shown, but are presented this way to facilitate comparison with other tables and figures.

The estimates in Table 8 probably understate energy use integral to water use because data on water-related energy use in the commercial, industrial, and

TABLE 7
Estimated Energy Use Integral to Water End Use in San Diego County

Water Use Category	Estimated Percent of Total Use in 2010 (8)	Estimated Energy Intensity (kWh/af) (8)
Residential	**58%**	
Toilets and leaks	14%	0
Dishwashers	1%	27,200
Clothes washers	8%	11,650
Showers, faucets, and bathtubs (1)	12%	6,700
Landscape irrigation	23%	0
Commercial, industrial, and institutional	**32%**	
Kitchen dishwashers	0.5%	27,200
Prerinse nozzles	0.2%	6,700
Other kitchen use	1.2%	Not Estimated
Laundries	0.6%	11,650
On-site wastewater treatment (2)	5.8%	800
Water-cooled chillers (3)	2.4%	67,700
Single pass cooling (3)	2.4%	0
Landscape irrigation	12.1%	0
Other heated water (4)	0.3%	6,700
Other unheated water (5)	6.5%	Not Estimated
Agricultural (6)	**10%**	**Not Estimated**
Totals and weighted average (7)	**100%**	**3,900**

Notes: (1) Showers and tubs heated to 105 degrees; faucet water conservatively assumed to be cold. (2) Estimate shown is for on-site wastewater treatment. (3) Assumes 50 percent of cooling water is single pass since the SDCWA provides financial incentives for water-efficient cooling investments. (4) CII water heating estimate from Sezgen and Koomey (1995), less other CII water heating estimated separately. (5) May use energy for recirculation or pressurization. (6) Data not available for San Diego County. (7) May differ from figures shown due to rounding. (8) Numbers are not significant to digits shown, but presented this way to facilitate comparison with other tables and figures.

TABLE 8
Energy Intensity of Sources of Water in San Diego County

	Energy Intensity (equivalent kWh/af)	Notes
Current Source Weighted Average:	**2,040**	
San Francisco Bay Delta (SWP)	3,240	Wilkinson (2000)
Colorado River (CRA)	2,000	Wilkinson (2000)
Local surface water	80	Raw water lift to treatment plants
Local groundwater	570	
Recycling	400	Includes one brackish groundwater treatment facility at 405 kWh/af
Potential Sources:		
Imperial Irrigation District	2,110	CRA (2000) plus hydroelectricity not generated in the All American Canal (110)
Seawater desalination	4,200	SDCWA seawater desalination facility at Encina
Water bags	1,180	900 mile tow

Our analysis shows that satisfying all growth in water demand via conservation would reduce the overall energy intensity of the SDCWA water supply by 13 percent.

institutional (CII) and agricultural sectors are incomplete, and the analysis conservatively omits some uses of energy for which credible estimates could not be made at present (e.g., CII process water heating or recirculation, and water lift or pressurization for agricultural irrigation).

Conservation and Water Recycling are the Least Energy Intensive Sources of Potential Supply

Our analysis shows that satisfying all growth in water demand via conservation would reduce the overall energy intensity of the SDCWA water supply by 13 percent. In comparison, satisfying all growth in water demand via recycling would reduce overall energy intensity by only 4 percent, while using seawater desalination to satisfy growth would increase overall energy intensity by 5 percent.

Table 8 presents the energy intensity of actual and potential sources of water in San Diego County. The first line in the table shows the weighted average energy use for the current mix of water sources.

The results presented above can be taken a step further by assessing the energy intensity implications of various "sources" of additional water (Table 9). An additional 100,000 af/yr implies an additional 108,000 af/yr of water from desalination or recycling facilities because 7 percent of water is estimated to be lost in distribution (i.e., 100,000/0.93 = 108,000). It implies an additional 113,000 af/yr of water delivered to San Diego County via the State Water Project, the Colorado River Aqueduct (presumably Imperial Irrigation District water rerouted to San Diego), or water bags because an estimated 5 percent more is lost in treatment. Or it implies no additional water, but conservation of about 16 percent of the estimated 610,000 af/yr of water actually delivered to customers today after losses in conveyance, treatment, and distribution.

As in the rest of this report, the total energy use is divided by the quantity of water delivered to the end user to calculate the average energy intensity. That

TABLE 9
The Energy Intensity for Satisfying 100,000 af/yr of Additional Demand

	Source and Conveyance Energy (kWh/af)	Water Treatment (kWh/af) (1)	Distribution (kWh/af) (2)	End Use (kWh/af) (3)	Wastewater Treatment (kWh/af) (4)	Total (kWh/af)
Status quo	2,040	60	330	3,900	570	6,900
Status quo plus scenario:						
Conservation	1,780	50	290	3,400	500	6,020
Recycling	1,830	50	330	3,900	500	6,610
Water bag transfer	1,950	60	330	3,900	570	6,810
Imperial Irrigation District transfer	2,080	60	330	3,900	570	6,940
Additional State Water Project	2,240	60	330	3,900	570	7,100
Seawater desalination	2,400	50	330	3,900	570	7,250

Notes: (1) The conservation, recycling, and desalination scenarios assume the additional 100,000 acre-feet of water do not require treatment, reducing the average energy intensity of treatment from 60 to 50 kWh/af delivered to customers. (2) Conserved water does not need to be distributed, reducing the energy intensity of distribution from 330 to 290 kWh/af delivered. (3) Conservation assumes no energy is conserved when water is conserved, but no energy is expended to conserve water either. (4) Wastewater is not generated by conservation or by recycling if recycled water is used for landscape irrigation, reducing energy intensity from 570 to 500 kWh/af delivered.

quantity is 710,000 af/yr in all but the conservation scenario. In order to make a fair comparison, however, the conservation scenario also uses a denominator of 710,000 af/yr, although only 610,000 af/yr would actually be delivered to customers. This is an appropriate adjustment because this level of conservation would meet the same need as 710,000 acre-feet would if San Diego were to choose to obtain additional water from the State Water Project or the other sources included in this analysis.

The table shows that water conservation is the far superior water "source" from an energy perspective. Of course, other considerations are relevant to the choice among "source" alternatives. For example, seawater desalination and recycling probably offer greater reliability benefits than the other alternatives.

Energy Implications of Water Supply Decisions Are Large and Warrant Inclusion in Water Supply Planning

Our analysis shows that not only are conservation and recycling the most energy efficient sources of new water supply, but also that shifting to conservation and recycling would generate large energy savings. Total energy savings from relying on conservation instead of additional State Water Project water to provide the next 100,000 acre-feet of water could be approximately 767 million kWh, or enough to provide the annual electricity for 118,000 households—25 percent of all of the households in the city of San Diego.[83] The scale of these potential energy benefits can also be illustrated by another comparison. The amount of energy that this conservation option would save is equal to 150 percent of the maximum annual output of the proposed—but now inactive—62.4 MW Chula Vista II power plant.[84] Relying on recycling rather than additional State Water Project water would save 348 million kWh, or enough to provide for the annual electricity needs of 53,500 households. Total energy use of the alternatives for adding 100,000 acre-feet to the status-quo water supply are presented in Table 10.

This case study demonstrates that water policy choices can save significant amounts of energy. The magnitude of these potential savings has important implications for decision-makers. An integrated approach to assessing San Diego's water supply options could save water and energy, and reduce emissions that contribute to climate change and other air pollution problems. Future planning efforts should capitalize on these opportunities. The type of analysis presented in this case study can easily be incorporated into local and regional water supply planning. Consultation between water agencies, state energy agencies, and local energy utilities can help California better manage our precious water and energy resources.

TABLE 10
Total Energy Use and Savings from San Diego Water Supply Options

Status quo plus scenario	Average Energy Intensity (equivalent kWh/af)	Total Energy Required for Water Supply (million kWh/yr)	Savings from Conservation Rather than an Additional 100,000 af/yr of Physical Supply (million kWh/yr)
Conservation	6,020	4,274	Not Applicable
Recycling	6,610	4,963	689
Water bag transfer	6,810	4,835	561
Imperial Irrigation District transfer	6,940	4,927	653
Additional State Water Project	7,100	5,041	767
Seawater desalination	7,250	5,148	874

CHAPTER 4

Westlands Water District—Energy and Agricultural Water

The Westlands Water District is one of the largest agricultural water users in California and the western United States. The district faces long-standing problems associated with soil quality and poor water drainage and is now negotiating with the Department of the Interior to retire—permanently fallow—a large portion of its agricultural lands.[85] In fact, the district has already started the fallowing process by retiring 33,000 acres. Retiring land presents significant implications for California's water use, since it raises the question of where water formerly used for crops will go instead. Our report asks and answers the question: how much energy will be required to use the water in a different way?

This report provides a case study of land retirement in Westlands because the results will be timely and could inform a real policy decision process. The study also illustrates more generally the energy-related issues and data that are necessary for evaluating energy impacts of agricultural water management decisions. Energy impacts have not previously been accounted for in analyses of land-retirement proposals.

This case study evaluates three alternatives for the disposition of the water formerly used to irrigate retired lands in the Westlands Water District: the water could be used to enhance environmental flows in the delta; it could be used on other land within the district; or it could be transferred to other agricultural or urban uses.

As with the San Diego example, care should be taken in making final policy decisions based on this case study without more detailed analysis. In particular, we present some information in the case study that is relevant to land-retirement decisions generally, but is not specific to the land currently proposed for retirement. This information is presented, rather, as an exploration of a new methodology that could be applied in other settings.

Our Westlands analysis indicates that:

- Significant amounts of energy can be embedded in agricultural water use. Agricultural water allocation decisions can have large energy impacts that warrant inclusion in analyses of water policy alternatives.

▸ The total energy implications of agricultural water policy decisions extend far beyond the energy embedded in water. To the extent possible, analyses of energy impacts should include harvest, cultivation, and other energy inputs.

▸ Retiring land south of the Sacramento–San Joaquin Delta and transferring water to environmental flows could save significant amounts of energy—the equivalent of powering more than 18,000 households for one year.

▸ Retiring land south of the delta and transferring water to urban users could dramatically increase energy use. For example, if water were transferred to San Diego County, energy use would increase by more than a factor of 8—that is, by more than 1.2 billion kWh/yr.

▸ Retiring land and allowing water to remain in the district for agricultural use would likely result in an increase in permanent crops, such as orchards, which under plausible assumptions would increase electricity use by 48 percent and total energy use by 16 percent.

Retiring land south of the Sacramento–San Joaquin Delta and transferring water to environmental flows could save significant amounts of energy—the equivalent of powering more than 18,000 households for one year.

The model used for the San Diego case study (Appendix A) was modified and simplified for the Westlands case study because many aspects of the urban water cycle (e.g., treatment before use) are usually not present in the agricultural sector. These modifications are described in Appendix C.

THE WESTLANDS CONTEXT

The Westlands Water District in California is one of the largest agricultural users of water in the West. It has a service contract with the United States Bureau of Reclamation for up to 1,150,000 acre-feet of water per year from the Central Valley Project (CVP). As a junior user in the overcommitted CVP system, Westlands currently receives on average about 65 to 70 percent annually of this amount.

Westlands' total water supply in 2001 was about 1,050,000 acre-feet. Of this total, about 200,000 came from groundwater. A 1980 study by the Bureau of Reclamation, the United States Geological Survey, and Westlands estimated that the sustainable yield of the deep confined aquifer under Westlands is in the range of 100,000 to 135,000 acre-feet. More recent district analysis of monitoring data suggests that the annual average sustainable yield might be as high as 200,000 acre-feet. Table 11 presents the district's

TABLE 11
Westlands Water District Estimates of Water Sources in 2002

Source of Water	Estimates for 2002
CVP deliveries	775,194 acre-feet
Groundwater	200,000 acre-feet
Private transfers	72,000 acre-feet
Additional district supplies	60,000 acre-feet
Total	**1,107,194 acre-feet**

estimates of its water sources in 2002. These figures were used in the analysis in this report.

Local groundwater has lower quality than CVP water. Depth to groundwater below the surface varied in 2001 from about 100 feet to 500 feet.[86] Energy consumption per acre-foot of groundwater pumped by the district is about 740 kWh.[87]

Westlands currently includes about 600,000 acres, 95 percent historically irrigable.[88] Approximately 470,000 acres were actually irrigated in 2002. Irrigation water is supplied by the San Luis Unit of the CVP and groundwater wells. Water provided to Westlands by the CVP is diverted from the Sacramento–San Joaquin Delta by the Tracy Pump Station and transferred south via the Delta-Mendota Canal. It is lifted several hundred feet, allowed to flow by gravity for about 150 miles, and is sometimes lifted another several hundred feet into the San Luis Reservoir. Some electricity is generated when water is released from the reservoir, but this offsets only about 70 percent of the energy used to fill the reservoir.[89]

Water is conveyed from the vicinity of the San Luis Reservoir to Westlands via the San Luis and Coalinga Canals. Westlands operates and maintains the 12-mile concrete-lined Coalinga Canal and the Pleasant Valley Pumping Plant, as well as other re-lift stations. Westlands' permanent distribution system consists of closed, buried pipes that convey water from the San Luis Canal, the Coalinga Canal, and a 7.4-mile unlined canal from the Mendota Pool. Approximately 88 percent of the irrigable land in the district is served by the system.

Water provided to Westlands by the CVP is lifted several hundred feet, allowed to flow by gravity for about 150 miles, and is sometimes lifted another several hundred feet into the San Luis Reservoir.

Technology for water distribution has become more efficient over the years. In 1996, about 36 percent of irrigated land was watered by gravity distribution alone, about 21 percent by pressurized distribution alone, and the remaining 43 percent by a combination. By comparison, acreage irrigated only by gravity distribution was 63 percent in 1985 and 43 percent in 1990.

CASE STUDY RESULTS

Substantial Energy Is Embedded in Westlands' Water Use

Sources and conveyance appear to represent the largest portion of energy embedded in Westland's water use. Our analysis indicates that substantial amounts of energy

TABLE 12
Energy Intensity of Surface Water Transport to the Westlands Water District

Location of Energy Use	Energy Intensity (kWh/af)
Tracy Pump Station (1)	238
Lift from O'Neal Forebay (1)	59
Lift to San Luis Reservoir	300
Hydroelectric generation from releases from the San Luis Reservoir (2)	–210
Dos Amigos Pump Station	138
Total CVP to the San Luis Canal	**435–525**
Pleasant Valley Pump Station	238
Total CVP to the Coalinga Canal	**673–763**

Notes: (1) The State Water Project Banks Pump Station is a parallel path for water en route to the San Luis Reservoir and eventually Westlands. Its energy use is nearly identical to the CVP pumps. (2) A negative number represents energy recovery, not use.

TABLE 13
Electrical Energy Requirements to Lift or Pressurize Sprinkler Systems

Activity	Approximate kWh/af
Flood irrigation without on-farm lift	0
Lifting water 10 feet for flood irrigation	30
Low-pressure sprinklers	100
Permanent set sprinklers	205

Our analysis indicates that substantial amounts of energy are required to deliver water to Westlands' fields, whether surface or groundwater.

are required to deliver water to Westlands' fields, whether surface or groundwater. Energy required for water pumping in the CVP is presented in Table 12.[90] Totals in the table are approximate and lower than actual consumption per acre-foot because water losses between pumping locations are not accounted for. Ranges represent uncertainty about whether water to Westlands should be charged 90 kWh/af for lift into or release from the San Luis.[91]

The amount of energy required to deliver water to a field in Westlands can vary widely depending on the location of that field within the district. Net electric energy consumption by the CVP to deliver water to canals in the Westlands Water District varies from about 435 to 763 kWh/af.[92] In addition, staff members report that district lift from the canals consumes about 245 kWh/af.[93] This implies that water available to farmers at the boundaries of their properties requires between 435 and 1,008 kWh/af.

Once water has been delivered to the field, additional energy may be required to lift and pressurize that water. Table 13 summarizes some average on-farm energy requirements for these irrigation purposes. It assumes a 10-foot lift and pressurization for the sprinklers. The figures are estimated from unit prices for electricity and expenditures per acre for water pumping and pressurization provided by the California Energy Commission in 2001 for grapes and almonds. The figures in the table are not specific to Westlands. The energy required for permanent set sprinklers is 20 to 47 percent of the energy required to deliver water to farms within Westlands (435 to 1,008 kWh/af). This demonstrates that energy used in on-farm water delivery systems can be significant in agricultural settings, depending on the types of crops grown and the choice of irrigation system.

Hydroelectric power issues are relatively insignificant for the Westlands analysis. Hydroelectric power production from the CVP is substantial (more than 4.5 billion kWh/yr), but nearly all irrigation water supply—such as that to Westlands—occurs downstream of CVP hydroelectric facilities. Therefore, there is no direct trade-off between irrigation and power generation as there is in the Columbia Basin study that follows. In addition, none of the scenarios analyzed in this case study would result in a dramatic change to hydroelectric operations upstream of the delta.

Energy Implications of Land Retirement Extend Beyond Water Delivery and Use

As discussed in Chapter 2, the full energy implications of a water policy decision may extend beyond the energy embedded in the water. In this case, permanent land

TABLE 14
Energy Intensity of Liquid Fuels Used to Cultivate and Harvest Crops

Crop	Energy Intensity (kWh equivalent per acre)
Alfalfa—California	145
Alfalfa—Ohio	205
Almonds	341
Almonds	373
Cotton—Alcala	472
Cotton—Pima	545
Tomatoes, processing	1,255
Tomatoes, fresh	710
Tomatoes, “typical” California	1,389
Wheat	247

Notes: Gasoline and diesel fuel converted to BTUs at 150,000 per gallon; BTUs converted to equivalent kWh at 10,239 per equivalent kWh.[94]

retirement would affect energy use in ways that are not captured by looking only at energy embedded in irrigation. In addition to irrigation, farms consume energy by operating farm machinery preparing soil, applying fertilizers and pesticides, and harvesting crops.

Permanent land retirement would affect energy use in ways that are not captured by looking only at energy embedded in irrigation.

This nonirrigation energy use varies enormously across crops.[95] Table 14 presents some sample calculations of gasoline and diesel energy used in agriculture. Again, these are not specific to Westlands but illustrate the type of analysis that is required to understand the energy implications of agricultural water use decisions. Energy used for irrigation is not included in the gasoline and diesel-fuel energy consumption estimates unless a power takeoff from farm machinery is used to drive a water pump.

To determine the nonirrigation energy savings from a land-retirement program, it is necessary to determine which crops will be phased out. Table 15 presents projected 2020 cropping patterns for Westlands without significant land retirement.[96] Crops projected for lands with shallow groundwater represent drainage-impaired lands that are candidates for retirement. The projection is extremely uncertain because it is based on estimated future market prices for crops obtained by extrapolation from historical trends and expert opinion. These trends and opinions may be altered by changes in other parts of the western United States and international agricultural regions that have not been evaluated. Nonetheless, Table 15 is the best available data on the types of crops that might not be grown in drainage-affected areas if significant retirement programs are implemented.

Cotton takes up more than a third of the acreage likely to be grown on land with shallow groundwater. Cotton also represents a midpoint in its nonirrigation energy use listed in Table 16, roughly 500 equivalent kWh/acre. Therefore, a rough estimate of the nonirrigation energy savings associated with retiring 100,000 acres of land is approximately 50 million equivalent kWh. Note that these are nonelectric savings that have been converted to kWh. Although these potential savings are not available to other customers as electricity, they are important additional implications of land

TABLE 15
Forecast Demand for Westlands Crops in 2020

Crop	Shallow Groundwater (thousands of acres)	Remainder (thousands of acres)
Alfalfa hay	8.04	0.96
Cotton	73.72	83.76
Field crops	5.57	14.80
Irrigated grain	9.19	1.72
Grapes	1.40	8.02
Irrigated pasture	0.23	0.8
Orchards	2.75	55.03
Row crops	31.22	109.83
Sugar beets	0.98	0.96
Subtropicals	3.55	1.03
Tomatoes	17.45	97.56
Dry-land grain	14.00	0.00
Fallow and nonbearing trees and vines	22.39	11.99
Total: (577,000 acres)	**190.49**	**386.46**

Our analysis indicates that dedicating water from retired lands to environmental flows in the delta would have the greatest energy benefits.

retirement because of the potential for air quality and global warming benefits that are beyond the scope of this analysis.

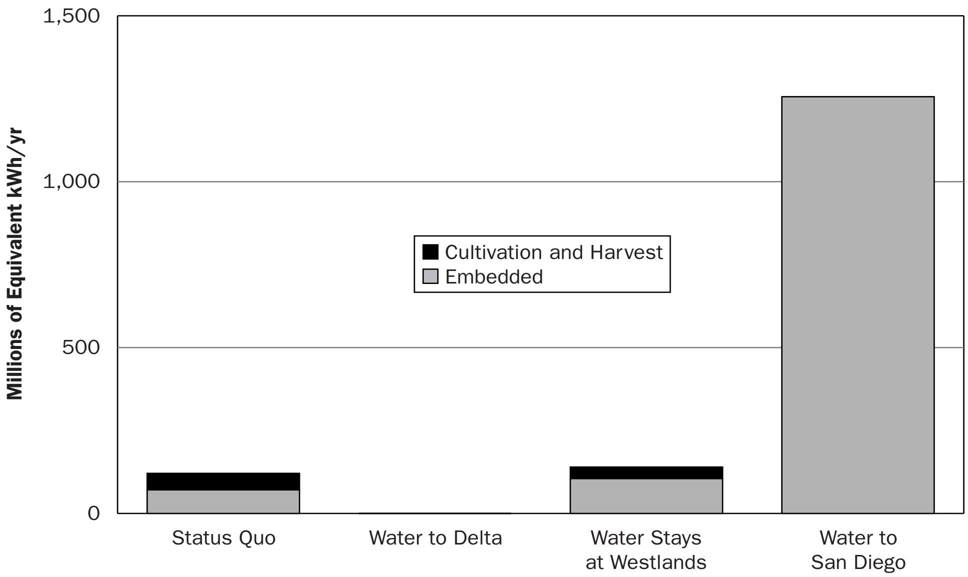
Dedicating Water to Environmental Flows Could Save Significant Energy

Long-standing problems associated with inadequate drainage, low quality of existing drainage water, and responsibility for management and disposal of drainage flows have led to recent proposals to retire—permanently fallow—200,000 acres within the district.[97] Under a Westlands proposal, farmers would receive federal payment for a significant part of the cost of land retirement, and the Westlands Water District would obtain or keep title to the land and all water associated with the land.

In concept, there is broad support for the retirement of drainage-impaired land on the west side of the San Joaquin Valley. However, current proposals are controversial for a variety of reasons not discussed in this report, including disposition of conserved water and the claim that the public cost of the retirement is higher than the public benefits that will be obtained. This case study considers three alternatives for the disposition of the water formerly used to irrigate the retired lands: dedicating the water to enhance environmental flows, transferring the water to other water users, and retaining the water for irrigation on other Westlands land. Summary statistics for the three alternatives are presented in Figure 5.

Our analysis indicates that dedicating water from retired lands to environmental flows in the delta would have the greatest energy benefits. The land targeted for retirement is predominantly downslope of the San Luis Canal and therefore receives water by gravity. On-farm pressurization is reported by Westlands staff to be minimal for these lands. Consequently, a conservative estimate of energy saved by reducing CVP water deliveries to Westlands, with that water left in the

FIGURE 5
Annual Energy Use by Water Disposition Scenario



San Francisco Bay-Delta for environmental purposes, is approximately 435 kWh/af. While average applied water in the district is 2.34 af/acre (1.1 million acre-feet divided by 470,000 cropped acres in 2002), not all of this is CVP water that could be dedicated to environmental flows. Since CVP water represented 70 percent of the district's 2002 supplies, we assume that 70 percent of the average applied water is CVP supply. Therefore, a 100,000-acre land-retirement program could save approximately 71 million kWh of electricity, or enough to power 11,000 households for a year.[98]

The full energy implications of land retirement extend beyond the energy embedded in water. Retiring 100,000 acres in Westlands and dedicating the conserved CVP water to environmental flows in the delta could have total energy implications of 121 million equivalent kWh (71 million kWh of embedded energy plus 50 million equivalent kWh used for cultivation and harvest).

It is important to note, however, that reduced groundwater pumping within the district would save even more electricity. Pumping groundwater alone uses about 740 kWh/af.[99] Electricity savings would be around 120 million kWh/yr if CVP deliveries were maintained and the district decreased groundwater pumping in the equivalent amount. Any pattern of reduction in total water use in the district implies significantly less electric and total energy use. However, given the lack of groundwater regulation in California at the moment, a retirement agreement would need to include special legal and enforcement provisions in order to ensure any reduction in groundwater pumping.

This analysis has implications for the Environmental Water Account, included in the CALFED Bay-Delta Program Record of Decision, signed in August 2000. The Environmental Water Account was created to provide water to compensate water users for delta pumping reductions needed to protect endangered species, and, if enough water remains, to restore the bay-delta ecosystem. From an operational perspective, this complex arrangement can be identical to dedicating existing water consumed by irrigation to delta protection. The Environmental Water Account water can come from a number of sources, including the purchase of surface and groundwater and purchases north or south of the delta. The extraction of groundwater for the Environmental Water Account requires greater energy than purchases from existing gravity-fed surface water facilities. Water purchases from agriculture north of the delta would result in changes in agricultural operations with relatively small conveyance energy benefits. The Environmental Water Account water purchased from CVP contractors south of the delta, such as Westlands, would generate greater conveyance energy benefits than water purchased north of the delta. The greatest conveyance energy benefits from Environmental Water Account purchases in the Central Valley would be achieved from purchases of surface water from the Central Valley location with the greatest lift for imported delta irrigation supplies—Kern County.

Transferring the Water to Urban Users Would Dramatically Increase Energy Use

Transferring water from Westlands to urban locations would significantly increase energy use. Table 16 presents the conveyance energy that would be required to transfer the water to urban users.[100] As documented in the San Diego case study, other parts of the water cycle—water treatment, distribution, end use, and wastewater treatment—also use energy. Figure 5 uses data from the San Diego case study and Table 16 to estimate the energy use that would result if water conserved by retiring 100,000 acres in Westlands were transferred to San Diego. Total energy use—all electricity in this scenario—would increase by more than eight times the energy use in the status quo: more than 1.2 billion kWh/yr.

Water from land retirement at Westlands could also be transferred to other agricultural users. Transfers to locations that use less energy for conveyance (e.g., north of Westlands, such as the Sacramento Valley area) would have net energy benefits unless the types of crops and irrigation systems at the new location were sufficiently more energy intensive than those on retired lands at Westlands. In contrast, transfers to locations that use more energy for conveyance (e.g., south of Westlands, such as Kern County) would have net energy costs unless the types of

TABLE 16
Energy Used to Deliver Water to Various Users

Representative Points of Delivery	Energy Intensity (kWh/af)
Environmental flows in the Sacramento–San Joaquin Delta	0
Westlands Water District	435–1008
San Jose area	1,165
Santa Barbara area	2,826
Northern Los Angeles Basin	2,580
Southern Los Angeles Basin	3,236

crops and irrigation systems at the new location were sufficiently less energy intensive than those on retired lands in the district.

Retaining Water at Westlands Could Increase Energy Use

Westlands proposes to keep water formerly used to irrigate retired lands and reallocate this water to remaining agricultural lands within the district. Determining the energy implications of this policy requires forecasting the impact of water supply changes on cropping patterns. For example, land retirement without reduction in CVP deliveries creates greater reliability and availability of water per acre of land still farmed. One recent study estimates that a 39 percent increase in permanent crops, such as orchards, would result from increased reliability of water supply.[101] These reliability benefits are one reason Westlands has been pursuing its own land-retirement program.

District staff report that this level of increased tree planting would consume about an additional 170,000 af/yr.[102] Assuming for illustration purposes that permanent set sprinklers are used to deliver this amount of water previously delivered by gravity to retired lands, electricity use would increase by about 200 kWh/af. This would amount to about 35 million kWh/yr, as shown in Figure 5. In addition, irrigating orchard lands might require an additional 245 kWh/af for district lift from the canals, increasing electricity use even more than is presented in Figure 5.

The impact on other energy use on farms, however, might be positive. Tree crops tend to use less energy for cultivation and harvest than row crops. Figure 5 shows a reduction in energy used in cultivation and harvest that reflects 150 equivalent kWh per acre saved by switching from cotton to almonds. This type of change might amount to 15 million equivalent kWh/yr less energy use.

Overall, allowing Westlands to continue using water now applied to the retired lands would increase total energy use by approximately 19 million equivalent kWh/yr under the assumptions used. These assumptions illustrate the type of analysis that is important to perform when evaluating land-retirement proposals, such as the one for Westlands, but are only approximately accurate and should not be relied upon in making final decisions about land retirement in Westlands.

The analysis in this case study demonstrates three points that are relevant to agricultural water management decisions and worthy of further research:

- The importance of accounting for end use energy in agriculture;

- The importance of understanding the changes in land use or cropping patterns that are likely to result from a land-retirement decision;

- The importance of clearly defining, in an enforceable manner, the ultimate disposition of water no longer required to irrigate land that is retired.

Unfortunately, these concerns could not be quantified in further detail within the resources available for this report. But our analysis demonstrates that these concerns are quantitatively significant relative to energy use in agricultural water conveyance and distribution—a point that had not been established prior to this report.

NRDC
THE EARTH'S BEST DEFENSE

ENERGY DOWN THE DRAIN

The Hidden Costs of California's Water Supply

August 2004

CHAPTER 5

The Columbia River Basin—Energy and Hydropower

The Columbia River supports powerful farming, hydropower, and environmental interests, and their competing concerns reveal just how complex the relationship between energy and water can be.

Thanks to its unique plumbing, the Columbia River has numerous hydroelectric dams located downstream of major irrigation diversions. As a result, energy and water policy discussions have been more integrated here than elsewhere in the West. Despite this initial progress, however, water and energy planners in the region have a long way to go toward fully integrating energy and water policy. This shortcoming was brought into sharp focus by the drought and energy crisis of 2001, when energy production demands caused farmers, industry, and the environment to suffer severely.

In this chapter, we examine the energy implications of diverting irrigation water upstream of hydroelectric facilities. Our analysis leads to several key findings:

- A substantial amount of energy is embedded in the water consumed by agricultural users where substantial pumping is required to deliver water.

- When accounting for the energy costs of irrigation along rivers that have hydro-electric dams downstream of major irrigation diversions, policymakers must examine both the energy used to deliver the water to the field and the energy foregone, or not produced, as a result of taking water out of the river before a dam.

- In future droughts, cost-effective water transfers may make it possible to improve conditions for salmon, power generation, and agriculture.

The model used in the Westlands Water District chapter was abbreviated for this case study to focus on the diversion of water for agricultural purposes upstream of hydroelectric facilities. Nonetheless, the Columbia analysis shares the methodology used in the other case studies, and is described in Appendices A and C.

While the Westlands and San Diego case studies focused on the energy embedded in agricultural and urban water use, this case study takes the analysis a step further by examining another important energy implication of water use: energy production that is lost or foregone as a result of water policy decisions. This opportunity cost must be included in any calculation of how much energy is embedded in water use.

This case study also includes a discussion of the energy required to plant, cultivate, and harvest crops—additional energy use associated with water used by agriculture. By more fully analyzing the energy implications of water used in agriculture, this methodology allows for the more accurate calculation of the potential energy savings of dry-year fallowing agreements. Water marketing arrangements are increasingly common throughout the West. This methodology allows us to demonstrate the potential energy benefits of some of these transfers.

THE COLUMBIA RIVER CONTEXT

The Columbia River travels over 1,200 miles from its headwaters to the Pacific Ocean, draining a watershed of 259,000 square miles and discharging an annual average of 160 million acre-feet (Figure 6). The Columbia and Snake Rivers are, respectively, the

FIGURE 6
The Columbia River Basin

12th and 13th longest rivers in the nation. This river system is an international and interstate resource that provides the basis for the region's charm, history, environment, recreational opportunities, and agricultural and industrial successes.

The Decline of the Columbia River Ecosystem

Human activities have taken a heavy toll on the Columbia River and its fisheries. The Columbia once supported more than 11 million salmon and steelhead annually, but by the 1990s, the river supported only about one million anadromous fish.[103] This remaining population consists of a majority of unsustainable hatchery fish and a very small population of wild spawning fish. Table 17 presents the 12 evolutionarily significant units of anadromous fish now listed under the Endangered Species Act as endangered or threatened in the basin. A variety of causes are responsible for this decline; however, diversions and dams have played a primary role.

Unfortunately, an effective response to restore Columbia fisheries has not yet emerged. Fishery management is particularly complicated due to perceived conflicts among energy, irrigation, and the environment.

Hydropower on the Columbia River

Dams in the Columbia River system represent 95 percent of the region's hydroelectric supply and produce 60 percent of its electricity.[104] The 31 dams owned by the Bureau of Reclamation and the Army Corps of Engineers make up the Federal Columbia River Power System (FCRPS). In 2000, the National Marine Fisheries Service issued a Biological Opinion (BiOp) regarding the impacts of the FCRPS on anadromous fish. The BiOp recommended 199 actions to enable listed fish populations to survive rather than continue to decline.[105]

The actions regarding hydropower call for augmenting flows and spilling water through spillways or bypasses. The 2000 BiOp also recommends specific quantities of water for flow augmentation and spill at the federal hydroelectric dams. If insufficient progress is made toward restoring fisheries, stronger measures, such as breaching four Lower Snake River dams, may need to be pursued.

TABLE 17
ESA Listed Fish of the Columbia Basin

	Endangered	Threatened
Resident Fish	Kootenai River white sturgeon	Bull Trout
Anadromous Fish	Snake River sockeye Upper Columbia River spring Chinook Upper Columbia River steelhead	Snake River spring/summer Chinook Snake River fall Chinook Snake River steelhead Middle Columbia River steelhead Lower Columbia River Chinook Lower Columbia River steelhead Columbia River chum salmon Upper Willamette River Chinook Upper Willamette River steelhead

Source: U.S. Bureau of Reclamation, Finding and Commitments. Implementing December 2000 Biological Opinions for the Federal Columbia River Basin System and Other Related Actions, 2001.

Agriculture in the Columbia Basin

The diversion of millions of acre-feet of water from the Columbia Basin has enabled farmers to grow crops in the arid climate of the interior Northwest. While the economy has diversified in the last 20 years, agriculture remains a major industry. Major crops in the Columbia Basin include potatoes, alfalfa, sugar beets, wheat, and onions. The potential crops in much of this region are limited by the relatively short growing season for high-altitude farmland.

About 6 percent of the Columbia's flows are diverted for agricultural purposes.[106] While this seems like a low number, the National Marine Fisheries Service says that "Water withdrawals for irrigation throughout the Columbia River Basin have an enormous effect on the flow of the Snake and Columbia rivers, especially during dry years when river volumes are low."[107]

THE DROUGHT OF 2001

The drought of 2001 in the Pacific Northwest was one of the worst on record, comparable to the drought of 1977. By the summer of 2001, instream flows were naturally low and were further exacerbated by water diversions. The pumps for some of these diversions consumed significant amounts of energy. Low rainfall affected farms and reduced hydropower generation. Spot market power was prohibitively expensive because of the California electricity crisis. Salmon advocates, irrigators, and generators feared the worst. Decisions made during 2001 imposed major hardships on the environment, particularly salmon. With naturally producing salmon populations already at disastrously low levels, management of the Columbia River pushed many species closer to extinction.

Other load-reduction programs simply purchased the hydropower used to pump irrigation water, leading farmers to substitute diesel generation to run their pumps.

Hydropower Impacts from the Drought

Understandably, Northwest utilities were concerned about avoiding blackouts during the summer of 2001. Bonneville Power Administration (BPA) responded by declaring an emergency situation, thereby avoiding carrying out some of the BiOp actions designed to help salmon recover, including much of the scheduled spill over the dams for fish passage. Utilities also launched several energy load-reduction programs and encouraged conservation.

The two largest agriculture load-reduction programs were run by the Idaho Power Company in Idaho and the BPA in the Columbia Basin Project. Some programs paid farmers not to pump irrigation water, freeing up for other uses the energy typically used for pumping and leaving water in the river for downstream generation. Most of this water was sent through the generating plants rather than spilled. Other non-BPA load-reduction programs simply purchased the hydropower used to pump irrigation water, leading farmers to substitute diesel generation to run their pumps, worsening air pollution and generating no in-river benefits.

The drought response included industrial load-reduction programs as well. One major focus of this effort was the energy intensive aluminum smelting industry. Creative BPA load-reduction programs cut power use during 2001 while ensuring continued compensation for plant workers.[108] The load-reduction programs during

2001 allowed the BPA to continue exporting significant amounts of power to assist California during its power crisis. This demand for energy exports increased the challenges facing those managing the Columbia River system.

Although the drought required major efforts in the energy arena, the overall response to the drought was considered a success for the utilities. No blackouts made the headlines during the drought of 2001 in the Northwest.

Agriculture Impacts of the Drought

In the agricultural community, there was little that could be termed a success. Higher energy prices increased costs. The drought caused yields to fall. Low commodity prices worsened conditions. Because of overproduction, farmers were earning only $1.50 per 100 pounds of potatoes, although it takes $4 to $5 to grow a hundred pounds, leading the United States Farm Services Agency to institute a program to buy potatoes and raise prices.[109]

The irrigation buyback programs offered by utilities provided a lifeline for some of the unfortunate farmers facing low commodity prices and high energy cost. However, despite the financial appeal of the buyback programs, for a variety of reasons, it remained far more difficult to obtain water in the Upper Snake River than in other regions. By way of contrast, the Washington State Department of Ecology spent more than $300,000 to secure in-stream flows from farmers through 21 leases during this same drought.[110]

During 2001, buyback programs helped some farmers to survive during difficult farming conditions. According to one media report, "Some Idaho farmers reported that kilowatt hours were their best crop [in 2001]."[111] Implementing the recommendations discussed in Chapter 6 would allow farmers to use their water rights to provide a cushion against the challenging conditions facing them in the agricultural market.

Environmental Impacts of the Drought

For Columbia Basin fish, things were even bleaker. Already struggling to migrate past numerous dams, anadromous fish faced even lower flows because of the drought. In the Hanford Reach, 1.6 million young Chinook were stranded. In 2001, the drought prevented the agencies from meeting any of the BiOp objectives. Relying on the drought emergency, federal agencies reduced spills over the summer to only 10 percent of BiOp recommendations. The Fish Passage Center and the National Marine Fisheries Service both found that "the lowest survivals and slowest travel times for smolts resulted from the lowest flow and spill that has occurred in recent years."[112] In harsher terms, Save Our Wild Salmon characterized the hydropower operations as a "massacre."[113]

According to the Fish Passage Center, "the suspension of Biological Opinion measures resulted in very poor in-river migration conditions in 2001."[114] For endangered fisheries, 2001 represented another disturbing step toward extinction rather than recovery.

Lessons from the 2001 Drought

Was there any way to meet expected electricity needs without sacrificing the salmon? Some groups believed so. In a letter addressed to Congress on March 19, 2001, environmental groups, scientists, and Native American tribes proposed that water be obtained from a point higher in the Columbia Basin, so that instream flows could be maintained while hydropower generators met their needs.

Clearly, hydropower generation was given the highest priority for Columbia water resources in 2001. Agricultural, industrial, and fishery interests all suffered, but there were no blackouts in the Northwest that year. Many farmers and industrial interests were compensated for reduced power—and water—use. Fish and fishery interests, including fishermen and Native Americans, however, had no choice and bore major hardships. In short, during 2001, several key factors came together:

- The drought worsened conditions for hydropower production.
- Exacerbated by diversions and power operations, the drought threatened the environment, particularly salmon.
- Spills over hydroelectric dams were inadequate.
- River flows were inadequate.
- Power prices peaked, due to the electricity crisis in California.
- Commodity prices were low.

These factors and the priorities given to the various uses of water in the Columbia River system led to a particularly unfortunate outcome—Idaho farmers lost money and plowed under unwanted, but water intensive, potatoes, while fish and hydropower production suffered from a lack of water. It is important for us to learn from this experience. It may be possible to address all of these problems during dry years by capturing some of the energy opportunity cost embedded in irrigation water in this region.

Idaho farmers lost money and plowed under unwanted, but water intensive, potatoes, while fish and hydropower production suffered from a lack of water.

CASE STUDY RESULTS

The Columbia case study examines energy implications of water use in one large federal project, the Columbia Basin Project (CBP). This project is located near Grand Coulee Dam, upstream of many of the Federal Columbia River Power System hydroelectric generating facilities. To simplify this effort, this analysis focused on the implications of only one crop, potatoes. Potatoes are one of the major crops in the Columbia Basin. Just as salmon are an iconic wildlife species for the Pacific Northwest, potatoes are agriculture's signature crop in parts of the region.

Significant Amounts of Energy Are Embedded in Agricultural Water Use

In the Columbia Basin Project, delivering water requires a significant amount of energy: 340 kWh per acre-foot. Our analysis of embedded energy use is shown as source and conveyance energy in Figure 7. This figure also shows the energy required to plant, cultivate and harvest this crop—385 kWh per acre-foot. Cultivation and harvest energy use, however, comes primarily in the form of diesel fuel consumption. Saving this energy is not, therefore, translatable directly into electricity. Nevertheless, it is also an important energy implication of water use by agriculture.

TABLE 18
Downstream Generation Gain from Reduced Diversion

Site	Net Energy Gain (kWh/af)
Columbia Basin Project	745
Upper Salmon	250
Walla Walla	140
Deschutes	36
Upper Snake	806

Energy Generation Opportunity Costs Must Be Added to Embedded Energy Costs

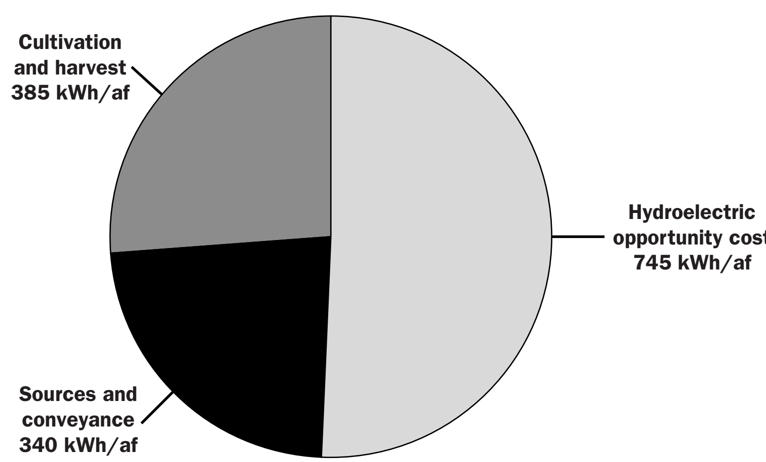
Because diversions from the CBP are upstream of major hydroelectric generation facilities, these diversions reduce the amount of water passing through those downstream facilities. Thus, one result of CBP diversions is a significant reduction in potential energy production. Figure 7 shows that this opportunity cost is 745 kWh/af. This hydroelectric opportunity cost was taken from Table 18, which summarizes the per-acre-foot energy potential of water at five points in the river system. Predictably, the energy opportunity costs in upper watersheds, above major hydroelectric dams, are extremely significant. In the case of the CBP, the energy opportunity cost is actually greater than the energy used to deliver water and to cultivate and harvest crops (725 kWh/af combined). Clearly, in regions like the Columbia River Basin, a full understanding of the energy implications of water use must include energy opportunity costs.

The total electricity implications of water used by the Columbia Basin Project can be estimated by multiplying the total electricity embedded in each acre-foot of water (to pump water from the Columbia River to the users) and potential downstream generation benefits from water released below the CBP (1,085 kWh/af—including both conveyance and downstream hydroelectric generation) times the annual average amount of water diverted by the CBP (2.4 million af/yr).[115] This exercise reveals that the embedded energy and potential generation benefits of the Columbia Basin Project alone amount to more than 2,600 gigawatt-hours per year, or nearly 25 percent of total annual energy consumption of the city of Seattle. An analysis of other diversions in the upper Columbia and Snake River systems would reveal similarly significant energy implications.

Water Transfers Could Benefit All Parties in Future Droughts

By combining embedded energy and opportunity costs, Figure 7 reveals the potential energy benefits of dry-year water transfers involving the Columbia Basin Project in

FIGURE 7
Energy Intensity of Water of Potatoes from Reduced Diversions



the future. Of the 1,470 equivalent kWh/af total energy implications of CBP water use, 1,085 consist of electricity used to pump water plus electricity not produced because water was diverted upstream of hydroelectric facilities.

This analysis demonstrates that if all water diversions to the Columbia Basin Project were to cease and if all of this water were instead run through downstream hydroelectric facilities, the additional energy produced would be more than 2,600 gigawatt-hours per year. We do not mean to suggest that this would be an appropriate reallocation. However, this analysis reveals the significant potential energy benefits that could accrue from realizing some of this potential under some circumstances. The BPA has conducted an analysis looking at different hydrological conditions that has reinforced this conclusion.[116]

During dry years, and especially when power costs are high and agricultural commodity prices are low, the value of this energy potential may be large enough for voluntary fallowing programs to pay farmers more than they could earn growing low-value crops and still have enough money left to purchase environmental flows. Such an arrangement would pay farmers to forego farming on some of their land, leaving more water in the river. Some of the conserved water could be used to generate additional energy, and some used to generate environmental benefits. Such hybrid energy and environmental transfers could improve low-flow conditions in places such as in the Hanford Reach, which suffered the large fish kill discussed previously. They could also help provide the spills from hydroelectric facilities required by the 2000 BiOp. During the disastrous conditions seen in 2001, voluntary fallowing arrangements could also have been beneficial to many farmers who lost money as a result of high production and low crop prices. In short, the opportunity for farmers, ratepayers, and the environment to mutually benefit from dry-year land fallowing in the Columbia Basin is significant.

The embedded energy and potential generation benefits of the Columbia Basin Project alone amount to nearly 25 percent of total annual energy consumption of the city of Seattle.

Experience in other states suggests that the greatest concerns regarding the type of marketing arrangements that this document recommends are likely to emerge from rural agricultural communities. We take these concerns seriously and will explore them further in a forthcoming report.

CONCLUSION

There are a few things upon which everyone associated with the management of the Columbia River would agree. The region will face droughts in the future. In fact, by reducing snowpacks, global warming may increase the frequency and severity of drought conditions in the future. These droughts will reduce the reliability of energy supplies that are essential to the region's economic vitality. Salmon populations are already at dangerously low levels and could be seriously imperiled in future droughts. And farmers in much of the basin are struggling to survive due to low crop prices and high costs. Any strategy that offers the potential to provide benefits in each of these interconnected areas deserves thoughtful evaluation. Voluntary dry-year marketing arrangements offer the potential to improve conditions for salmon, increase energy production, and provide badly needed income for farmers. The

Some of the conserved water could be used to generate additional energy, and some used to generate environmental benefits.

potential impacts of such arrangements on local communities should be carefully evaluated. However, if designed properly, such arrangements could significantly strengthen the region's economy and protect many thousands of jobs from potentially disruptive energy shortages.

On the Columbia River and on other river systems, a better understanding of the energy implications of water use can help managers design strategies in the future that will better meet the needs of our economy and environment. In these cases, the careful, regulated use of market principles offers the potential to produce broad benefits reflecting modern environmental values.

CHAPTER 6

RECOMMENDATIONS FOR WATER POLICY

The case studies in this report support water policy conclusions that are widely applicable in the western United States. Overall, our analysis indicates that energy implications of water policy decisions are large and warrant inclusion in water and energy policy decisions. All three case studies demonstrate that inclusion of energy considerations can improve resource management decisions and avoid potentially significant unintended energy consequences.

ENERGY IN URBAN WATER USE

The most striking conclusion is that the amount of energy required for end uses of water is the largest component of energy use in the urban water supply cycle. Therefore, urban conservation, particularly for energy intensive uses such as clothes washers and commercial cooling towers, is important regardless of the source of the water or location of its use. San Francisco, as well as Los Angeles, should be aggressively pursuing water conservation.

This finding implies that policy actions that affect water use may have much larger energy implications than policy actions that affect the mix of physical water sources. This is true in San Diego, at the most energy intensive "ends" of the State Water Project and Colorado River Aqueduct, but it is even more valid in other locales.

However, our analysis also reiterates that conveying water can be highly energy intensive. Since conservation saves all of the "upstream" energy inputs as well as end use inputs, conservation in areas with energy intensive water supplies will save substantially more energy than conservation in other areas.

Another conclusion from the urban case study—as well as the agricultural analysis—is that water reuse is far less energy intensive than any physical source of water other than local surface water. The San Diego case study explicitly supports this point, and tailwater recovery uses far less energy than urban water recycling since it usually requires no more than lifting tailwater from low points to high points on each farm. Even groundwater pumping is more energy intensive in San Diego and the Westlands Water District than water recycling from urban wastewater; and the depth to groundwater in these locations is not atypical for western settings.

ENERGY IN AGRICULTURAL WATER USE

In agricultural settings, energy use varies widely and it is not possible to generalize about which stage of water use dominates. Source and conveyance and end use of water appear to demand the largest portions of energy in water use, but their respective energy use will vary by water source, district location, topography, and irrigation technology, among other factors.

The energy impacts of agricultural water policy decisions may also extend beyond the energy embedded in water use. For example, in some cases, water policy decisions may affect the amount of energy used for harvest and cultivation, which can be quite large. The Westlands Water District case study shows that the energy implications of land fallowing are complicated and worthy of further study, not just in Westlands but in other settings where fallowing (permanent, dry-year, or rotational) is being considered.

Our analysis indicates that the energy impacts of fallowing farmland depend largely on where the water formerly used to irrigate that land is sent instead. From an energy perspective, a combination of conservation and water recycling may be the best path for meeting growing urban needs, while water freed up in agriculture due to efficiency improvements and fallowing might be the best source to satisfy environmental flow needs.

From an energy perspective, a combination of conservation and water recycling may be the best path for meeting growing urban water needs.

Finally, the Columbia case study demonstrates that foregone hydroelectric production (energy opportunity cost) can be very significant when irrigation water is diverted above power production facilities. For example, the foregone energy production in the Columbia Basin Project is the equivalent of 25 percent of the total energy use for the city of Seattle. In some cases, particularly during times of high energy prices, it may be possible to purchase water from farmers for environmental flows and finance those purchases through the additional hydropower revenues. Our analysis strongly suggests that environmental flows and quality can be enhanced in the Columbia Basin without permanent land retirement or reduction in power production, at least in some dry years.

IMPLICATIONS OF THE CASE STUDIES

The analysis in this report supports two primary recommendations:

Decision makers should better integrate energy issues into water policy decision making. The background information in Chapters 1 and 2 and the case studies in Chapters 3, 4, and 5 demonstrate that looking at energy use and water use simultaneously generates valuable insights that do not arise from separate policy analyses of water and energy issues. The specific policy and planning recommendations that flow from this primary recommendation are presented below. Many of these recommendations are potentially relevant—with appropriate modification to account for differences in the policy context—outside California and the Columbia Basin.

Water conservation should be given higher priority by policy planners in both water and energy sectors. Although many planners in the water sector support conservation,

conservation program implementation has been slow. We conclude that conservation has much stronger economic and environmental benefits than has been recognized to date. Given this strong finding, a policy agenda for promoting water conservation is presented below.

RECOMMENDATIONS FOR WATER RESOURCE PLANNING

Water resource planning must incorporate energy considerations. Given the close relationship between water use and energy use, water and energy policies should be managed comprehensively. State energy and environmental policies must provide consistent encouragement for cities and agriculture to invest in cost-effective energy and water demand-side strategies.

Federal Level

▶ **Perform Energy Intensity Analysis.** The Bureau of Reclamation should perform an energy intensity analysis of its distribution system and identify regions and districts where large amounts of power are required to deliver water. State agencies and the Bureau of Reclamation should fully implement water-use efficiency programs in those regions and should include calculation of energy benefits in determining the cost-effectiveness of water conservation measures in those areas.

The legislature should revise the Urban Water Management Planning Act to require water suppliers to consider the energy implications of their water management options.

▶ **Produce a Power Balance.** The Bureau of Reclamation and the Power Marketing Authorities should produce a power balance that reconciles power generation and purchases with power consumption. There are many discrepancies between the Power Marketing Authorities and the Bureau of Reclamation data sources, which make it difficult to construct a full picture of energy generation and use. For example, given the available data, it's not possible to balance total energy resources (generation and purchases) with energy disposition (sales, consumption, and transmission losses.)

▶ **Change Energy Use Reporting Requirements.** The Department of Energy should ask manufacturers to report energy information on water heating, recirculation, pressurization, and other functions in separate categories rather than embedding that use in broader categories.

▶ **Include Energy in NEPA Evaluations.** The National Environmental Policy Act analyses for water supply issues should take particular care to address energy and related air quality impacts.

State Level

▶ **Revise the Urban Water Management Planning Act.** The legislature should revise the Urban Water Management Planning Act to require water suppliers to consider the energy implications of their water management options, and to factor in related energy costs and benefits when considering water conservation measures or water supply projects.

▶ **Include Energy Intensity in Bulletin 160.** The Department of Water Resources should include a regional energy intensity analysis in Bulletin 160 and should identify ways to reduce the energy intensity of water use on a regional basis.

▶ **Integrate Energy Costs into Economic Analysis of Water Management Alternatives.** CALFED should modify this analysis to include energy costs and benefits from the various CALFED alternatives and to evaluate the economic cost of various alternatives under a variety of energy price scenarios. CALFED should carefully evaluate claims that new water storage facilities will increase net energy production.

▶ **Coordinate Among Resource Management Agencies.** The Department of Water Resources should consult with the California Energy Commission and the Public Utilities Commission on the potential energy impacts of proposed water policies. For example, the Department of Water Resources should work with the California Energy Commission to evaluate how the proposed increase in delta pumping capacity would affect total energy consumption as well as load shape.

Regional/Local Level

▶ **Modify the MOU.** The California Urban Water Conservation Council should modify the MOU to require coordination with energy utilities and include energy costs and benefits in the cost-effectiveness methodology.

▶ **Investigate Energy Implications of Dry-Year Strategies.** The Metropolitan Water District of Southern California, the Department of Water Resources, and the California Energy Commission should investigate the different energy implications of dry-year strategies for Southern California, taking into consideration the premium value of energy during dry years and focusing on regional self-reliance.

▶ **Include Energy in Integrated Resource Planning.** Water agencies should include energy in their integrated resources plans. These plans should quantify the energy benefits of conservation and water recycling projects.

▶ **Reduce Energy and Environmental Impacts of Desalination.** Desalination proponents should minimize the energy and environmental impacts of desalination by: 1) looking for opportunities to use this technology on brackish and contaminated groundwater, 2) exploring desalination for use as peak or drought supply rather than base supply, and 3) seeking opportunities to reduce freshwater diversions.

Land Fallowing and Water Transfers in California, the Columbia Basin, and Beyond

Land fallowing and water transfer policies under consideration in California and throughout the West should specifically address the following points:

▶ **Include Energy in Environmental Analyses.** Environmental analyses for water transfer proposals should explicitly review the energy and subsequent air quality implications of the transfer proposal. The environmental impact report for the Imperial Irrigation District–San Diego transfer did not evaluate these impacts.

▸ **Plan for Energy Costs in Environmental Water Purchases.** Purchasers for CALFED's environmental water account should include in their purchase plans the conveyance energy benefits of purchasing account water from sources south of the delta. The retirement of drainage-impaired land in the Westlands Water District presents an opportunity to save energy and provide water for environmental restoration.

▸ **Build a Consensus for Dry-Year Contingency Plans on the Columbia River.** The Bureau of Reclamation should initiate a discussion with the Power Marketing Authorities, salmon advocates, regulatory agencies, and farmers in the Northwest regarding the development of a mutually beneficial dry-year contingency plan, designed to provide benefits for agriculture, energy, and the environment along the lines of the scenario presented in Chapter 5.

▸ **Focus on Rivers with Diversions Upstream of Hydropower Plants.** Policy makers around the West should investigate the potential for dry-year partnerships on river systems where there are large water diversions upstream of hydropower facilities and degraded rivers.

RECOMMENDATIONS FOR ADVANCING WATER CONSERVATION

Our analysis shows that the most effective way to reduce energy related to water use is to consume less water. In addition to reducing the energy required for end use, conservation eliminates all of the upstream energy required to bring the water to the point of use, as well as all of the downstream energy that would otherwise be consumed to treat and dispose of this water. In many cases, conservation provides the most cost-effective water supply option, particularly once energy costs are included. The federal, state, and local governments, as well as water and energy utilities, should prioritize conservation. To increase conservation, decision makers should:

In many cases, conservation provides the most cost-effective water supply option, particularly once energy costs are included.

Conservation Funding

▸ **Prioritize Conservation Funding.** State, federal, and local budget problems will limit the availability of public funding for many programs. Nonetheless, investment in conservation may forestall or avoid larger public investments for drinking water, clean water infrastructure, or power generation facilities, and it will help stretch available funds.

Conservation Requirements

▸ **Implement Existing Requirements.** The Bureau of Reclamation should implement the water conservation planning requirements of the Central Valley Project Improvement Act and Reclamation Reform Act.

▸ **Ensure Compliance with the MOU.** The Department of Water Resources should require anyone receiving water from the State Water Project, directly or indirectly, to fully implement the terms of the Memorandum of Understanding Concerning Urban Water Conservation in California.

Water Measurement and Pricing

▶ **Enact Universal Measurement Legislation.** All water use in the state, including surface and groundwater, should be measured, and water users should be charged for each unit of water they use. This is a precondition for efficient water use. The CALFED Authority should meet its commitment to develop legislation requiring appropriate measurement of water use for all water users in California.[117] This legislation should require:

- ▷ Measurement and volumetric billing of all urban and agricultural water use;
- ▷ Dedicated meters for large landscapes;
- ▷ Submetering of multi-family housing.

▶ **Conduct Groundwater Monitoring.** The CALFED Authority should develop and the legislature should adopt groundwater monitoring legislation to improve management of this unregulated resource.[118]

The CALFED Bay-Delta Authority should require full implementation of conservation measures, including water measurement and volumetric pricing, as a prerequisite for receiving any program benefits.

▶ **Eliminate Subsidies.** The federal government should phase out irrigation, energy, and crop subsidies, which encourage wasteful use of water and energy, as well as cultivation of low-value crops and cultivation of marginal lands where irrigation contributes to water quality problems.

▶ **Establish Wastewater Volumetric Pricing.** The legislature should pass legislation requiring wastewater agencies to bill their customers volumetrically. Flat rates for wastewater fail to deliver a price signal to customers to reduce their indoor water use. Volumetric billing of wastewater is already endorsed by Best Management Practice 11 in the Urban MOU. This measure has strong precedent in other states: in Texas and Florida, more than 97 percent of sewer rates are volumetric and in Arizona 68 percent are volumetric. In California, only 13 percent of the state's wastewater treatment providers bill by volume.

▶ **Require Dedicated Meters for Large Landscapes.** The legislature should pass AB 2298 (Plescia), requiring dedicated meters to measure landscape water use. This complements Best Management Practice #5 in the Urban MOU, and would provide a valuable conservation tool for water agencies and landscape managers.

▶ **Establish Rates for Outdoor Water Use.** Water agencies should establish seasonal or tiered water rates to target outdoor water use. The Urban MOU has not yet successfully addressed outdoor water use. Rate structures are an effective tool for targeting outdoor water use.

Conservation Incentives

▶ **Tie CALFED Benefits to Conservation.** The CALFED Bay-Delta Authority should require full implementation of conservation measures, including water measurement and volumetric pricing, as a prerequisite for receiving any program benefits.

▶ **Broaden Energy Conservation Programs.** Energy utilities should broaden their water conservation efforts to include all water use, not just the conservation of heated water.

▸ **Pursue Conservation above the MOU.** The CALFED Bay-Delta Authority and its member agencies should develop programs targeted at obtaining water conservation savings beyond the levels specified in the MOU. The MOU does not require implementation of all cost-effective conservation. Indeed, while much of the focus in CALFED and elsewhere tends to be on implementation of the best management practices, there remain significant cost-effective conservation savings beyond those practices.

▸ **Link Loans to Conservation Achievements.** The State Board and Department of Health Services should tie clean-water and drinking-water revolving-fund loans to conservation achievements. The state operates two federally authorized revolving funds that provide loans to local agencies for certain drinking water and wastewater infrastructure investments. California's total estimated needs for these expenditures is approximately $30 billion. A large percentage of these needs are flow-related and could be delayed or reduced if projected flows or volumes were reduced through conservation. As a condition to granting revolving-fund support, the State Board and Department of Health Services should require applicants to demonstrate that all projects for which funding is being sought have been sized and timed to account for full implementation of conservation programs.

Conservation Assurances

▸ **Adopt Best-Management-Practice Certification.** The CALFED Authority should adopt a best-management-practice certification process for urban conservation with consequences for noncompliance.[119]

▸ **Establish Agricultural Water-Use Efficiency Objectives.** The Department of Water Resources should finalize the remaining quantitative objectives for agricultural water use efficiency and an assurances package that includes consequences for failing to meet those objectives. The Department of Water Resources should conduct the overdue evaluation of progress toward meeting the quantitative objectives.

▸ **Verify Water Savings.** The Department of Water Resources must include a monitoring component in all water conservation grants to verify conservation savings and track disposition of conserved water. Expediting distribution of funds should not take precedence over good science.

▸ **Revise the Cost-Benefit Analysis.** The Department of Water Resources should revise the cost-benefit methodology required as part of the water-use efficiency grant process to require inclusion of energy costs and benefits.

▸ **Pass a Retrofit-Upon-Resale Law.** The state legislature should adopt a retrofit-upon-resale law requiring replacement of inefficient toilets with ultra low-flow toilets upon sale of a home. Such ordinances are in effect in Los Angeles, Santa Monica, San Diego, and other cities. The Urban MOU requires signatories to adopt programs that are at least as effective as a retrofit-upon-resale ordinance, but to date, few programs have achieved that level of implementation. The California real estate market remains incredibly strong, and a retrofit-upon-resale requirement would have little impact on this market.

▶ **Improve the Model Landscape Ordinance.** The existing model landscape ordinance, developed in response to AB 325, is deficient in several respects. The California legislature should pass legislation to revise and improve the model ordinance.

AREAS FOR ADDITIONAL RESEARCH

Our research highlighted several areas where additional data could improve energy intensity analysis and facilitate the integration of energy considerations in water policy. Some of these are listed below:

▶ **Investigate Evaporative and Conveyance Losses.** The California State Water Project, the Central Valley Project, and water districts, agencies, and companies should conduct analyses of evaporative and conveyance losses throughout their systems, not just in large canals, aqueducts, and distribution piping.

▶ **Go Beyond Appliances.** The Department of Energy or another party should analyze energy use integral to end use of water beyond domestic fixtures and appliances.

▶ **Fund Research in Water Use Efficiency.** The Department of Water Resources should fund research to address remaining areas of uncertainty in water use efficiency, including the relationship between evaporation and transpiration and the potential for reducing irrecoverable losses through reductions in evaporation.

▶ **Study the Link Between Water Policy and Emissions.** The Department of Water Resources or another party should extend the models presented in this report to estimate changes in air emissions resulting from water policy decisions. Demonstrating the linkage all the way through to air quality would greatly strengthen the policy recommendation that water management decisions should account for the energy dimension.

▶ **Examine the Climate Change Implications for Water Policy.** The Department of Water Resources and the California Energy Commission should evaluate the climate change implications of water policy.

URBAN MODEL DESCRIPTION

ENERGY DOWN THE DRAIN

The Hidden Costs of California's Water Supply

August 2004

We have modified and expanded the methodology of Wilkinson into a user-friendly spreadsheet to determine the energy embedded in water use from source to disposal.[120] Filling out the spreadsheets completely would require full information about actual and potential water and water-related energy use in San Diego County. Full information is never available in practice, but the information gaps that will exist are not known in advance, so this type of spreadsheet is the best analytical starting point. Note that the spreadsheets include water sources that are being considered for San Diego but are not actual (e.g., seawater desalination, transfer from the Imperial Irrigation District, and water bags towed by sea from Northern California).

The eight Excel spreadsheets we used are organized in three layers (see Figure A-1):

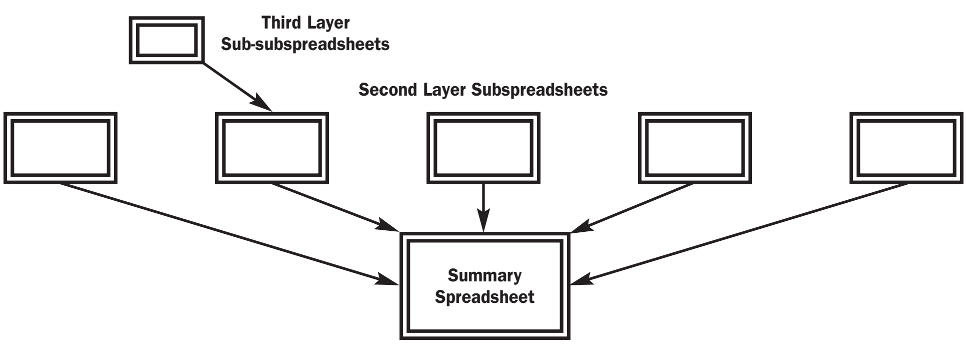
1. One summary spreadsheet.

2. Five subspreadsheets, one each for sources, water treatment, water distribution, end use, and wastewater treatment. Water recycling projects are considered to be sources of water. Their energy use consists of the energy required to upgrade water from discharge-suitable quality into reuse-suitable quality.

3. Two sub-subspreadsheets, one each for groundwater sources and water recycling sources.

Copies of the spreadsheets are available from Pacific Institute.

FIGURE A-1
Diagram of the Flow Between Spreadsheets



The summary spreadsheet does not allow for data input, while the other seven spreadsheets require data input. All eight spreadsheets perform calculations. The five steps in the water-supply-use-disposal chain fix the number of spreadsheets in the second layer. The number of the third-layer spreadsheets depends on the circumstances. Each third-layer spreadsheet allows the user to assemble disaggregated data about one aggregate item in a second-layer spreadsheet. For example, the groundwater spreadsheet contains data on various groundwater sources that are aggregated into a single column in the sources and conveyance spreadsheet.

SUMMARY SHEET (TOP LAYER)

The summary spreadsheet does not allow inputs, and incorporates data directly from the penultimate spreadsheets (and indirectly from the subpenultimate spreadsheets). Here, the user can gain an overview of the energy embedded in water use as a function of the five principal energy components of urban water cycles. The effect of new water sources or conservation measures on energy use can be analyzed in the summary spreadsheet through changes in the data inputs of the other spreadsheets.

Row 5 summarizes the volume of water that enters each of the five principal energy components. Decreases in volume that occur between the first (sources and conveyance) and last (wastewater collection and treatment) of these components reflects water loss (both consumptive and nonconsumptive) that occurs during the water cycle. Row 6 summarizes the average annual energy use for each of the five steps in the supply-use-disposal chain, with total energy use summed across the five components presented in column K. Because these are total energy use figures for each component, their sum is an accurate number—it reflects total energy use in the chain based on the mix of supplies, the level of conservation, and so forth, input to the other spreadsheets.

Row 7 calculates the energy factor, a ratio of energy consumed (kWh/yr) to water consumed for end uses (af/yr), thus normalizing energy consumption per unit across the five principal energy components. The total of the energy factors for row 7 is in column K. Row 8 reports the energy factors as percentages and contains the data used to create "The Percent Energy Use in the Five Components of Urban Water Systems" graph. This graph visually depicts the percentage energy use by the urban water system component and helps to show where energy is being consumed under the assumptions that have been input. Although the first summary spreadsheet that a user of the model creates should reflect actual conditions, one can examine counterfactual scenarios by changing the inputs in the penultimate and subpenultimate spreadsheets.

SUBSPREADSHEETS (SECOND LAYER)

We have organized this layer of spreadsheets according to the five steps described previously: 1) sources and conveyances, 2) water treatment, 3) distribution, 4) end use, and 5) wastewater collection and treatment. Each subspreadsheet has a similar format and requires three types of data: 1) average annual volume (in af/yr) of water "in," 2) average annual energy use (in kWh/yr), and 3) percentage of water loss. Several spreadsheets require additional data and are noted as such in the following descriptions.

Sources and Conveyances

This category represents the energy required for the extraction of raw water from its source and the conveyance of water to the site of treatment, either via pumping or water transport (e.g. water bags). For example, it requires more than 3,200 kWh/yr of energy to pump water from intakes in the delta through the State Water Project to San Diego (row 8, column C). For water recycling and desalination, this category includes the energy required to extract usable water from wastewater, brackish water, or salt water. San Diego potentially obtains water from the seven sources and conveyances listed as columns in this spreadsheet.

For each source and conveyance, the following inputs are required and calculations are performed. The average annual water supplied (in acre-feet) from each source and conveyance is input and is summed across to obtain a total average annual water supply (row 5, column K). Using the data from row 5, row 6 calculates the percentage of water supplied by each source and conveyance. The cells in row 6 are locked, meaning the user cannot change the percentage of water supplied by each source and conveyance. Users may investigate how changing the water supply and conveyance portfolio (i.e. percentage of water supplied by each source and conveyance) affects energy use by changing the water supply data in row 5. Users may also change the total average annual water supply (but keep the water supply and conveyance portfolio constant) to investigate how absolute rather than relative changes affect energy use.

The percentage of water loss that occurs after removal from a source and/or during conveyance may be input into row 7. This is useful information if available, but is not necessary for the calculations leading to the summary spreadsheet. If water "in" is input for all cells in all the spreadsheets, percent loss is the difference between water "in" to one step of the chain and water "in" to the next step of the chain. The input for percentage of water loss here provides an alternative method for estimating the amount of water into the next step in the chain if the user is unable to obtain "in" data for the next step (in this case, water treatment).

The average annual energy use (in kilowatt-hours) required for each source and conveyance is input in row 8 and is summed across sources and conveyances to obtain total average annual energy use (row 8, column K). Row 9 allows for the user to enter comments regarding the quality of the water supply should there be any unusual aspects of a water source and conveyance. The quality of raw water will often affect energy used to treat it, with more than average energy used if raw water is brackish and less than average energy used if raw water is from a desalting facility or very high-quality natural source.

The groundwater sources and water reuse columns are calculated from sub-penultimate spreadsheets described below. These subspreadsheets keep the sources and conveyance spreadsheet manageable. We recommend using a subspreadsheet when more than two facilities exist for a column in a penultimate spreadsheet.

Water Treatment

This category represents the energy required for the processes that occur within a water treatment facility to obtain treated water that meets potable water health standards. Often, filtration or flocculation and sedimentation, followed by disinfection, are adequate. There are 10 water treatment facilities that process water treated in San Diego County. In addition, the Metropolitan Water District delivers treated water from the Skinner treatment plant in Riverside County. For simplicity, the model structure assumes that the location of the treatment facility (e.g., in the county or out of the county) does not affect the energy used to convey and distribute water to customers.[121]

The inputs required and calculations performed for the water treatment spreadsheet are the same as those for the sources and conveyances spreadsheet. As in the sources and conveyances spreadsheet, the user can enter information regarding water quality, highlighting the variation in energy factors across plants.

Distribution

This category represents the energy required for any pressurization or pumping that occurs as treated water leaves the water treatment facility and for the transport of treated water through the distribution blocks. There are many distribution zones within San Diego County. Note that the spreadsheet is constructed as if each distribution zone conveys water from one or more treatment plants to end users. If water were to pass through two distribution zones between treatment plant and end users, the spreadsheet would need to be modified to account for energy use "in series" rather than "in parallel."

The distribution spreadsheet does not allow for the user to enter notes regarding water quality. The assumption is that all water is of the same quality (i.e., treated to potable standards). Otherwise, the inputs required and calculations performed are the same as those for the sources and conveyances spreadsheet.

End Use

This category represents the energy required for all end uses; i.e., those that are measured via metered water consumption. Urban water users are primarily those in the municipal and industrial sector. For the general spreadsheet, we divide water use into the two large categories typical of urban water supply planning: 1) residential and 2) commercial, industrial, and institutional (CII). We further subdivide residential use into categories that apply throughout the western United States: clothes washers; dishwashers; showers, tubs, and faucets; toilets; turf landscape; and non-turf landscape. We do not subdivide CII uses at this time.

The inputs required and calculations performed for the end use spreadsheet are the same as those for the sources and conveyances spreadsheet, with the exception that average annual energy use includes kilowatt-hours actually used plus thermal energy converted to kilowatt-hours at a heat rate of 10,239 British thermal units per kilowatt-hour. This conversion represents the electrical energy that could be produced at average thermal power plant efficiency if thermal energy were in fact converted to electricity prior to use. This is necessary to report total energy intensity numbers (equivalent kilowatt-hours), but should not be misinterpreted as actual kilowatt-hours used in any category.

Energy use during end use is in addition to the energy used to pressurize water in distribution systems. Some end uses do not use additional energy. For example, flush toilets with gravity sewers do not use additional energy, so the cell for energy use by toilets contains a zero value. Similarly, irrigation systems that operate solely from distribution pressure do not use additional energy unless they have electrically operated valves or control systems. In contrast, any use of hot water involves additional energy, as do appliances that include motors, pumps, automatic valves, timers, and so forth (e.g., clothes washers or recirculating pumps at car washes).

In this sense, end use energy is no different than source and conveyance, treatment, distribution, and disposal energy. It is one of five parts of a chain of energy uses that must be added to obtain total energy use associated with each acre-foot of water used by customers.

However, end use represents a unique step among the five parts of the supply-use-disposal chain. It is the only step where conservation saves energy in the other four steps. Reducing water losses in conveyance will reduce the amount of energy associated with each acre-foot delivered. But it will not reduce total energy consumed in other steps if water delivered to customers is held constant. Reductions in distribution losses (the biggest part of "unaccounted-for water") are similar. But reductions in water consumption will affect total energy use in all five parts of the chain, even though it may not reduce the amount of energy associated with each acre-foot of use.

Stated another way, total energy use depends on the average energy factor of a system (average kWh/af delivered to customers) and the total water consumption of the system (acre-feet). Conservation doesn't necessarily affect the average energy factor, although it may, but it will always affect total energy use. Many water conservation technologies also reduce energy use, so conservation will often save energy in total and pull down the average energy factor of the system. However, some water conservation measures use more energy than pre-conservation practices, driving up the average energy factor of the system. But even if the average energy factor is driven up because energy is being substituted for water, speaking in the jargon of economics, total energy use can still decline because the increased energy in end use may be smaller than the energy savings from reducing the customer's need for water.

The linked spreadsheets account for these possibilities. First, one inputs average energy use associated with water use in each category (e.g., CII) or subcategory (e.g., clothes washers). Then, when considering implementation of water conservation measures, one both reduces total end use of water by the amount of conservation and adjusts the energy use in each end use category and subcategory to reflect energy use after implementation of that amount of conservation. The adjusted energy use inputs may be higher or lower than before conservation. If lower, the average system energy factor and total system energy consumption will decline. If higher, the average system energy factor will increase but total system energy consumption may increase or decrease.

Wastewater Collection and Treatment

This category represents the energy required for the transport of wastewater to the wastewater treatment facility—lift requirements are significant in many places and all wastewater treatment processes, which usually consist of a series of physical processes (e.g., pumping, screening, and filtration), chemical processes (e.g., chlorine addition), and biological processes (e.g., microbial removal of contaminants) to prepare wastewater and waste solids for release back into the environment. San Diego County has 14 wastewater treatment facilities.

The wastewater collection and treatment spreadsheet is similar to the other spreadsheets with respect to data input and calculations; any unusual wastewater treatment requirements can be noted in the bottom row.

SUB-SUBSPREADSHEETS (THIRD LAYER)

The sub-subspreadsheets perform calculations, the results of which feed into the subspreadsheets. Thus, the subspreadsheets remain streamlined with a consistent format while background calculations are conducted in the sub-subspreadsheets. Based on our evaluation of San Diego County, we believe that two spreadsheets in the third layer are adequate to model any water system. Another spreadsheet for local reservoirs might be necessary if energy use or production from those reservoirs were significant. In San Diego County, however, energy used to charge the reservoirs with imported water is included in the import columns of the source and conveyance spreadsheet, and energy production from the reservoirs is reported to be very small. This is typical for relatively small terminal reservoirs in a system that depends heavily on imported water.

Groundwater Sources

The objective of this spreadsheet is to determine the average annual volume of water that comes from each of the groundwater sources (row 5) and the average annual energy use associated with each groundwater source (row 7). Energy requirements are due primarily to pumping and conveyance of groundwater. Groundwater pumps are either electric or gas; if they use gas, energy use in therms is converted into kilowatt-hours (row 6). Row 8 allows the user to input information regarding the quality (e.g. brackish water, seawater) of the groundwater source if it is unusual. The weighted averages from the groundwater sources spreadsheet are linked to the groundwater column in the sources and conveyances spreadsheet.

Water Reuse Projects

The objective of this spreadsheet is to determine the average annual volume of water (row 5) that comes from each of the water recycling projects and the average annual energy use associated with water recycling (row 7). Energy requirements are due primarily to pumping and conveying recycled water. Row 8 allows the user to input data regarding the water quality associated with each water reuse project. The results from the water reuse projects spreadsheet are linked to the water reuse column in the sources and conveyances spreadsheet.

San Diego has 24 water reuse projects; the water from these projects is primarily used for agriculture, landscaping, and irrigation purposes. Note that this is the energy used to upgrade water from a quality level adequate for legal discharge to the quality level required for reuse. Energy used to treat wastewater to discharge quality is included in the wastewater collection and treatment subspreadsheet.

APPENDIX B

San Diego Case Study Data Sources and Assumptions

▶ The State Water Project (SWP) pumping energy is from Wilkinson.[122] Flow from Devil's Canyon to the San Diego County Water Authority (SDCWA) is assumed to be by gravity via Lake Perris, the Diamond Valley Lake, or Lake Skinner. Energy intensity is assumed to be for water delivered to Devil's Canyon. That is, water losses in the SWP are already accounted for in this energy intensity figure.

▶ The Colorado River Aqueduct (CRA) pumping energy is from Wilkinson.[123] Flow to the SDCWA is assumed to be by gravity via Lake Mathews, the Diamond Valley Lake, or Lake Skinner. Energy intensity is assumed to be for water delivered to Lake Mathews, or equivalent.[124] That is, water losses in the CRA are already accounted for in this energy intensity figure.

▶ Water-bag towing expenditures are for diesel fuel energy from Spragg for a 400-mile round-trip from the Mad River to Monterey, adjusted for a 900-mile round-trip from the Mad River to San Diego.[125] Energy expenditures were converted to kilowatt-hours equivalent using $1.50 per gallon, 150,000 BTU per gallon, and 10,239 BTU required to produce each kilowatt-hour.

▶ Hydroelectricity is not produced in the Colorado River between the intake of the CRA and the intake of the All American Canal.[126]

▶ Hydroelectric power not produced in the All American Canal if water were transferred to San Diego is based on an average of 2.85 million af/yr of flow in the canal and an average of 3 million kWh/yr of hydroelectricity produced from that flow.[127] Adjusting for an assumed 5 percent loss of water in the CRA, these figures yield 110 kWh lost per acre-foot delivered to San Diego County.

▶ Energy use per acre-foot for the SDCWA Seawater Desalination Facility at Encina is from SDCWA staff.[128]

▶ Raw water lift to treatment plants is from SDCWA. Staff provided data for the Levy and Perdue water treatment plants.[129] It is assumed to be representative of other plants in the county and the Skinner treatment plant operated by the Western Municipal Water District in Riverside County.

▶ Groundwater lift data are from SDCWA. Staff provided data for the Yuima Municipal Water District and the Sweetwater Authority.[130]

▶ Energy use in water recycling is from SDCWA. Staff provided data for supplemental treatment at San Elijo and Santee Basin and brackish groundwater treatment at Reynolds.[131]

▶ Energy use in water treatment is from SDCWA. Staff provided data for Vista (Escondido), Levy, and Perdue water treatment plants.[132]

▶ Water loss in water treatment was assumed to be 5 percent based on calculations at the Perdue (Sweetwater) treatment plant.[133]

▶ Energy use in water distribution is from the Helix Water District's distribution system from the Levy treatment plant and the North City recycled water system.[134] Note that about half the distribution system flow from Levy is pressurized by gravity, so pump pressurization requirements are higher per acre-feet than the figures used. Our analysis uses the weighted average figure because, according to SDCWA staff, significant portions of the distribution system in San Diego County are pressurized by gravity.[135]

▶ Distribution loss (unaccounted-for water) is assumed to be 7 percent based on one estimate of the sum of losses in regional distribution and local distribution provided by SDCWA staff.[136]

▶ Water use in the SDCWA service area in 2010 is projected to be 32 percent CII (commercial, industrial, and institutional uses); 58 percent residential (41 percent single-family, 17 percent multi-family); and 10 percent agricultural, according to SDCWA staff.[137] Our analysis assumed these figures are also roughly representative of current use.

▶ Residential water use is assumed to be 60 percent indoor, 40 percent outdoor.[138]

▶ Indoor use is further disaggregated according to the Awwa Research Foundation: toilets, 26.1 percent; clothes washers, 22.7 percent; showers, 17.8 percent; faucets, 15.4 percent; leaks, 12.7 percent; baths, 1.8 percent; dishwashers, 1.4 percent; other, 2.1 percent.

▶ CII use was disaggregated as in Gleick et al: 38 percent landscaping, 6 percent kitchen (composed of 24 percent dishwashers, 14 percent pre-rinse nozzles, 62 percent other kitchen), 15 percent cooling, 14 percent restroom, 18 percent process, 2 percent laundry, and 7 percent other.[139]

▶ Energy use in clothes-washers and dishwashers are averages from the Department of Energy's Energy Star website.[140] Energy use in showers and baths assumes heating from 60 to 105 degrees Fahrenheit; faucet water is conservatively assumed to be unheated.

▶ All dishwasher energy savings are assumed to be from reduced consumption of hot water; three-quarters of clothes-washer savings are assumed to be from reduced consumption of hot water.[141]

▶ Water-cooled chiller energy consumption of 0.5 kWh/ton from the Federal Energy Management Program website.[142]

▶ Evaporative water consumption and the ratio of evaporative consumption to blowdown in water-cooled chillers from city of San Jose.[143]

▶ CII energy use for water heating from Sezgen and Koomey.[144]

▶ Energy use in industrial wastewater treatment in the United States is from Amarnath,[145] conservatively assuming the reported $2.5 billion of annual fuel and energy expenditures for treatment were for diesel fuel or gasoline at $1.50 per gallon, with heat content of 150,000 BTUs per gallon.[146]

▶ Industrial water use for the United States also from Amarnath, but cross-checked against United States Geological Survey Circular 1081.[147]

▶ Energy use in wastewater treatment is from SDCWA. Staff provided data for the North City and Santee Basin facilities.[148] Note that energy intensity per acre-foot treated is significantly higher than the energy intensity presented in Figure 4 because the latter is energy intensity per acre-foot of end use. Only 46 percent of countywide water use is estimated to enter the wastewater system because landscape and agricultural water use, pipe leaks, and some CII processing and cooling water are not tributary to wastewater treatment plants.

APPENDIX C

AGRICULTURAL MODEL DESCRIPTION

The agricultural model structure is parallel to the urban model presented in Appendix A. However, a number of modifications were required to account for differences between urban and agricultural settings. Some of the differences include:

▸ Sources other than surface and groundwater, recycled water, and conservation are rarely used for agriculture. For example, desalination for agricultural use is unheard of. The economic value of agricultural products is not high enough to justify the more expensive sources of water used in urban settings.

▸ Water for agriculture is rarely treated unless it is reclaimed from a wastewater source.

▸ Hydroelectric production opportunities and trade-offs are often more complicated for agricultural water than urban water.

▸ Agricultural water is often distributed to end use (the plants in the fields) by gravity in open channels, although pressurized distribution via sprinklers or drip irrigation systems is also common. Often, water is lifted a short height—such as 10 feet—from the distribution canal to the field.

▸ On-farm redistribution from irrigation-tailwater-return ponds is growing in popularity as a way of conserving water and reducing discharge of pollutants. The urban analogy is on-site water reuse by industry. However, industrial water reuse usually involves treatment, while on-site agricultural reuse usually does not.

▸ The water quality standards for recycled wastewater intended for agricultural reuse are lower than for urban reuse, which implies less energy consumption per unit of water recycled. Recycling wastewater for agricultural purposes is common in the western United States, especially in landlocked areas where discharge to receiving waters is restricted either during the dry season or year-round.

There is no treatment spreadsheet since agricultural water is not treated between source/conveyance and distribution. As in the urban model, distribution is separated into generic blocks. End uses are defined as crop type/irrigation system combinations. For example, one could grow almonds with flood irrigation or with permanent sprinklers. Energy for pressurizing the sprinklers or lifting water from edge-of-farm canals is included in end use energy, not in distribution energy. In

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concept, a spreadsheet for drainage management would replace the wastewater treatment spreadsheet in the urban model. In the Westlands Water District, however, drainage management other than tailwater-return ponds does not use energy. Tailwater-return energy use is accounted for in the third-layer water-reuse spreadsheet that feeds the sources and conveyances spreadsheet. The groundwater spreadsheet is conceptually identical to the urban model.

ENDNOTES

1 The use of water in producing energy is an important subject but is beyond the scope of this report. For information on this issue see, for example Ellen Baum, et al., *The Last Straw: Water Use by Power Plants in the Arid West,* (Boston: The Clean Air Task Force and the Land and Water Fund of the Rockies, 2003).

2 California Water Code, Section 522.

3 California Energy Commission, *Agricultural Rates in California* (Sacramento, California: California Energy Commission, 2001), p. 9.

4 Electric Power Research Institute, *Energy Audit Manual for Water/Wastewater Facilities*, (Palo Alto: 1999), Executive Summary.

5 There are 11.5 million households in California (U.S. Census). Each of these households consumes an average of 6,500 kWh/yr. "California Energy Consumption by Sector," available at http://energy.ca.gov/electricity/consumption_by_sector.html.

6 Nathanael Greene and Roel Hammerschlag, "Small and Clean Is Beautiful: Exploring the Emissions of Distributed Generation and Pollution Prevention Policies," in *The Electricity Journal*, June 2000, pp. 50–60.

7 Frank Burton, *Water and Wastewater Industries: Characteristics and Energy Management Opportunities* (Palo Alto, CA: Electric Power Research Institute, 1996), pp. 3–9.

8 Robert C. Wilkinson combines treatment and distribution; i.e., he divides the water chain into four stages in *Methodology for Analysis of the Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy Efficiency Measures* (Santa Barbara, CA: University of California, Santa Barbara, Environmental Studies Program, 2000).

9 Electric Power Research Institute, Executive Summary.

10 Carrie Anderson, *Energy Use in the Supply, Use, and Disposal of Water in California*, (Sacramento: California Energy Commission, 1999), p.9.

11 "Power Plants Kill Billions of Fish," available at: www.riverkeeper.org/campaign.php/fishkills/the_facts/178. For additional information on the impacts of power plants on aquatic resources, see, for example, Peter Raimondi's testimony before the Central Coast Regional Water Quality Control Board, July 10, 2003, entitled "Cooling Water System: Findings Regarding Clean Water Act Section 316(b), Diablo Canyon Power Plant." This testimony is available at: www.swrcb.ca.gov/rwqcb3/Facilities/Diablo/Diablo.htm.

12 For more information on these impacts see, for example, Bruce Driver and Gregg Eisenberg, *Western Hydropower: Changing Values/New Visions, Independent Report to the Western Water Policy Review Advisory Commission* (Boulder, CO: 1997); and Phillip Williams, "The Flood Next Time: Restoring Living Rivers," in *World Rivers Review,* February 2000, p. 6.

13 For further discussion of global climate change and its impacts on water supply, see Peter H. Gleick and D. Briane Adams, *Water: The Potential Consequences of Climate Variability and Change for the Water Resources of the United States, the Report of the Water Sector Assessment Team for the U.S. Global Change Research Program* (Oakland, CA: Pacific Institute, 2000); Victor S. Kennedy, et al., *Coastal and Marine Ecosystems and Global Climate Change: Potential Effects on U.S. Resources* (Arlington, VA: Pew Center on Global Climate Change, 2002); Jay R. Lund, et al., *Climate Warming and California's Water Future* (Davis, CA: Department of Civil and Environmental Engineering, University of California, 2003), Kirkman O'Neal, *Effects of Global Warming on Trout and Salmon in U.S. Streams* (Washington, DC: Defenders of Wildlife, 2002); N. Leroy Poff and Mark Brinson, *Aquatic Ecosystems and Global Climate Change: Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States* (Arlington, VA: Pew Center on Global Climate Change, 2002); and *Confronting Climate Change in California: Ecological Impacts on the Golden State* (Cambridge, MA: Union of Concerned Scientists, 1999).

14 *Climate Changes the Water Rules: How Water Managers Can Cope With Today's Climate Variability and Tomorrow's Climate Change* (Delft, The Netherlands: The Dialogue on Water and Climate, 2003). This collaborative report is available at: www.waterandclimate.org/report.htm.

15 Peter H. Gleick and Linda L. Nash, *The Societal and Environmental Costs of the Continuing California Drought* (Oakland, CA: Pacific Institute, 1991).

16 A full discussion of water and power subsidies is beyond the scope of this report. For more information on the magnitude of these extensive subsidies, see, for example, Norman Myers and Jennifer Kent, *Perverse Subsidies: How Misused Tax Dollars Harm the Environment and the Economy* (Washington, DC: Island Press, 1998); Committee on Natural Resources, *Taking from the Taxpayer: Public Subsidies for Natural Resource Development* (Washington: U.S. Government Printing Office, 1994); B. Delworth Gardner, *Plowing Ground in Washington: The Political Economy of U.S. Agriculture* (San Francisco: Pacific Research Institute for Public Policy, 1995); Ronald Bailey, ed., *The True State of the Planet* (New York: Competitive Enterprise Institute, 1995); and Dr. E. Phillip LeVeen and Laura B. King, *Turning Off the Tap on Federal Water Subsidies* (New York: NRDC, 1985).

17 Committee on Natural Resources, p. 64.

18 Committee on Natural Resources, p. 66.

19 The Central Valley Project no longer charges a power rate for its water deliveries. In part, this seems to be because it does not want to be subject to oversight by FERC or other agencies. Instead, the Central Valley Project includes a per-acre-foot power charge for water deliveries. The per-acre-foot energy rates vary widely from contractor to contractor, ranging from one penny to $4.96 per acre-foot. Jesus Reynoso, Water Rate-Setting Section, United States Bureau of Reclamation Finance Office, personal communication, April 2003.

20 *Mid-Pacific Region 1999 Irrigation Water Rates, Central Valley Project* (Sacramento, CA: U.S. Bureau of Reclamation, Mid-Pacific Region, 1999).

21 B. Delworth Gardner, *Plowing Ground in Washington: The Political Economy of U.S. Agriculture* (Pacific Research Institute for Public Policy), p. 296.

22 Our San Diego case study shows that about 2,100 kWh/af will be required to support the transfer. About 5 percent of this amount (100 kWh/af) is hydroelectricity not produced in the All American Canal; the other 2,000 kWh/af are used as electricity to pump the transferred water through the Colorado River Aqueduct. Each 100,000 af/yr of water transferred to San Diego, therefore, may increase electricity demand by 210 million kWh/yr. This is certainly not negligible, and should have been discussed in the environmental impact review.

23 S. Joshua Newcom, "Dealing with the Shock: Shedding Light on the Link Between Water and Power in California," in *Western Water*, September/October 2001, p. 7.

24 Wilkinson, p. 6.

25 Surface and groundwater figures come from Department of Water Resources, *Bulletin 160-98*; recycled water figure comes from Department of Water Resources, *Water Recycling 2030: Recommendations of California's Recycled Water Task Force*, 2003; desalination figure comes from Department of Water Resources*, Bulletin 160-03*, 2003 stakeholder draft.

26 Carrie Anderson, *Energy Use in the Supply, Use, and Disposal of Water in California* (Sacramento: California Energy Commission, 1999) p. 1.

27 Wilkinson, p.7.

28 Steve Kashiwada, State Water Project, personal communication, June 2002.

29 Barry Mortimer, Central Valley Project, May 2002, and Steve Kashiwada, State Water Project, personal communication, June 2002.

30 Larry Dale, et al., *The Impact of Electricity Prices on the Cost of Five Options to Increase Southern California's Urban Water Supplies* (prepared for NRDC, 2003), p. 4.

31 Anderson, p.4.

32 Larry Dale, et. al., 2003.

33 California Energy Commission, p. 16.

34 Department of Water Resources, *California Water Plan Update 2003–Stakeholder Draft,* (Sacramento, CA: 2003).

35 *Seawater Desalination and the California Coastal Act (DRAFT)* (Sacramento, CA: California Coastal Commission, 2003).

36 John Kiernan, personal communication, March 2003.

37 Wilkinson.

38 Ibid.

39 Barakat & Chamberlin, Inc., *The Value of Water Supply Reliability: Results of a Contingent Valuation Survey of Residential Customers* (Sacramento, CA: California Urban Water Agencies, 1994).

40 The Ocean Conservancy, *Desalination: An Overview*, prepared for May 5, 2003, Environmental Roundtable Meeting in San Francisco.

41 California Water Code Section 13050 (n).

42 Department of Water Resources, Recycled Water Task Force, *Water Recycling 2030: Recommendations of California's Recycled Water Task Force*, (Sacramento: June 2003), p.7.

43 Ibid., p.5.

44 Ibid., p.5.

45 Newcom, p.12.

46 "Water Pipeline Project Underway in Orange County," Orange County Water District Press Release, February 19, 2004, available at: http://www.gwrsystem.com/news/releases/040219.html.

47 Burton, pp.3–30. In addition to direct energy costs for water treatment, substantial energy is also required to produce the chemicals used for water treatment. Those costs, while beyond the scope of this report, are part of the life-cycle energy costs of water.

48 Burton, p. ES–5.

49 Burton, p. ES–4.

50 Burton, pp. 3–9.

51 Burton, pp. 3–27.

52 *Draft WUE Program Plan* (Sacramento, CA: CALFED Bay-Delta Program, 1999), pp.5–21.

53 National Renewable Energy Laboratory, "Cities Cut Water System Energy Costs," 1994.

54 Irrigation Training and Research Center, *Variable Frequency Drives and SCADA—Are They Worthwhile Investments?* ITRC Report 02-006 (San Luis Obispo, CA: California Polytechnic State University, 2002).

55 Gleick, et al., p.3.

56 Gleick, et. al., p.2.

57 Peter W. Mayer, et al., *Residential End Uses of Water* (Denver, CO: American Water Works Association Research Foundation, 1999).

58 Tables 3 through 5 modified from Amy Vickers' *Handbook of Water Use and Conservation: Homes, Landscapes, Business, Industries, Farms* (Amherst, MA: WaterPlow Press, 2001).

59 Gary H. Wolff and Peter H. Gleick, "The Soft Path for Water," in *The World's Water: The Biennial Report on Freshwater Resources* (Washington, DC: Island Press, 2002).

60 For a complete discussion of residential conservation measures, see Vickers, and Gleick, et.al., 2003.

61 *Codes and Standards Enhancement Initiative For FY2003: Title 20 Standards Development, Comments of PG&E Regarding Proposed Residential Clothes Washer Water Factor Standards* (Docket No. 03-AAER-01) (RCW) November 11, 2003, p. 11. Comments were prepared for PG&E by Energy Solutions.

62 Gleick, et al.

63 Gleick et al., p. 63.

64 Gleick, et al., p.2.

65 Vickers, p.232.

66 Benedykt Dziegielewski, et al., *Commercial and Insitutional End Uses of Water* (Denver, CO: American Water Works Association Research Foundation, 2000).

67 Gleick, et al., p.2.

68 For additional descriptions of CII water conservation measures, see Vickers; Gleick, et.al.; and Miriam Pye, *Making Business Sense of Energy Efficiency and Pollution Preventio*n (Washington, DC: American Council for an Energy Efficient Economy, 1998).

69 Vickers, p.235.

70 Gleick, et.al., p.83.

71 Ibid. p.91.

72 "Conservation Tips," Sacramento Municipal Utility District, available at: www.smud.org/residential/saving/conservation.html.

73 Department of Water Resources, *California Water Plan Update: Bulletin 160-98*.

74 Anderson, p.6. This latter figure includes energy used in food processing such as water sterilization, pumping, reclamation for washing, and other purposes.

75 California Energy Commission, p.1.

76 The Department of Water Resources does not have a good estimate of agricultural water use efficiency. While the CALFED water use efficiency program plan estimates average statewide water use efficiency as 73 percent, there is good reason to doubt this estimate. The estimate is based on data from the Westlands Water District during a limited number of irrigation seasons—a very limited and nonrepresentative sample. For additional discussion of agricultural water conservation, see Vickers; Ronnie Cohen and Jennifer Curtis, *Agricultural Solutions: Improving Water Quality in California Through Water Conservation and Pesticide Reduction* (New York: NRDC, 1998); Elise Fulstone, *The Role of Improved Irrigation Technologies in Helping Farmers Meet Environmental and Economic Challenges* (Washington, DC: Environmental and Energy Study Institute, 1997); and Department of Water Resources, *Agricultural Efficient Water Management Practices that Stretch California's Water Supply* (Sacramento, CA: 1995).

77 California Energy Commission, p. 5.

78 Anderson, p. 9.

79 Table 8 is modified from Burton.

80 Edward R. Osann and John E. Young, *Saving Water, Saving Dollars: Efficient Plumbing Products and the Protection of America's Waters* (Washington, DC: Potomac Resources, 1998), p. 10. Capital cost savings from reductions in wastewater flows will vary tremendously by location, particularly for older systems designed for certain flows. For new systems, however, water conservation and reduced wastewater flows should translate more reliably into reduction in wastewater capital costs.

81 To create this spreadsheet, we modified and expanded the methodology of Wilkinson (2000) to determine the energy embedded in water use from source to disposal.

82 The residential, commercial/industrial/institutional (CII), and agricultural percentages of total use in the table are from San Diego County Water Authority staff for the year 2010. They were disaggregated using data from the Awwa Research Foundation (1999) and Gleick (2003).

83 U.S. Census Bureau, Census 2000 figures available at: www.census.gov.

84 California Energy Commission, "Chula Vista Power Project, Chula Vista, Emergency Peaker Project," Energy Commission Docket Number: 01-EP-3. Available at: www.energy.ca.gov/sitingcases/peakers/chulavista/.

85 For more information about the environmental implications of drainage water and conflicts over responsibility for management and disposal of drainage flows, see, for example, *Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Jaoquin Valley*, (Sacramento, CA: U.S. Department of Interior and California Resources Agency, 1990).

86 The district is within the Tulare Lake groundwater basin, and Westside and Pleasant Valley subbasins. Historic groundwater depth maps are available from the Westlands Water District at: www.westlandswater.org/maps/dgwmapsel.htm and the Department of Water Resources online database, available at: http://wdl.water.ca.gov.

87 Russ Freeman, Resources Division, the Westlands Water District, personal communication, June 2003.

88 The original district included approximately 376,000 acres. It is currently referred to as Priority Area I (PAI). Most of PAI is east of the San Luis Canal and has gravity water service. Small recirculating pumps are used to pressurize supply laterals serving land adjacent to the San Luis Canal that is too high to be served through gravity laterals. The Westplains Water Storage District merged with Westlands in 1965, adding 210,00 acres. These lands are referred to as Priority Area II (PAII). Much of it is west and upslope of the San Luis Canal. It is served by pumping from the San Luis Canal and gravity supply from the Coalinga Canal. About one-third of the land between the San Luis Canal and the Coalinga Canal is served by pumping from the San Luis Canal. About 18,000 acres were added to the district subsequent to the Westplains merger. These lands are referred to as Priority Area III (PAIII). Unlike

PAI and PAII, PAIII does not have a water service contract. It receives surplus Central Valley Project water or hardship water when available from the bureau during drought periods to preserve trees and vines.

89 Barry Mortimeyer, chief, Central Valley Operations, U.S. Bureau of Reclamation, personal communication, June 2003.

90 The unit factors are for water moved at the point of energy use. Due to system losses, actual energy used per acre-foot of water delivered is higher, as discussed in Chapter 2. In this case study, conveyance losses were not included due to data limitations.

91 Barry Mortimeyer, chief, Central Valley Operations, U.S. Bureau of Reclamation, personal communication, May 2003.

92 Since water in the canals cannot be differentiated by recipient, just as electrons in power lines cannot be labeled "for customer A," it is unclear how the 90 kWh/af net consumption of storing water in San Luis should be allocated. Westlands Water District staff claim it should not be allocated to them (Russ Freeman, Resources Division, The Westlands Water District, personal communication, July 2003) because priority is given to deliveries to exchange contractors and wildlife refuges. But it is not clear how these priorities affect timing of deliveries or that it is appropriate to differentiate this energy by recipient. An equally valid approach would be to charge a percentage of 90 kWh/af to all recipients, where the percentage reflects the percentage of water passing the San Luis Reservoir outlet that is pumped into and then recovered from San Luis Reservoir.

93 The 245 kWh/af figure does not apply to every acre-foot of Central Valley Project water delivered in the district since the district lifted only about 400,000 af/yr, or about 50 percent of Central Valley Project deliveries, in 2002.

94 Pimental and cost and return studies prepared by the University of California Cooperative Extension, which are available at www.agecon.ucdavis.edu/outreach/crop/cost.htm.

95 We have not, for example, estimated the energy embedded in the materials used on farm. Pimental and Pimental provide such data for around a dozen examples, including some relatively old data on tomato production in California. In that example, gasoline and diesel fuel account for a little more than half of the embedded energy inputs. See D. Pimental, and M. Pimental, editors, *Food, Energy, and Society* (Niwot, Colorado: University of Colorado Press, 1996).

96 W. Illingworth, D. Mitchell, L. Dale, A. Fargeix, R. T. Mott, and S. Msangi, *Analysis of Economic Impacts of Proposed Land Retirement in Westlands Water District, Final Report* (Westlands Water District, May 2003).

97 Permanent retirement of up to 200,000 acres of land within the Westlands Water District has been proposed by the district itself. According to Illingworth, et.al., the Westlands Water District is developing plans to purchase and retire up to 100,000 acres of land within the district. The district would retain ownership of these lands and would redirect the water from these lands to non-drainage impaired land within the district. An additional 100,000 acres of land retirement may take place if an agreement is reached with the Department of the Interior.

98 100,000 acres times 2.34 acre-feet of water-use-per-acre times 435 kWh per acre-foot times 70 percent = 71 million kWh.

99 Russ Freeman, Resources Division, the Westlands Water District, personal communication, June 2003.

100 Wilkinson (2000) and Table 12 of this report.

101 W. Illingworth, D. et.al., May 2003.

102 Russ Freeman, Resources Division, the Westlands Water District, personal communication, August 2003.

103 *Pocket Guide: The Northwest Power Planning Council's Fast Facts about the Columbia River Basin,* (Portland, Oregon: Northwest Power and Conservation Council, 1992), p. 9.

104 Ibid.

105 The National Marine Fisheries Service's RPAs are "expected to cost $1 billion a year, significantly more than the $800 million estimated one-time cost of breaching the four dams," (*Chicago Tribune*, March 5, 2001).

106 Foundation for Water and Energy Education, "What Makes the Columbia River Basin Unique and How We Benefit," available at: www.fwee.org/c-basin.html.

107 The National Marine Fisheries Service Press Release NOAA 97-R136, "Federal Fishery Agency Calls for a No-Net-Loss Approach to New Irrigation Pumping in Columbia Basin," May 16, 1997. Available at: www.publicaffairs.noaa.gov/pr97/may97/noaa97-r136.html.

108 Bonneville Power Administration, "Aluminum Companies Chip In," *Journal of the Bonneville Power Administration*, February 2001, p.2.

109 Linda Mapes, "Abundant Idaho Water Tied Up Tight," *Seattle Times*, April 29, 2001.

110 Washington State Department of Ecology, *2001 Drought Response Report to the Legislature*, (Olympia, WA: 2001), p. 18.

111 Joel R. Hamilton and R. Garth Taylor, "The Idaho Power Irrigation Electricity Buyout," *Idaho Economics*, November 2001.

112 Michele DeHart, manager, Fish Passage Center, in a letter to Rich Zabel, National Marine Fisheries Service, commenting on the National Marine Fisheries Service draft report on survival estimates for spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs during 2001, February 27, 2002.

113 "The [Federal Salmon Plan]'s flow and spill provisions were not met on even a single day during 2001," Save Our Wild Salmon, *Failing Salmon, Failing People*, (Seattle, 2001), Executive Summary.

114 Fish Passage Center *Annual Report* (Portland, OR: 2001), p. xix.

115 This estimate assumes that energy used to grow potatoes is an average for the project area. The assumption needs verifying, but it is useful for illustration purposes and is plausible based on cultivation and harvest energy estimates per acre-feet of water use developed in the Westlands case study.

116 Bonneville Power Administration, "Follow Up Questions for Power Net Revenue Improvements," *Sounding Board*, March 2004, p. 2.

117 The CALFED Bay-Delta Program Record of Decision indicates that the program will produce a "definition of appropriate measurement by the end of 2001," and that it will work "to develop legislation for introduction and enactment in the 2003 legislative session requiring the appropriate measurement of all water uses in the state of California," (record of decision, p. 63). CALFED has missed both of these dates.

118 The record of decision was adopted in August 2000 by state and federal water management agencies. The plan states that "CALFED agencies will support legislation that encourages groundwater management at the sub-basin level," (record of decision, p.47). We are not aware of progress toward the enactment of this legislation.

119 The record of decision states that "(By) the end of 2002, CALFED Agencies will implement a process for certification of water suppliers' compliance with the terms of the urban MOU, including implementation of best management practices for urban water conservations," (record of decision, p. 62). CALFED has missed this target.

120 Wilkinson.

121 This assumption is worthy of further research in some settings. Since both treated and untreated water are delivered to San Diego County in pipelines rather than canals, the assumption is probably valid in our case study. But it may not be valid in all settings since friction losses in pipelines often exceed those in open channels.

122 Robert C. Wilkinson, *Methodology for Analysis of the Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy Efficiency Measures* (Santa Barbara, CA: University of California, Santa Barbara, Environmental Studies Program, 2000).

123 Wilkinson.

124 Robert Wilkinson, Professor, University of California Santa Barbara, personal communication, September 2003.

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126 William L. Kahrl, *California Water Atlas* (The State of California, 1979).

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128 Jeff Stephenson, water resources specialist, San Diego County Water Authority, personal communication, June 2003.

129 Ibid.

130 Ibid.

131 Ibid.

132 Ibid.

133 Ibid.

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135 Ibid.

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137 Ibid.

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139 Ibid.

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141 Amy Vickers' *Handbook of Water Use and Conservation: Homes, Landscapes, Business, Industries, Farms* (Amherst, MA: WaterPlow Press, 2001).

142 United States Department of Energy, "How to Buy an Energy Efficient Water-Cooled Chiller," available at: www.eere.energy.gov/femp/procurement/wc_chillers.html.

143 City of San Jose Environmental Services Department, *Water Conservation Guide for Office Buildings and Commercial Establishments* (San Jose, California: City of San Jose, 1992).

144 Osman Sezgen and Jonathan G. Koomey, *Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting* (Berkeley, California: University of California Berkeley, Lawrence Berkeley National Laboratory, 1995).

145 A. Amarnath, *Maximizing Wastewater Reduction for Process Industries*, TR-1114205 (Palo Alto: Electric Power Research Institute, 1999).

146 Ibid.

147 U.S. Geological Survey, "Estimated Use of Water in the United States, 1990," in *USGS National Circular* 1081, available at: http://water.usgs.gov/watuse/wucircular2.html.

148 Jeff Stephenson, Water Resources Specialist, San Diego County Water Authority, personal communication, June, 2003.