Water and Electricity Do Mix
A Summary of the Water Energy Connection in Northern California

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Introduction: In California and the entire arid west, there has always been great interest in all things related to water. Mark Twain's statement that "Whiskey is for drinking. Water is for fighting over." shows the historic importance that water has played in our region. Energy efficiency and climate change are two of the latest items to be linked to water, with growing attention being paid to the connection between water use and energy consumption. The California Energy Commission estimates that 19% of all the State's electricity; 30% of all natural gas use; and more than 80 million gallons of diesel fuel are used each year to acquire, treat, and convey water to its end users.[1] This article summarizes a PG&E funded research study that investigated the energy intensity of non-agricultural water consumption in Northern California. Non-agricultural water consumption in counties served by PG&E is estimated at 31 million acre-feet per year.[2] While the amount varies by location, this comes to between 36,000 and 110,000 gallons of water per person, per year.

The study provides data on specific and average water energy use intensity (EUI) and quantifies the energy related benefits of water efficiency in green buildings and projects. The purpose of the study was to identify variations in the water energy relationship and provide case study information on the water energy relationship for a group of representative water agencies and firms. The study included a literature review, interviews with water agency/city/company staff and data collection from twelve organizations serving a population of 4.5 million people.

The Water Cycle

The life of a raindrop/snowflake slated for use by urban users begins with that drop being collected at its source, conveyed to a wholesaler, treated for use and being stored, used by a consumer, treated and either re-used before or discharged to a receiving body of water. Each step in this cycle has an energy footprint that can vary widely depending on geography and technology. Over the course of its travels, our drop of water comes under the control of several local, state and/or federal agencies, possibly a private water or energy utility company, and probably one or more cities and counties.

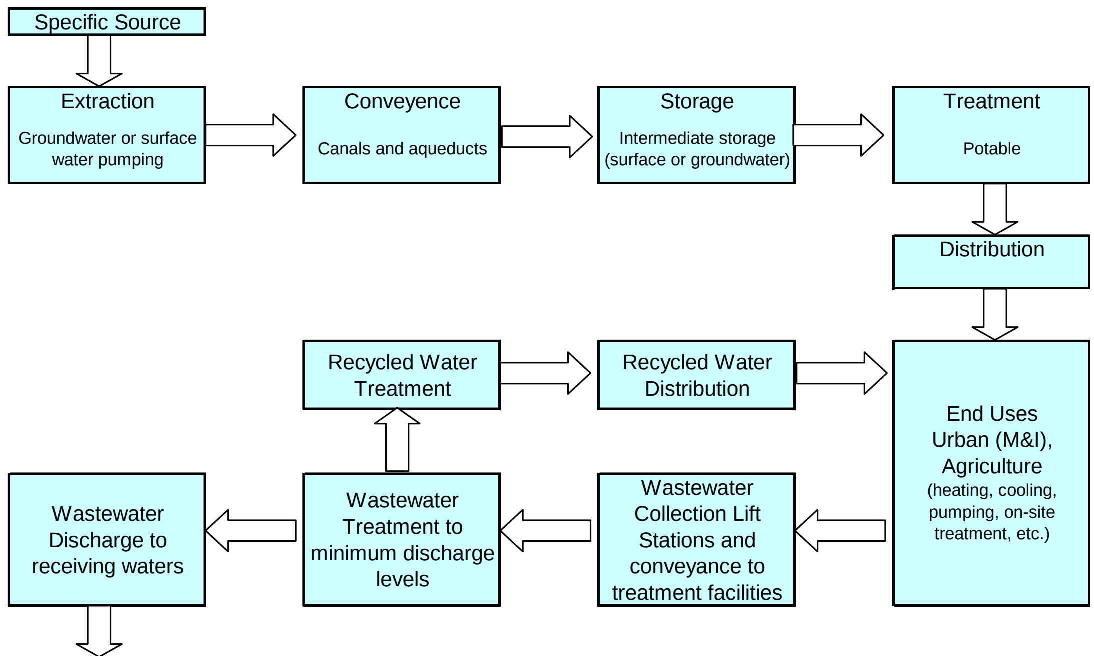

Figure 1—The Water Use Cycle (Source: Wilkinson)

Figure 1 taken from Robert Wilkinson's work[3] shows the cold water use cycle from a water agency's perspective.[4] For the purposes of this paper, the stages in the water use cycle have been reduced to four, primarily because it was not possible to gather energy use data for each of the nine stages shown in the previous chart. In several cases disaggregating water energy data into four stages was problematic. The four stages in the water use cycle used for this study were:

1. Supply and Conveyance

2. Treatment

3. Distribution

4. Wastewater Treatment

This study focused on the EUI of water within Northern California. However, nearly 80% of the urban California water demand is in the south even though approximately 70% of the state's total stream runoff is north of Sacramento. In addition, the energy intensity of water in Southern California is higher than Northern California water. Most of Southern California's water has to be pumped over a 2,000 foot range before being delivered to end-users, the highest lift of any water system in the world. The highest pump lift in the California aqueduct is 1,926 feet, with a volume of 4,480 cubic feet per second, the equivalent of almost 20,000 tanker trucks hauling water up and over the pass every hour.

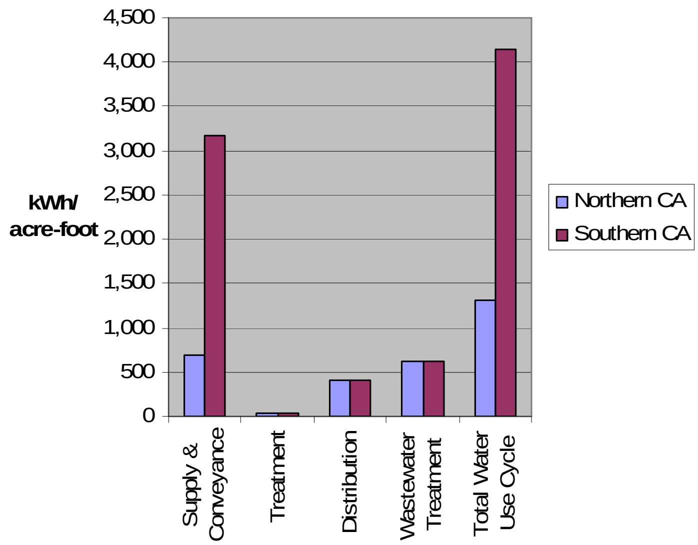

Figure 2—Water Energy Intensity - Southern vs. Northern California (California Energy Commission)

Figure 2 shows the average energy intensity of water in Southern vs. Northern California. The graph shows that the “supply and conveyance” stage of the water cycle is approximately four times more energy intensive in Southern California than it is in Northern California. The bars labeled “Total Water Use Cycle” shown in the chart should be used with care. The sum of water-use energy intensity can be misleading because the fresh water flow volumes do not correspond one-to-one with the wastewater volumes. The total energy intensity of a gallon of water that is used for irrigation purposes and does not flow through the wastewater treatment system is different than the energy intensity for a gallon of water that does end up treated as wastewater. For this reason the data gathered for this study and presented later in this paper present water EUI for all stages, but do not sum the energy intensities.

The following sections summarize the findings of research into the energy intensity of each stage of the water use cycle.

Supply and Conveyance

If our drop of water/snowflake falls into an area behind a dam, it may become “surface water”. If on the other hand our drop/flake fell at a lower elevation it typically percolates through the ground and begins its life for our purposes as groundwater. In Northern California most counties receive portions of their supply from each source. In the following graphic the upper bars represent the portion of each Northern California County’s water consumption that originates as surface water and the bottom bar represents the portion that is groundwater. At the far right end of the graph is San Francisco County which receives all of its water from dams in the Hetch Hetchy valley near Yosemite. Monterrey County at the other end of the spectrum pumps all of its water from the ground.

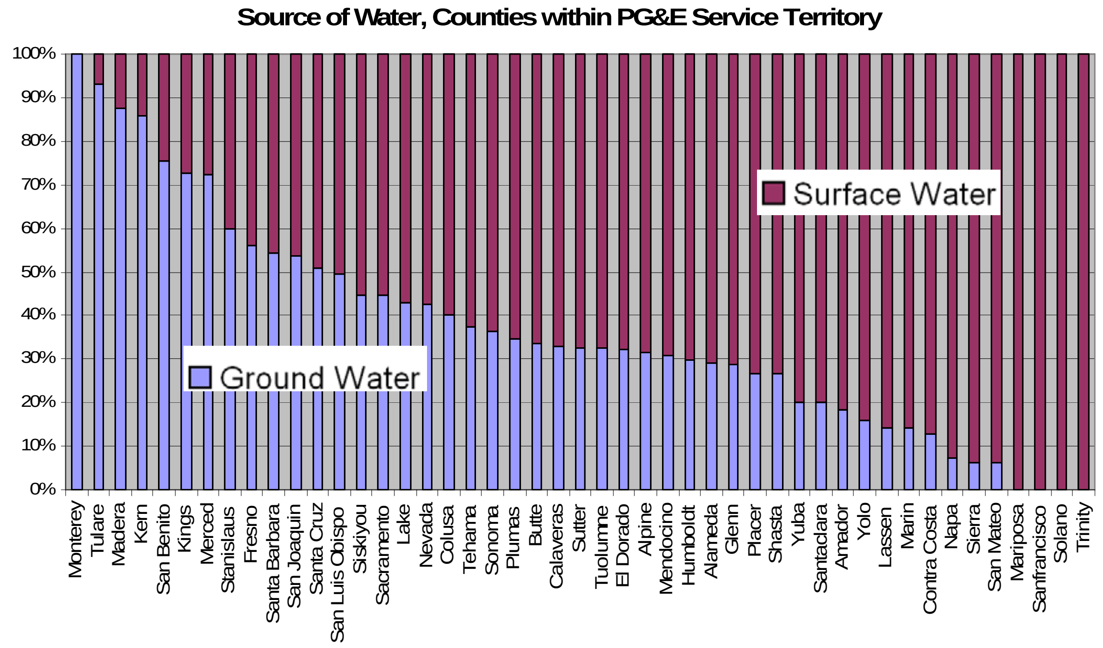

Figure 3—Surface vs. Ground Water for Northern California Counties

The energy intensity for “extraction” of gravity-fed surface water is assumed to be zero. Surface water comprises about 60 percent of the water use in Northern California, with the remaining 40 percent being from groundwater, which is pumped from great depths, ranging in this study from approximately 200 feet to over 1,000 feet. Well depths in some areas are increasing as the rate of extraction exceeds the rate of replenishment, leading to increases in extraction energy. In addition, global warming is likely to increase well depths as surface water originating from the snowpack is reduced. The following table illustrates the difference in supply and conveyance water EUI between surface and ground water.

	Supply and Conveyance EUI (kWh/A-F)			
Water Source	**High**	**Low**	**Weighted Average**	
Surface	331	0	54	5 sites
Ground	650	437	620	5 sites

Table 1—Supply and Conveyance EUI

Water Treatment

Energy associated with potable water treatment varies based upon the condition of the source water and the intended use of the water. Most residential and commercial users need potable water, which requires more extensive treatment than water used for irrigation purposes in the agricultural sector. The following table illustrates the range of energy intensity associated with potable water treatment and confirms that the potable water treatment is a relatively small contributor to the overall water EUI.

	Potable Water Treatment EUI (kWh/A-F)			
Source	**High**	**Low**	**Weighted Average**	
Current Study	127	2	61	6 sites
CEC Report (Northern CA only)	—	—	36	—
Pacific Institute's Water to Air Urban model assumptions	—	—	55	—

Table 2— Potable Water Treatment EUI

These values agree with previous smaller single-site studies that found water EUIs for potable treatment ranged from 40 – 70 kWh/acre-foot.

Water Distribution

If water distribution systems are gravity-fed, there is much less energy required than for systems that require pumping. According to the CEC, urban growth is the primary factor in increased energy for water distribution.[5] The water distribution energy data gathered for this study is presented below. For this study "distribution" is the stage of the water use cycle in which treated, potable water is distributed to the end users.

	Water Distribution EUI (kWh/A-F)			
Source	**High**	**Low**	**Weighted Average**	
Current Study	626	18	289	7 sites
CEC Report (Northern CA only)	—	—	417	—

Table 3—Water Distribution EUI

Wastewater Collection, Treatment and Discharge

The energy intensity of this stage of the cycle depends upon whether the collection system uses gravity or pumping, the size of the facility, and technologies used for treatment. The following table shows the range of wastewater EUI values with benchmarks for comparison. The numbers in the table include collection, treatment and discharge.

	Wastewater Treatment EUI (kWh/A-F)			
Source	**High**	**Low**	**Weighted Average**	
Current Study	2,028	472	642	8 sites
CEC Report (Northern CA only)	—	—	623	—
Pacific Institute's Water to Air Urban model assumptions	—	—	440	—

Table 4—Wastewater EUI

Newer regulations requiring greater levels of wastewater treatment will tend to increase wastewater energy intensity.

With the caveat stated earlier that summing the EUI of the stages of the water use cycle should be done with care, Figure 4 illustrates the EUIs for each stage and the sum of water-use energy within each water agency's service territory.

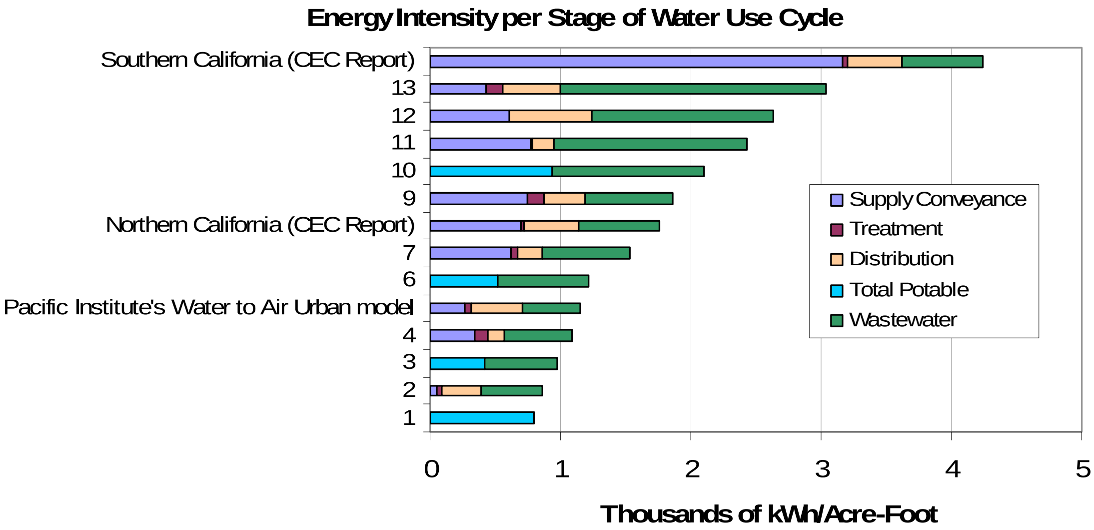

Figure 4—Energy Intensity by Water Agency

Total Energy Consumed by End Users within a Service Territory.
Each Agency is not responsible for the full energy use. Includes energy for water imported from other agencies and wastewater treatment services provided by other agencies.

Each number on the vertical axis represents a specific water agency territory. For the bars labeled “Total Potable”, it was not possible to separate the water EUI into the four stages. While the Northern California “CEC report number is a reasonable starting point for water energy intensity, the graph shows that there is a large variation, dependent primarily on wastewater and supply energy intensity.

Marginal Water Supply Sources

As the demand for water stresses accessible supplies, water will come from either conservation or marginal sources of water that require greater amounts of energy to procure. These marginal sources include old and inefficient pumps, drawing water from deeper wells, and use of desalination plants. Water conservation has the benefit of allowing agencies to either avoid, or reduce and delay, their reliance upon the more energy intensive water sources, thereby saving both water and energy.

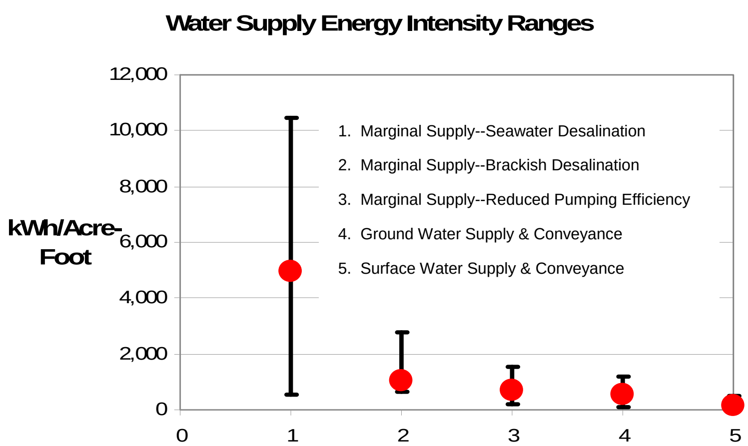

Figure 5—Water Supply Energy Intensity Ranges

Figure 5 illustrates the EUI ranges for various typical and marginal water supplies. Seawater desalination has 10 times the EUI of ground water supply, and nearly 30 times the EUI of surface water.

Water Conservation and Energy Impacts

There is significant potential to reduce the energy consumption associated with the cold water cycle (the cold water cycle excludes any energy savings related to the heating or cooling of water). The technical potential energy savings associated with improved water use efficiency ranges from 13% to 34% for the nine water agencies and companies that provided information on conservation savings. These savings do not include savings associated with improving the efficiency of the conveyance, treatment, distribution or wastewater processes, rather the energy savings come from a reduction in the consumption of water by end-users.

Water conservation energy and water savings estimates were based upon the best management practices (BMPs) developed by the California Urban Water Conservation Council (CUWCC). The CUWCC was created in 1991 to manage the implementation of best water management practices. As of 2006, 189 water agencies have pledged to adopt the BMPs. To date the CUWCC has developed a list of 14 BMPs, with 8 having results that can be quantified in water use efficiency savings in acre feet per year. The following table outlines the BMPs and indicates which ones were included in the Study.

	Description	**Included in Study**
BMP 1	Residential Surveys (Single-Family)	X
BMP 1	Residential Surveys (Multi-Family)	X
BMP 2	Low Flow Showerheads (Single-Family)	X
BMP 2	Low Flow Showerheads (Multi-Family)	X
BMP 2	Faucet Aerators (Single-Family)	X
BMP 2	Faucet Aerators (Multi-Family)	X
BMP 1 or 2[6]	Moisture Sensor (Evapo-Transpiration) irrigation controllers (Single-Family)	X
BMP 3	System Water Audits, Leak Detection and Repair	
BMP 4	Metering with Commodity Rates for all New Connections and Retrofit of Existing	
BMP 5	Large Landscape Conservation Programs and Incentives	
BMP 6	Hi-Eff. Clothes Washer (Single-Family)	X
BMP 6	Hi-Eff. Clothes Washer (Multi-Family)	X
BMP 7	Public Information Programs	
BMP 8	School Education Programs	
BMP 9a	Commercial Industrial and Institutional Surveys	X
BMP 9a	Commercial Industrial and Institutional Ultra-Low Flow Toilets	X
BMP 10	Wholesale Agency Assistance Programs	
BMP 11	Conservation Pricing	
BMP 12	Conservation Coordinator	
BMP 13	Water Waste Prohibition	
BMP 14	Ultra-Low Flush Toilet (Single-Family)	X
BMP 14	Ultra-Low Flush Toilet (Multi-Family)	X

Table 5—California Urban Water Conservation Council Best Management Practices List

The energy savings potential for each of the BMPs included in the study are shown in Figure 6 below. Each number on the vertical axis represents a specific water agency territory. In the chart, SF represents single family savings opportunities, MF represents multi-family and CII represents commercial, industrial and institutional.

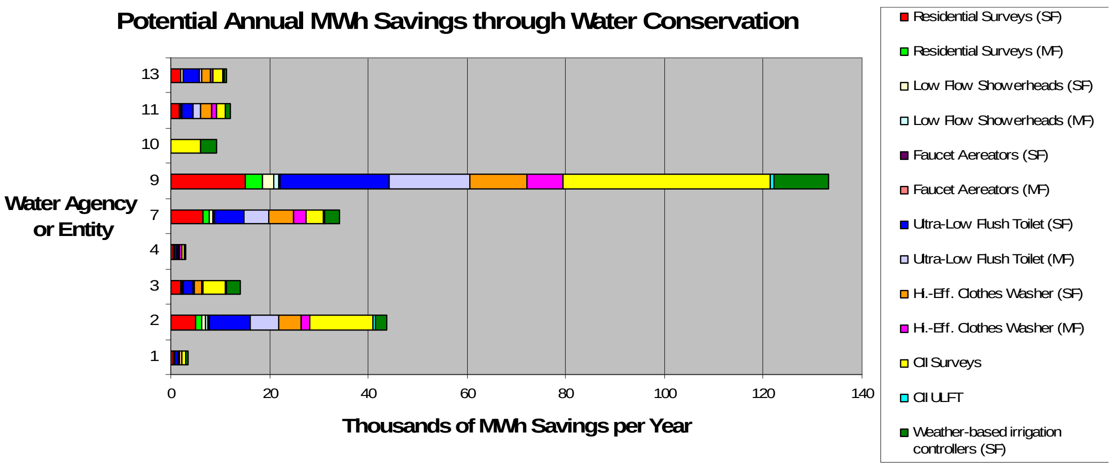

Figure 6—Annual Potential Energy Savings

These savings potentials are based upon the current BMPs, and do not include any emerging technologies. For example, these saving estimates use the Ultra-Low Flow Toilets (ULFTs) at 1.6 gallons per flush (gpf), and not the High Efficiency Toilets (HETs) at 1.3 gpf. There are many additional BMPs, identified by the CUWCC that any water energy conservation program should consider, such as: pre-rinse spray valves for the food service industry; steam sterilizer retrofits; and x-ray film processor recycling units. In addition, one of the most basic BMPs that is not included in the list consists of converting a water system from "flat rate" to a "metered rate". According to individuals at the City of Fresno:

Fresno is beginning the process of metering all services; we project a water savings of about 20%. There are several cities in [Northern California] that are flat rate. The largest, besides Fresno, is the City of Sacramento. There are many medium to small systems that are still flat rate. When customers pay for the water they use by a volumetric rate they will use less water. A good example of this is the City of Clovis and the City of Fresno, they are side by side, yet Clovis, which is metered, has a per capita rate 30% less than Fresno.

The energy savings presented in Figure 6 assume all customers within a water agency's service territory adopt all water conservation recommendations (taking into account the assumed water conservation penetration already existing within each water agency, for each measure). This study did not attempt to estimate an implementation target for each measure, but assumed a 100% target as a means of quantifying the entire potential.

Summary and Recommendations

Since this study was completed, California has endured a dry winter, climate change is in the news on a daily basis, and water agencies are renewing talk of mandatory water curtailments. While climate change awareness has lead to an important movement toward more energy efficient buildings, it is essential that an energy efficient design also incorporate water conservation measures. Why? Although it may not be front-page news, there is a critical relationship between water, energy, and global warming. We are all familiar with efficient water-using appliances such as washing machines. However even toilets and irrigation systems consume electricity, but because that usage doesn't show up on the electric meters in our homes and offices it's easy to ignore. What are the next steps? In order to develop effective water-energy conservation programs, more geographical energy intensity data is critical. Currently there is no detailed data available for Southern California comparable to the recent PG&E Study, even though supplying water to Southern California is much more energy intensive than supplying water to Northern California.

Water and Climate Change.

There is growing evidence that global warming will have a negative impact on water availability and hence water energy intensity in many regions. A study recently published in the journal *Science*, has predicted a permanent drought in the Southwestern United States by the year 2050. Some even speculate that this drought, likely the result of global warming, has already begun. California is particularly vulnerable to water shortages; the State relies upon the Sierra snowpack for much of its water and studies indicate that a warming climate means more rainfall and less snow. In addition to a reduced snowpack, warmer temperatures will result in earlier snowmelt as well. The snowpack accounts for about one-third of the State's surface water, and global warming could feasibly reduce the spring snowpack by 90%.

1 Zarembo, Alan, Bettina Boxall. April 6, 2007. Permanent drought predicted for Southwest. Los Angeles Times. http://www.latimes.com/news/science/la-sci-swdrought6apr06,0,7403662,full.story

2 Anderson, Leonard. Apr 5, 2007. California snowpack melt stirs water worries. Reuters. http://www.reuters.com/article/environmentNews/idUSN0526172720070405?feedType=RSS

3 Global Warming and California's Water Supply: A Fact Sheet of the Union of Concerned Scientists. Union of Concerned Scientists. Berkeley, CA

Estimates of total water savings for all of the agencies participating in this study found that over 161,000 acre-feet of water could be conserved every year by implementing the best practices listed in this paper, and more if emerging technology water savings measures are included. This is an amount of water equivalent to a lake covering the entire city of San Francisco to a depth of five feet. The corresponding electricity savings are at least 215,000 MWh, an amount of electricity comparable to eliminating the electricity from over 14,000,000 square feet of office space.

What's next?

- This study covered only 12% of the State's population—and included only urban water use, not agricultural use. Similar studies should be done for the rest of the state, starting with areas with high water use and presumed high water EUIs. Assuming that 100% of California's population could save comparable amounts of energy through urban water conservation, the State could save more than 1,791,000 MWh annually. This is approximately 0.7% of the total electricity consumed by the State. Again, this is a very conservative estimate: it assumes adoption of only existing BMP's and assumes the energy intensity associated with Northern California water use.

- There are many logistical barriers that make it difficult for water agencies, energy utilities and various federal, state and local entities to cooperate. Water agencies do not typically have the resources to implement the robust efficiency programs that are mandated for energy utilities. Regulatory agencies should encourage pilot efforts at saving both energy and water, and let the rules governing how the efforts are measured be developed concurrent with the roll-out of pilots.

- There are many areas of water-energy overlap, but to date little work has been done in these areas. For example, a more comprehensive examination of the energy intensity of marginal water supplies, such as desalination facilities, would be useful as more and more agencies are considering adding marginal water sources to their portfolios.

- As mentioned earlier, existing studies have focused on conventional water conservation practices. An analysis of cutting edge water conservation measures beyond the existing BMPs has not been fully explored. Examples might include: waterless urinals, high efficiency toilets, and trade-offs between energy and water.

For example evaporative cooling and cooling towers improve energy efficiency but increase water use.

- Current plumbing and other codes often prohibit or place unreasonable restrictions on greywater systems. Issues related to greywater, cisterns and other catchment and re-use mechanisms are relevant to water conservation and merit study as well.
- With the signing of AB 32 into law, the California Air Resources Board is required to develop a means of reducing California's greenhouse gas emissions to 1990 levels (about 25% below current levels) by 2020. Obviously water conservation has a role to play if we hope to meet these aggressive goals.

Acknowledgements

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[1] Klein, Gary, Martha Krebs, Valerie Hall, Terry O'Brien, B. B. Blevins. November 2005. *California's Water-Energy Relationship*. California Energy Commission Report CEC-700-2005-011-SF

[2] One acre foot equals 325,851 gallons

[3] Wilkinson, Robert, PhD. January 2000. *Methodology for the Analysis of Energy Intensity of California's Water Systems and An Assessment of Multiple Potential Benefits Through Integrated Water-EnergyEfficiency Measures.* Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy Efficiency. Agreement No. 4910110.

[4] The energy intensity for a given gallon of water supplied by a given water agency is not simply a matter of dividing energy consumption for that agency by gallons of water provided by that agency. For example, The San Jose Water Company (SJWC) relies upon the Santa Clara Valley Water District (SCVWD) for 60% of its potable water and the City of San Jose for treatment of all of its wastewater. The total energy includes the energy consumed by SJWC, SCVWD and the City of San Jose. Not all of this energy is consumed by San Jose Water Company. The purpose of this research is to estimate the energy intensity of water consumed by the end user (and therefore how much energy each gallon of water conserved can save), regardless of which entity was billed for the energy.

5 Klein, Gary, Martha Krebs, Valerie Hall, Terry O'Brien, B. B. Blevins. November 2005. *California's Water-Energy Relationship*. California Energy Commission Report CEC-700-2005-011-SF

[6] According to the CUWCC, weather-based irrigation controllers do not neatly fit into any of the BMPs; however they are related to surveys and retrofits covered by BMPs 1 and 2. Weather-based irrigation controllers include devices that automatically adjust the irrigation schedules based upon evapotranspiration measurements, or temperature, rainfall, and/or soil moisture. The CUWCC cites costs for this measure of $100 for materials plus $75 for installation, with a monthly fee of $4 and an expected life of 10-15 years.

[7] There is an overlap between the water wholesalers and several of the agencies, for example the Santa Clara Valley Water District provides some of the supply water to the San Jose Water Company. Likewise, the Sonoma County Water Agency provides water to the North Marin Water District, and the City of Santa Rosa. These overlaps have been taken into account when summing up the savings potential of all agencies.

[8] The EIA reported a total sale of 254,250 Million Kilowatt hours of electricity to California customers in 2005. http://www.eia.doe.gov/cneaf/electricity/esr/esr_sum.html