

Congressional Hearing on:

Water Supply Challenges for the 21st Century

*Committee on Science and Technology
United States House of Representatives*

Subcommittee on Energy and the Environment

Testimony of:

Robert Wilkinson, Ph.D.
Director, Water Policy Program
Donald Bren School of Environmental Science and Management
University of California, Santa Barbara*

The Committee on Science and Technology of the United States House of Representatives has chosen a critically important topic with this hearing on *Water Supply Challenges for the 21st Century*. Thank you for the opportunity to share some information and ideas with you today.

I will focus on the water/energy nexus as it relates to science and technology, and also as it relates to policy design and implementation. The selection and implementation of policy instruments to address water and energy management challenges is integrally linked to the foundation provided by science and technology. Policy frameworks are important in achieving positive outcomes based on our investments in science and technology.

The two main points I would like to convey today involve the need for:

1. *Integrated, whole-system approaches* to water and energy management in the context of science and technology, climate change, economics, and environmental concerns, and;
2. Policy strategies that are designed to tap *multiple benefits* and are flexible in the face of changing circumstances.

Due to the importance of the climate change context for both water and energy, I provide brief comments on water/energy/climate links and tie them specifically to science and technology policy developments, particularly at the state level.

This testimony presents both detailed California examples and U.S.-wide data and considerations. Because we have developed good data and analyses of some of the water/energy/climate challenges in California, I will focus in this testimony on specifics from the state. The methodology and many of the lessons may be extrapolated to other parts of the country.

* Contact: Wilkinson@es.ucsb.edu

The Water and Energy Context

Water use for urban and agricultural purposes around the world has been facilitated through diversions of surface water and extraction of groundwater delivered through conveyance systems. Both water and energy are often transported over long distances from their sources to the place where they are ultimately used. As technological capacity developed over the past century, surface water diversions, groundwater extraction, and conveyance systems increased in volume and geographic extent. Interbasin transfers supplemented water available within natural hydrological basins or watersheds. Agricultural and urban uses of arid lands were vastly extended by imported water. Similarly, energy systems have evolved from largely local sources a century ago to continent-wide electricity grids and pipeline networks, and to global supply-lines.

Rainfall patterns in the United States vary widely. In Las Vegas, the driest of America's major cities, precipitation averages barely four inches (102 mm) per year. Portland, Oregon has nine times the precipitation of Las Vegas. Miami, Florida is doused with over 55 inches (1,397 mm) per year, and the Northeast usually receives above 75 inches (1,778 mm) per year.

Generally, states east of the Mississippi have been assumed to have abundant water resources for water supply purposes. Recent droughts and shortages in Florida and the Southeast as well as other parts of the "wet" east are changing this perception. West of the Mississippi, and particularly west of the Rocky Mountains, federally subsidized engineered systems of large dams and aqueducts or pipelines provide water supplies to many users. These systems were constructed during the 1900s, motivated primarily by droughts that occurred periodically. Today, the sources of water for these facilities are over-allocated, and "new" future supplies are increasingly coming from improved water-use efficiency and recycling rather than from expensive new water supply development projects.

The focus of technology development and policy for much of the past century has been on the supply side of both the energy and water equations. That is, the emphasis was on extracting, storing, converting, and conveying water and energy from natural systems to users. Water and energy policy throughout the world has generally been designed to facilitate the development and use of these supply-side technologies. In the last quarter century, however, scientific developments and technological innovation has increasingly been applied to improvement of the *efficiency of use* of energy and water resources. (*"Efficiency"* as used here describes the useful work or service provided by a given amount of water or energy.) Significant potential economic as well as environmental benefits can be cost-effectively achieved through efficiency improvements in water and energy systems. Various technologies, from electric motors and lighting systems to pumps and plumbing fixtures have vastly improved end-use efficiencies.

Today, the main constraints on water *extractions* are not technology limitations. Indeed, there is significant spare capacity for pumping and conveyance in many areas. The limits are increasingly imposed by competing claims on scarce water resources (e.g. the various claims to the Colorado River), legal constraints, and environmental impacts.

Costs of building and maintaining infrastructure have also risen dramatically. The maintenance cost for existing water and wastewater systems is staggering. The American Society of Civil Engineers estimate an annual need for over \$30 billion for safe drinking water (\$11 billion) and properly functioning wastewater treatment systems (about 20 billion) in the United States.¹ They also indicate a need for about \$1 billion per year to repair unsafe non-federal dams, the number of which has increased by a third in the past decade.²

The focus of technology development and implementation policy to meet water needs is therefore increasingly on more efficient use and on water treatment technologies. Innovation and development of technology in the areas of end-use water applications and water treatment has progressed rapidly. Techniques and technologies ranging from laser leveling of fields and drip irrigation systems to the improved design of plumbing fixtures, industrial processes, and treatment technology have changed the demand side of the water equation. End-uses of water now require much less volume to provide equivalent or superior services. Rainwater capture for groundwater recharge and other innovative water capture strategies are also enhancing water supply reliability. Water supply systems (e.g. treatment and distribution) are also becoming more efficient. For example, geographical information systems (GIS) and field technologies allow for improved capabilities to locate leaks in buried pipes.

The Climate Change Context for Water Policy

Climate change poses important water and energy management challenges. Science is indicating that the rate and magnitude of warming and related impacts are increasing. The Intergovernmental Panel on Climate Change's (IPCC's) Fourth Assessment Report in 2007 projected that the rate of warming over the 21st century – up to 11.5 degrees Fahrenheit – would be much greater than the observed changes during the 20th century. The report also confirmed that “11 of the last 12 years (1995 to 2006) rank among the twelve warmest years... since 1850”³ (The year 2007 has now registered as the second hottest year, extending the trend.) The IPCC projects the following changes as a result of increased temperatures:⁴

- more frequent hot extremes, heat waves, and heavy precipitation events
- more intense hurricanes and typhoons
- decreases in snow cover, glaciers, ice caps, and sea ice
- rise in global mean sea level of 7 to 23 inches, however this projection does not include accelerated ice sheet melting and other factors.

Climate models consistently indicate a warmer future for the U.S. West. Evidence of warming trends is already being seen in winter temperatures in the Sierra Nevada, which rose by almost 2 degrees Celsius (4 degrees Fahrenheit) during the second half of the 20th century. Trends toward earlier snowmelt and runoff to the Sacramento–San Joaquin Delta over the same period have also been detected.⁵ Water managers are particularly concerned with the mid-range elevation levels where snow shifts to rain under warmer conditions, thereby reducing snow-water storage. California's Department of Water Resources, along with the California Energy Commission, has been tracking the climate change science since the 1980s.⁶

California law states clearly that “Global warming poses a serious threat to the economic well-being, public health, natural resources, and the environment of California.”⁷ The potential impacts of climate change and variability to California are serious.⁸ Integrated policy, planning, and management of water resources and energy systems can provide important opportunities to respond effectively to challenges posed by climate change. Both mitigation (i.e. reducing greenhouse gas emissions) and adaptation (dealing with impacts) strategies are being developed. While both energy and water managers have used integrated planning approaches for decades, the broader integration of water and energy management in the context of climate change is a relatively new and exciting policy area.

Integrating Water and Energy Policy

Government agencies at various levels are currently integrating water and energy policies to respond to climate change as well as to environmental challenges and economic imperatives. Water and energy systems are interconnected in important ways. Developed water systems provide energy (e.g. through hydropower), and they consume energy through pumping, thermal, and other processes. Government agencies are looking at water delivery system and end-use water efficiency improvements, source switching (e.g. using recycled water for industry and irrigation), improved rainwater capture and groundwater recharge, and other measures that save energy by reducing pumping and other energy inputs. Recent studies are indicating significant opportunities in each area.⁹ Several California examples of coupled science/technology/policy approaches are presented here. While they are specific to the state, many of the basic features are similar in other states across the U.S.

New approaches to the integration of water, energy, and climate change policy and planning, including policy processes at the state's Energy Commission, Public Utilities Commission, Department of Water Resources, Water Resources Control Board, and Air Resources Board, are being developed. Methodologies to account for embedded energy in water systems – from initial extraction through treatment, distribution, end-use, wastewater treatment and discharge – and water use by energy systems, have been developed and are outlined below.¹⁰ Institutional collaboration between energy, water, and other management authorities is also evolving.

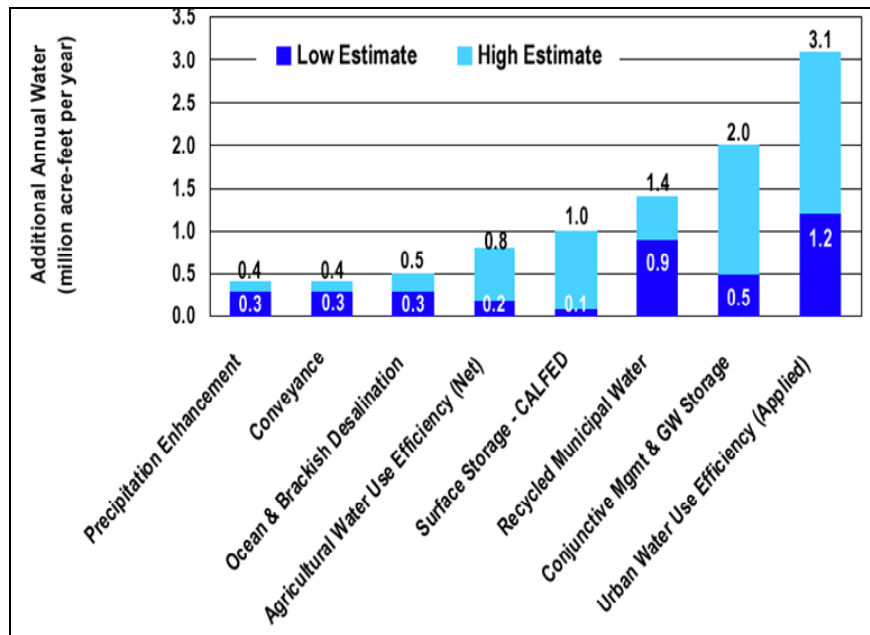
Water is now recognized as the *largest electricity use* in California. Water systems account for approximately 19% of total electricity use and about 33% of the non-power plant natural gas use in the state.¹¹ The California Energy Commission (CEC) and the California Public Utilities Commission (CPUC) have both concluded that energy embedded in water presents large untapped opportunities for cost-effectively improving energy efficiency and reducing greenhouse gas (GHG) emissions. The CEC commented in its 2005 *Integrated Energy Policy Report* that: “The Energy Commission, the Department of Water Resources, the CPUC, local water agencies, and other stakeholders should explore and pursue cost-effective water efficiency opportunities that would save energy and decrease the energy intensity in the water sector.”¹² Fortunately this corresponds with the state's 2005 Water Plan.¹³

The California Energy Commission's staff report, *California's Water – Energy Relationship*, notes that: “In many respects, the 2005 *Water Plan Update* mirrors the state's adopted loading order for electricity resources described in the Energy Commission's *Integrated Energy Policy Report 2005* and the multi-agency *Energy Action Plan*.”¹⁴

One of the top recommendations in the California Energy Commission's 2005 *Integrated Energy Policy Report* (IEPR) is as follows: “The Energy Commission strongly supports the following energy efficiency and demand response recommendations: The CPUC, Department of Water Resources, the Energy Commission, local water agencies and other stakeholders should assess efficiency improvements in hot and cold water use in homes and businesses, and include these improvements in 2006-2008 programs.” It observes that “Reducing the demand for energy is the most effective way to reduce energy costs and bolster California's economy.”¹⁵

Improvements in urban water use efficiency have been identified by the Department of Water Resources in its official State Water Plan as the *largest new water supply* for the next quarter century, followed by groundwater management and reuse. The following graph indicates the critical role water use efficiency, groundwater recharge and management, and reuse will play in California's water future.

**Water Management and Supply Options for the Next 25 Years
California State Water Plan 2005**



Source: California Department of Water Resources, 2005.

The CEC staff report notes that, “As California continues to struggle with its many critical energy supply and infrastructure challenges, the state must identify and address the points of highest stress. At the top of this list is California’s water-energy relationship.”¹⁶ It continues with this interesting finding: “The state can meet energy and demand-reduction goals comparable to those already planned by the state’s investor-owned energy utilities for the 2006-2008 program period by simply recognizing the value of the energy saved for each unit of water saved. If allowed to invest in these cold water energy savings, energy utilities could co-invest in water use efficiency programs, which would in turn supplement water utilities’ efforts to meet as much load growth as possible through water efficiency. Remarkably, staff’s initial assessment indicates that this benefit could be realized at less than half the cost to electric ratepayers of traditional energy efficiency measures.”¹⁷

This finding is consistent with an earlier analysis which found that energy use for conveyance, including interbasin water transfer systems (systems that move water from one watershed to another) in California, accounted for about 6.9% of the state’s electricity consumption.¹⁸ Estimates by CEC’s Public Interest Energy Research – Industrial, Agriculture and Water (PIER-IAW) experts indicate that “total energy used to pump and treat this water exceeds 15,000 GWh per year, or *at least* 6.5 percent of the total electricity used in the state per year.” They also note that the State Water Project (SWP) – the state-owned storage and conveyance system that transfers water from Northern California to various parts of the state including Southern California – is the largest single user of electricity in the state, accounting for 2% to 3% of all the electricity consumed in California and using an average of 5,000 GWh per year.¹⁹

The magnitude of these figures suggests that *failing* to include embedded energy in water and wastewater systems, and *failing* to tap energy saving derived from water efficiency improvements would be a policy opportunity lost.

Tapping Integrated Water/Energy Opportunities

Elements of typical water infrastructures are energy intensive. Moving large quantities of water long distances and over significant elevation gains, treating and distributing it within communities, using it for various purposes, and collecting and treating the resulting wastewater, accounts for one of the largest uses of electrical energy in many areas.²⁰

Energy intensity of water is the total amount of energy, calculated on a whole-system basis, required for the use of a given amount of water in a specific location.

Water systems include extraction of “raw” (untreated) water supplies from natural sources, conveyance, treatment, storage, distribution, end-uses, and wastewater treatment. The total energy embodied in a unit of water used in a particular place varies with location, source, and use.

There are four principle energy elements of water systems:

1. primary water extraction, conveyance, and storage
2. treatment and distribution within service areas
3. on-site water pumping, treatment, and thermal inputs (heating and cooling)
4. wastewater collection, treatment and discharge

Pumping water in each of these stages is energy-intensive. Other important energy inputs include thermal energy (heating and cooling) applications at the point of end-use, and aeration in wastewater treatment processes.

1. Primary water extraction, conveyance, and storage. Extracting and lifting water is highly energy intensive. Surface water and groundwater pumping requires significant amounts of energy depending on the depth of the source. Where water is stored in intermediate facilities, net energy is required to store and then recover the water.

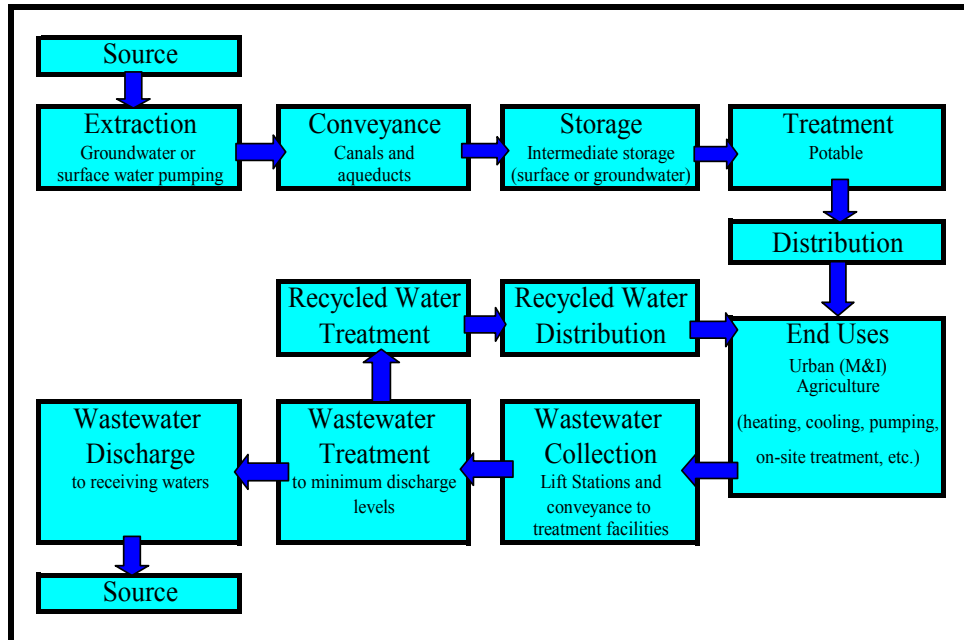
2. Treatment and distribution within service areas. Within local service areas, water is treated, pumped, and pressurized for distribution. Local conditions and sources determine both the treatment requirements and the energy required for pumping and pressurization. Some distribution systems are gravity-driven, while others require pumping.

3. On-site water pumping, treatment, and thermal inputs. Individual water users require energy to further treat water supplies (e.g. softeners, filters, etc.), circulate and pressurize water supplies (e.g. building circulation pumps), and heat and cool water for various purposes.

4. Wastewater collection, treatment, and discharge. Finally, wastewater is collected and treated by a wastewater system (unless a septic system or other alternative is being used) and discharged. Wastewater is sometimes pumped to treatment facilities where gravity flow is not possible, and the standard treatment processes require energy for pumping, aeration, and other processes.

The simplified flow chart below illustrates the steps in the water system process.

Flow Diagram of Energy Inputs to Water Systems



Source: Wilkinson²¹

The energy intensity of water varies considerably by geographic location of both end-users and sources. Water use in certain places is highly energy-intensive due to the combined requirements of conveyance over long distances and elevation lifts, treatment and distribution, and wastewater collection and treatment processes. Important work already undertaken by various government agencies, professional associations, private sector users, and non-governmental organizations in the area of combined end-use efficiency strategies has demonstrated considerable potential for improvement. Significant and profitable energy efficiency gains are possible through implementation of cost-effective *water* efficiency improvements.

The Energy Intensity of Water in California: A Case Study

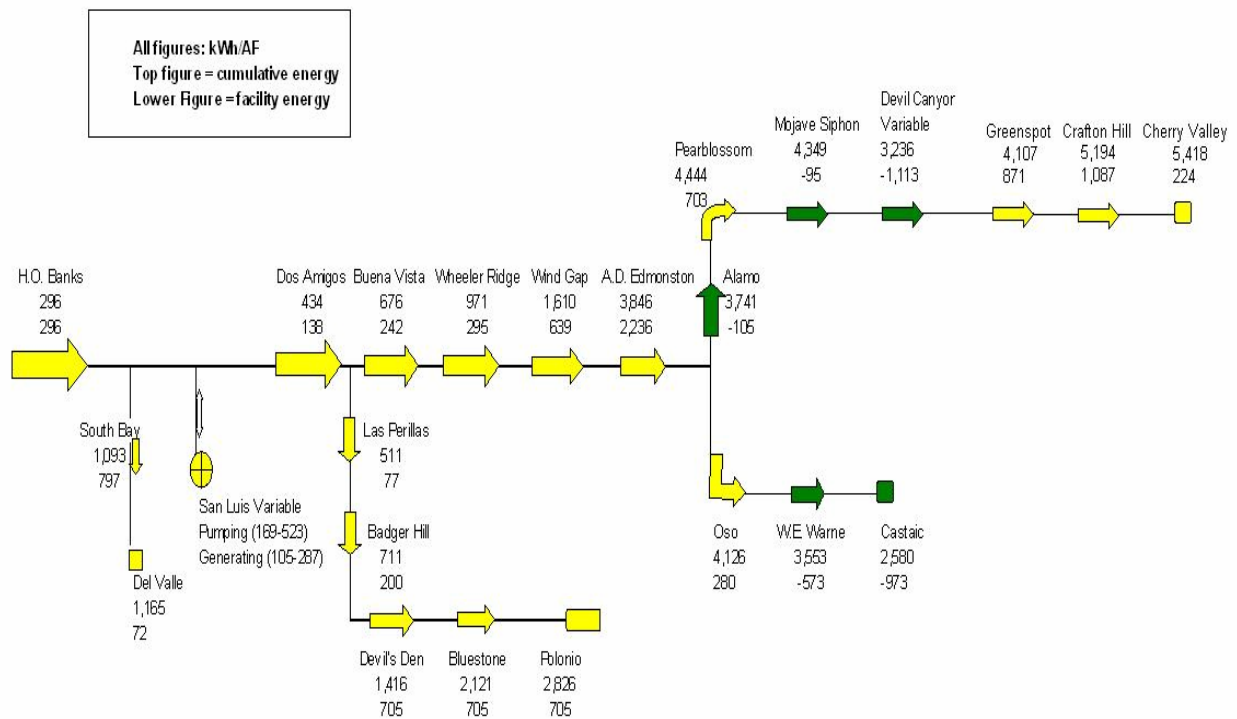
California's water systems are uniquely energy-intensive due in large part to the pumping requirements of major conveyance systems which move large volumes of water long distances and over thousands of feet in elevation. Some interbasin transfer systems such as California's State Water Project (SWP) and the Colorado River Aqueduct (CRA) require large amounts of electrical energy to convey water.

Water use (based on embedded energy) is the second or third largest consumer of electricity in a typical Southern California home after refrigerators and air conditioners.²² The electricity required to support water service in the typical home in Southern California is estimated to be between 14% to 19% of total residential energy demand.²³ The Metropolitan Water District of Southern California (MWD) reached similar findings, estimating that energy requirements to deliver water to residential customers equals as

much as 33% of the total average household electricity use.²⁴ Nearly three quarters of this energy demand is for pumping imported water.

Water system operations pose a number of challenges for energy systems due to factors such as large loads for specific facilities, time and season of use, and geographic distribution of loads. Pumping plants are among the largest electrical loads in the state. For example, the SWP's Edmonston Pumping Plant, situated at the foot of the Tehachapi Mountains, pumps water 1,926 feet (the highest single lift of any pumping plant in the world) and is the largest *single user* of electricity in the state.²⁵ In total, the SWP *system* is the largest user of electricity in the state.²⁶ A study for the Electric Power Research Institute by Franklin Burton found that at a national level, water systems account for an estimated 75 billion kWh per year (about 3% of total electricity demand).²⁷

The schematic below shows the cumulative net energy, and the incremental energy inputs or outputs, at each of the pumping and energy recovery facilities of the SWP. (Energy recovery is indicated with negative numbers, which reduce net energy at that point in the system.)



State Water Project Energy Inputs and Recovery
 (Kilowatt-Hours per Acre Foot Pumped - Includes Energy Recovery)

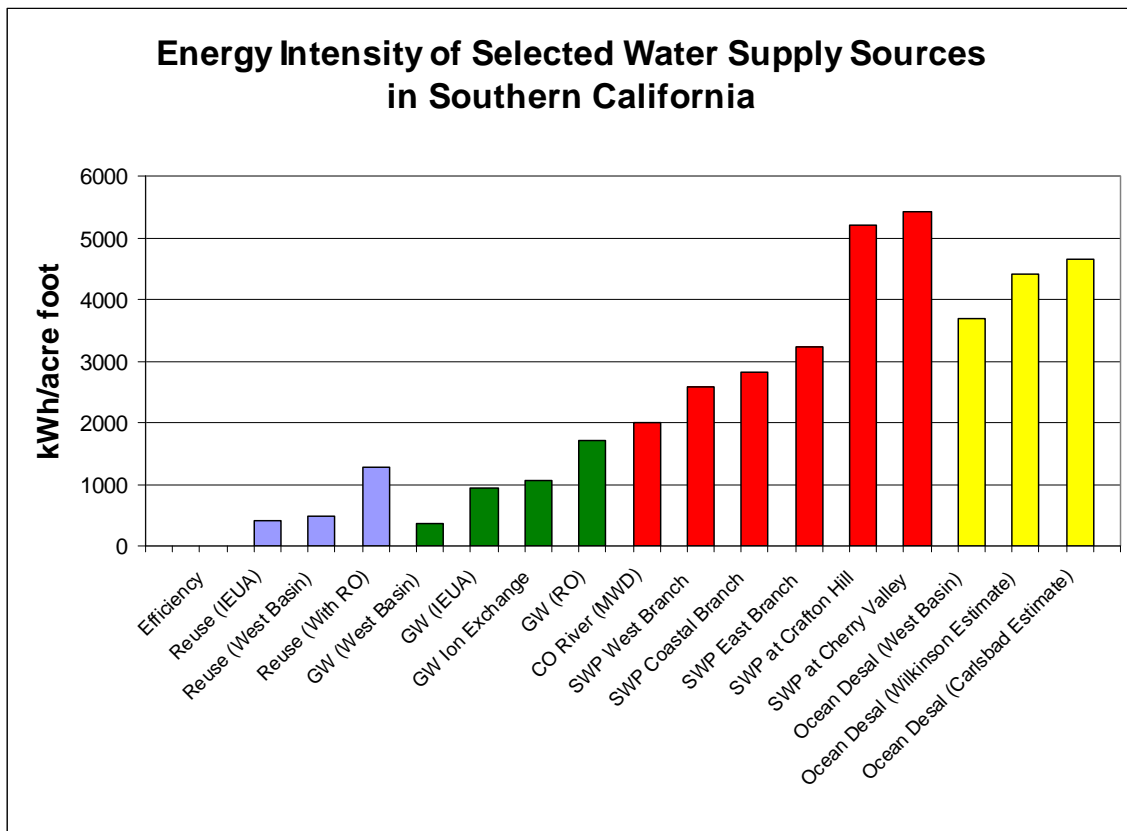
Source: Wilkinson, based on data from California Department of Water Resources.

Approximately 5,418 kWh are required to pump one acre-foot of SWP water from the Sacramento-San Joaquin Delta to Cherry Valley on the East Branch, 2,580 kWh/af at Castaic on the West Branch, and 2,826 kWh/af to Polonio on the Coastal Branch. Approximately 2,000 kWh/af is required to pump Colorado

River water to Southern California.²⁸ This is raw (untreated) water delivered to those points. From there conveyance continues by gravity or pumping to treatment and distribution within service areas.

Note that at certain points in the system the energy intensity is high because the service areas are located at higher elevations. At Pearblossom (4,444 kWh/af) raw water supplies are roughly equivalent to estimates for desalinated ocean water systems. (Ocean desalination is estimated at 4,400 kWh/af based on work by the author for the California Desalination Task Force.) At Crafton Hill and Cherry Valley, the energy intensity of imported water is well in excess of current estimates of ocean desalination.

The following graph shows the energy intensity of major water supply options for actual inland and coastal locations in Southern California.



Source: Wilkinson based on data from IEUA, West Basin MWD, DWR, and desalination estimates.

Each bar represents the energy intensity of a specific water supply source at selected locations in Southern California. The data is presented in kWh/af. Water conservation – e.g., not using water in the first place – avoids additional energy inputs along all segments of the water use cycle. Consequently, water use efficiency is the superior water resource option from an energy perspective (and typically from a cost perspective as well). For all other water resources, there are ranges of actual energy inputs that depend on many factors, including the quality of source water, the energy intensity of the technologies used to treat the source water to standards needed by end-users, the distance water needs to be transported to reach end-users, and the efficiency of the conveyance, distribution, and treatment facilities and systems.²⁹

Note that improved efficiency (e.g. fixing leaks, replacing inefficient plumbing fixtures and irrigation systems, and other cost-effective measures) requires no water system energy inputs. Next to water conservation, recycled water and groundwater are lower energy intensity options than most other water resources in many areas of California.³⁰ Even with advanced treatment to deal with salts and other contaminants (the blue and green bars), recycled water and groundwater usually require far less energy than the untreated imported water (red bars) and seawater desalination (yellow bars). The Chino desalter, a reverse osmosis (RO) treatment process providing high-quality potable water from contaminated groundwater (the energy figure above includes groundwater pumping and RO filtration) is far less energy intensive than any of the imported raw water. From an energy standpoint, greater reliance on water conservation, reuse and groundwater provides significant benefits. From a greenhouse gas emissions standpoint, these energy benefits provide significant potential emissions reduction benefits in direct relation to their energy savings.

Groundwater pumping energy requirements vary depending on the lift required. The California Energy Commission's Public Interest Energy Research - Industrial, Agriculture and Water program provides the following assessment of pumping in important parts of the Central Valley: "The amount of energy used in pumping groundwater is unknown due to the lack of complete information on well-depth and groundwater use. DWR has estimated groundwater use and average well depths in three areas responsible for almost two-thirds of the groundwater used in the state: the Tulare Lake basin, the San Joaquin River basin, and the Central Coast region. Based on these estimates, energy used for groundwater pumping in these areas would average 2,250 GWh per year at a 70 percent pumping efficiency (1.46 kWh/acre-foot/foot of lift). In the Tulare Lake area, with an average well depth of 120 feet, pumping would require 175 kWh per acre-foot of water. In the San Joaquin River and Central Coast areas, with average well depths of 200 feet, pumping would require 292 kWh per acre-foot of water."³¹ Analysis of these different sources provides a reasonably consistent result: Local groundwater and recycled water are far less energy intensive than imported water or ocean desalination.

The energy intensity of most water supply sources may increase in the future due to increased concerns regarding water quality.³² It is worth noting that advanced treatment systems such as RO facilities that are being used to treat groundwater, reclaimed supplies, and ocean water have already absorbed most of the energy impacts of higher levels of treatment. By contrast, some of the raw water supplies may require larger incremental energy inputs in the future for treatment. This may further advantage the local sources.

Policy Implications: Tapping Multiple Benefits Through Integrated Planning

When the costs and benefits of a proposed policy or action are analyzed, we typically focus on accounting for costs, and then we compare those costs with a specific, well-defined benefit such as an additional increment of water supply. We often fail to account for other important benefits that accrue from well-planned investments that solve for multiple objectives. With a focus on *multiple benefits*, we account for various goals achieved through a single investment. For example, improvements in water use efficiency – meeting the same end-use needs with less water – also typically provides related benefits such as reduced energy requirements for water pumping and treatment (with reduced pollution and greenhouse gas emissions related to energy production as a result), and reduced water and wastewater infrastructure capacity (capital costs) and processing (operating costs) requirements. Impacts caused by extraction of source water from surface or groundwater systems are also reduced. Water managers often do not receive credit for providing these multiple benefits when they implement water efficiency, recharge, and reuse strategies. From both an investment perspective, and from the standpoint of public policy, the multiple benefits of efficiency improvements and recharge and reuse should be fully included in cost/benefit analysis.

Policies that account for the full embedded energy of water use have the potential to provide significant additional public and private sector benefits. Economic and environmental benefits are potentially available through new policy approaches that properly account for the energy intensity of water.

Energy savings may be achieved both upstream and downstream of the point of use when the energy consumption of both water supply and wastewater treatment systems are taken into account. Methods, metrics, and data are available to provide a solid foundation for policy approaches to account for energy savings from water efficiency improvements, though can and should be improved. Policies can be based on methodologies and metrics that are already established.

Policy Precedents and the Role of Government

Water and energy are currently regulated by government because there is a compelling public interest in oversight and management of these critical resources. Encouraging and requiring the efficient use of both water and energy is a well-established part of the policy mandate under which government agencies operate. Inefficient use of water and energy leads to public and private costs to the economy and the environment. The public interest in resource-use efficiency relates directly to environmental impacts and public welfare. This is why we have efficiency standards for energy and water resources. *Water-using devices*, like energy-using devices, are often regulated through various policy measures including efficiency standards.

Policy regarding both energy and water already addresses water use and related embedded energy use. For example, the U.S. *Energy Policy Act of 1992* set standards for the maximum water use of toilets, urinals, showerheads, and faucets. (See Table below) Why does the U.S. *energy act* include standards for water use? It is because the energy required to convey, treat, and deliver potable water supplies, and the energy required to collect, treat, and discharge the resulting wastewater, is significant. The energy savings resulting from water efficiency are also significant.

Plumbing Standards in the U.S. Energy Policy Act of 1992
(Standard measured at 80 psi or 552 kPa)

Fixture	U.S. Standard	Metric Equivalent
Water Closets (Toilets)	1.6 gallons per flush	6.0 liters per flush
Showerheads	2.5 gallons per minute	9.5 liters per minute
Faucets	2.2 gallons per minute	8.3 liters per minute
Urinals	1.0 gallon per flush	3.8 liters per flush

These standards became effective in 1994 for residential and commercial plumbing fixtures, although the commercial water closet standard was not required until 1997 because of uncertainties regarding performance of the fixtures. In this respect, the United States is well behind certain countries of Europe, where the 6-liter water closet has been in use for many years and where horizontal axis washing machines are more common than in the United States.

In 1996, the U.S. Congress passed a reauthorization of the Federal Safe Drinking Water Act. For the first time, Congress formally recognized the need for water conservation planning by allowing individual states to mandate conservation planning and implementation as a condition of receiving federal grants for

water supply treatment facilities.³³ This was a significant step for the federal government. At about the same time, the U.S. Bureau of Reclamation set conservation and efficiency requirements for those agricultural and urban water agencies that receive federally subsidized water from the Bureau facilities. This also was a significant step. Other federal statutes create incentives for farmers and landowners to participate in soil and water conservation programs, and to initiate voluntary water transfers of conserved water.

The significant water efficiency and conservation activity, however, takes place at the state and regional levels. Interest in water efficiency is primarily highest in those regions of the country where precipitation is lowest, or where wastewater treatment costs have skyrocketed. Seventeen states, representing over 60% of the nation's population, had already adopted their own plumbing efficiency standards long before passage of the Federal law in 1992. Fifteen states have also adopted specific conservation programs, which vary from mandating conservation planning by water utilities to requiring actual implementation of specific water efficiency programs. The states most active in conservation activities are: Arizona; California; Colorado; Connecticut; Florida; Kansas; New Jersey; Oregon; Texas; and Washington State.³⁴ Individual cities have also adopted water efficiency programs where necessary (New York City, Boston, and Las Vegas are examples).

In general, where water supply withdrawals are regulated by State agencies, water conservation is usually a prominent planning requirement for water utilities. A number of states not only require plans of their water utilities, but also require that progress be demonstrated in water efficiency programs before approvals for continued water supply withdrawals are given. Many states also condition state grants for new facility construction upon a satisfactory demonstration of conservation planning and implementation by the water utility.³⁵

California adopted plumbing standards in 1978 for showerheads and faucets, and water closet standards in 1992. Comprehensive conservation planning was adopted in 1983 for all water agencies serving more than 3,000 connections or 3,000 people.³⁶ In a unique consensus partnership, a Memorandum of Understanding was signed in 1991 by major water utilities and environmental groups pledging to undertake water efficiency practices (the "Best Management Practices").³⁷

Environmental Benefits of Integrated Water and Energy Efficiency Strategies

Water conservation is a powerful tool in the integrated resource management toolbox. By reducing the need for new water supply and additional wastewater treatment – particularly in areas of rapid population growth – conserved water allows more equitable allocation of water resources for other purposes. By way of illustration, one estimate indicates that the installation of 1.6 gallon per flush toilets in the U.S. will save over two billion gallons *per day* nationwide by the year 2010.³⁸ These saved water resources can be directed toward future water supply growth or other uses for the water. It "stretches" the available supply.

Perhaps most significantly, it has become clear in recent decades that the extraction and diversion of water supplies has had major impacts on the quality of the natural environment and on individual species. Facilities built to dam, divert, transport, pump, and treat water are massive projects that often cause serious and sometimes irreversible environmental impacts.

As a result, water conservation is playing an important role in helping meet the environmental goals of many communities. Efficiency programs have been required in numerous areas to help achieve some of the following results:

- Maintaining habitat along rivers and streams and restoring fisheries;
- Protecting groundwater supplies from excessive depletion and contamination;
- Improving the quality of wastewater discharges;
- Reducing excessive runoff of urban contaminants; and
- Restoring the natural values and functions of wetlands and estuaries.

The Role of Price Signals Coupled with Policy

Attention has turned to technologies that improve energy and water-use efficiency. From industrial processes to plumbing fixtures and irrigation systems, water is being used far more efficiently than in the past. One reason the focus of technological innovation has shifted from supply development to improving efficiency is economics. When water is cheap, there is little incentive to design and build water-efficient technologies. As the cost of water increases, technology options for reducing waste and providing greater end-use efficiency become more cost-effective and even profitable. Technologies for measuring, timing, and controlling water use, and new innovations in the treatment and re-use of water, are growing areas of technology development and application.

Impetus for scientific inquiry and technology innovation and development has been provided by both price signals (increasing costs) and public policy (e.g. requirements for internalization of external costs). Public policy is increasingly incorporating these costs, including those of climate change, into resource prices. As water and energy prices continue to reflect full costs, including environmental costs previously externalized, they increase.

At the same time, technology has provided a wide range of options for expanding the utility value through efficiencies (less water and energy required to perform a useful service). The ability to treat and reuse water, improve energy efficiency, and substituting ways to provide services previously performed by water and energy. Broader application of these technologies and techniques can yield significant additional energy, water, economic, and environmental benefits.

Public policy can be designed to encourage “best management practices” by both water and energy suppliers and users. Appliance efficiency standards (for both energy and water) and minimum waste requirements are examples. Policy measures have also been used to frame and guide market signals by implementing mechanisms such as increasing tiered pricing structures, meter requirements (some areas do not even measure use), and other means to utilize simple market principles and price signals more effectively.

In an economic and resource management sense, efficiency improvements are now considered as *supply* options, to the extent that permanent improvements in the demand-side infrastructure provide reliable water and/or energy savings. Most experts agree that coupling technology options such as efficient plumbing and energy-using devices to economic incentives (e.g. rebates) and disincentives (e.g. increasing tiered rate structures) is the best strategy. The coupling provides both the means to improve productive water and energy use and the incentive to do it.

Seawater Desalination's Role in Integrated Water Supply Portfolios

Seawater desalination has been viewed as the ultimate drought hedge, enabling water providers to augment water supplies with desalted ocean water, a virtually inexhaustible water source. Both the theory and practice of desalination date back to the ancient Greeks and perhaps earlier, but costs have held desalination to limited use.

The salinity of ocean water varies, with the average generally exceeding 30 grams per liter (g/l). The Pacific Ocean is 34-38 g/l, the Atlantic Ocean averages about 35 g/l, and the Persian Gulf is 45 g/l. Brackish water drops to 0.5 to 3.0 g/l. Potable water salt levels should be below 0.5 g/l.

Reducing salt levels from over 30 g/l to 0.5 g/l and lower (drinking water standards) using existing technologies requires considerable amounts of energy, either for thermal processes or for the pressure to drive water through extremely fine filters (RO), or for some combination of thermal and pressure processes. Recent improvements in energy efficiency have reduced the amount of thermal and pumping energy required for the various processes, but high energy intensity is still an issue. The energy required is in part a function of the degree of salinity and the temperature of the water.

Seawater desalination is a primary source of water in some countries in the Middle East. It is also becoming an important resource in other countries including Spain, Singapore, China, and Australia. A few recent examples include:

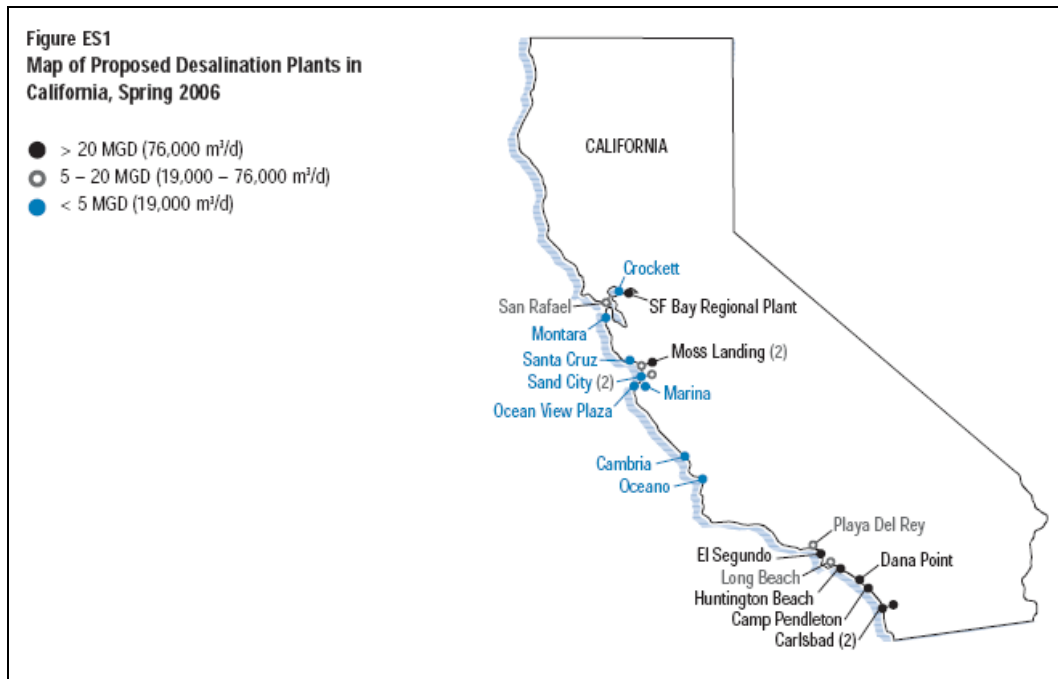
- In 2006, Singapore completed a 36 MGD seawater reverse osmosis (SWRO) plant capable of serving 10% of its national water demand.³⁹
- As of 2006, more than 20 seawater desalination plants were operating in China.⁴⁰
- In November 2006, Western Australia became the first state in the country to use desalination as a major public water source.⁴¹

A number of desalination plants are currently being planned or developed in the U.S. On January 25, 2008, Tampa Bay Water announced that it had commenced full operations of its 25 MGD desalination plant, presently the largest seawater desalination plant in North America. At full capacity, the plant will provide 10% of the drinking water supply for the Tampa Bay region.⁴² In 2004, the Texas Water Development Board (TWDB) identified desalination as an important strategy for meeting growth in water demand.⁴³ In its 2006 update to the Governor and the Legislature, the TWDB stated that "Seawater desalination can no longer be considered a water supply option available only to communities along the Texas Gulf Coast."⁴⁴ It must also be considered as an increasingly viable water supply option for major metropolitan areas throughout Texas."⁴⁵ The report encourages state investments for a full-scale seawater desalination demonstration project by the Brownsville Public Utilities Board "...as a reasonable investment in a technology that holds the promise of providing unlimited supplies of drinking water even during periods of extreme drought."



In California, interest in seawater desalination is also escalating. Heather Cooley and colleagues at the Pacific Institute found that as of 2006, about 266 to 379 MGD of new seawater desalination facilities were planned in California.⁴⁶

Planned Seawater Desalination Plants as of 2006



Source: Cooley, Heather, Peter H. Gleick, and Gary Wolff, 2006. *Desalination, With a Grain of Salt*, Pacific Institute, <http://www.pacinst.org/reports/desalination/index.htm>

In November 2007, Poseidon Resources won conditional regulatory approval from the California Coastal Commission to build a \$300 million plant north of San Diego. The Carlsbad Desalination Plant will be the largest in the western hemisphere if completed as planned. On its website, Poseidon reported that most of the plant's capacity has already been committed to serve base-load water requirements for local water agencies.⁴⁷

Water Inputs to U.S. Energy Systems

The other side of the water/energy nexus is the water intensity of energy. In this case, water inputs to energy systems are identified and quantified to understand where water is used, and how much is required for different types of energy sources and services.

Water inputs to energy systems are significant but highly variable. For example, primary fuels, such as oil, gas, and coal, often require water for production, and they sometimes “produce” water of various qualities as a by-product of extraction. Bio-fuels may require water not only for irrigation of crops but also for production processes. Electricity generation in thermoelectric plants typically uses water for cooling and other processes, although dry cooling technology exists and is improving. Some forms of electricity production such as wind and certain cogeneration processes require no water at all.

The USGS estimates in its most recent analysis that 48 percent of all U.S. freshwater and saline-water withdrawals were used for thermoelectric power, with the majority of the fresh water extracted from surface sources (e.g. lakes and rivers) and used for once-through cooling at thermal power plants. USGS notes that “about 52 percent of fresh surface-water withdrawals and about 96 percent of saline-water withdrawals were for thermoelectric-power use.”⁴⁸

Water is increasingly viewed as a limiting factor for thermal power plant siting and operation. Large-scale thermoelectric plants in the U.S., Europe, and elsewhere have experienced serious problems in recent years due to the lack of available cooling water. Power production was reduced or curtailed in Europe during the heat wave in 2003, and power plants in the U.S. have been impacted by low water and by elevated temperatures, or both, during the past decade. As recently as this past winter power plant operators were concerned about the impact of the drought in the U.S. Southeast and the potential for adverse impacts to thermal power plants. Hydroelectric power production is also impacted by low water levels, including a continuing long-term dry period in the Colorado River basin.

Although cooling systems account for the majority of water used in power generation, water is also used in other parts of the process: water may be used to mine, process, or transport fuels (e.g. coal slurry lines). These processes may have important local impacts on water resources. Some energy sources such as oil shale, tar sands, and marginal gas and petroleum reserves may have additional water needs and/or significant local impacts on water quality and quantity.

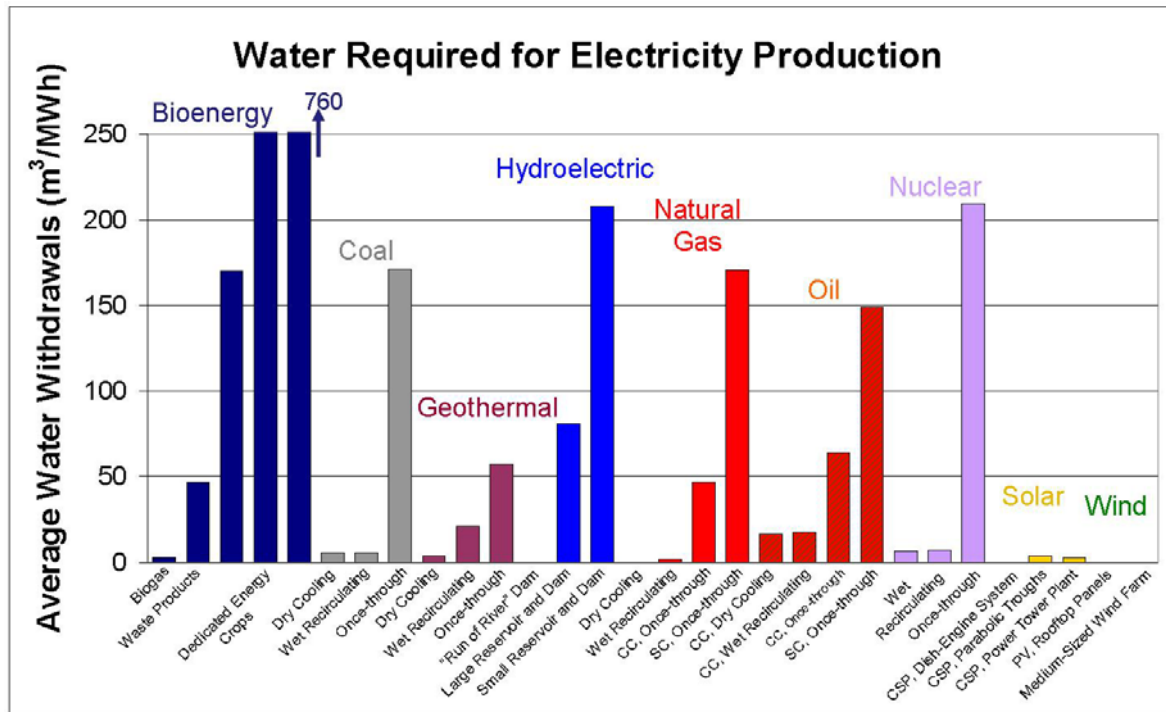
The U.S. National Labs have been working for several years on an “Energy/Water Nexus” effort.⁴⁹ A report entitled “Energy Demands on Water Resources Report to Congress on the Interdependency of Energy and Water” was submitted to Congress in 2007.⁵⁰ As with other analyses of the issue, the report found that some energy systems are highly dependent on large volumes of water resources (and vulnerable to disruptions), while other energy sources are independent of water. Further analysis of the opportunities for improving resilience and of beneficial decoupling water and energy are in order.

The National Energy Technology Laboratory (NETL) has developed several studies and reports, including an updated report entitled “Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements” in 2007.⁵¹ NETL has strong expertise on coal and thermal power production at coal-fired power plants. Its study indicates that water *consumption* is projected to increase over a range of scenarios, while *extraction* is expected to decline. This is due to an expected shift away from one-through cooling systems, which cycle more extracted water through the plants, but consume (e.g. evaporate) less than recycle cooling systems. The study also indicates that carbon capture and storage (CCS) as a strategy to reduce greenhouse gas emissions will add significant water consumptive demands to coal-based power production.

Other studies from federal labs and research institutions are exploring links between energy systems and water requirements. The National Renewable Energy Lab (NREL), for example, has been working on the role of renewables to reduce water demands from the energy sector.

A recent research project by graduate students at the University of California, Santa Barbara found that water use for renewable forms of energy varies substantially.⁵² Solar photovoltaics, wind turbines, and landfill gas-to-energy projects require very little water, if any. Likewise, geothermal and concentrating solar power (CSP) systems that employ dry cooling technology also have minimal water requirements. In contrast, irrigated bio-energy crops could potentially consume exponentially more water per unit of electricity generated than thermoelectric plants. Geothermal plants may also have high water requirements, depending on the geothermal resource and the conversion technology employed. Many geothermal plants, however, rely on geothermal fluids (often high in salts or other minerals). Finally,

although reservoirs often have multiple purposes (e.g. flood control, water storage, and recreation), evaporative (consumptive) losses from hydroelectric facilities per unit of electricity are higher than many other forms of generation. As the following graph indicates, water requirements vary substantially, depending on the primary fuel source and the technology employed.



Water requirements for different forms of electricity generation. Source: Dennen, Bliss, Dana Larson, Cheryl Lee, James Lee, Stacy Tellinghuisen, 2007. "California's Energy-Water Nexus: Water Use in Electricity Generation", Group Project Report, Donald Bren School of Environmental Science and Management, University of California, Santa Barbara.

The various water inputs to energy systems are, as noted, highly variable. It is not at all clear that meeting our energy needs requires large amounts of water, as has been the case in the past. Indeed, the data above indicate that we have choices. An important step in addressing the water and energy challenge is to analyze the relationships between them and the technology and policy options.

Recommendations for Further Research and Development

There are of course various approaches to meeting the challenge of water and energy in the 21st century. I am pleased to have been asked by this committee to provide some thoughts on directions for research and development.

It is always useful to begin by examining the questions to be addressed. If one asks how to provide low-cost water for energy supplies and low-cost energy for water supplies, then the question leads to certain kinds of analysis. This indeed is how some are framing the question at present.

It seems clear that both water and energy are scarce in both the economic and physical sense, and that there are many competing demands for them. It also seems self-evident that environmental impacts (often externalized in the past), are real and growing. One of the most significant, but by no means the only one, is climate change.

These observations lead to a conclusion that we should ask a different set of questions. It is tempting to take this opportunity to deluge a Congressional Committee with a wish-list of research ideas. Instead, I will start with just two questions:

1. How can we decouple water and energy systems where there are high costs, stresses, damages, or vulnerabilities to systems?
2. How can we maximize water and energy efficiency and productivity so as to reduce demands on each and maximize benefits to society?

Of course these questions involve important data collection and analysis of sub-elements of each. To take my first example, we need to identify costs (full costs and an accounting for distortions – e.g. subsidies and externalities – at all levels), stresses (e.g. limits of systems and things like the causes of, probabilities of, and consequences of, exceeding those limits), potential economic, environmental, and social damages (including irreversible damages), and vulnerabilities of systems to perturbations caused by either natural events (dry spells) and/or of those with bad intensions (national security). These are critically important questions for the nation, and they are not being properly asked and framed, let alone addressed.

The second question leads to a set of studies that is long overdue. We have focused so heavily on supplying energy and water in unlimited quantities at “low prices” that we have failed to ask the basic questions regarding opportunities to do more with less, let alone limits of the capacity of systems and the implications of inefficient and unproductive use (waste) of critical resources.

My recommendation to this Committee is that you follow these important hearings with a process to formulate key questions and issues to be addressed by the unsurpassed research, business, and public policy capacity of the United States in addressing these critical challenges. The committee should give careful consideration to designing, framing, and setting forth key questions to be addressed by the research and development community (which I would take to include research institutions, business, NGOs, and other interested stakeholders as well as key government agencies) to meet the challenges of water and energy for the country.

A good example of an effective collaborative along these lines that involves a number of federal agencies as well as the research community, local and state government, NGOs, business, and others is the Sustainable Water Resources Roundtable.⁵³

By focusing on the key questions, the Committee can provide both the leadership and the guidance that is needed.

Conclusion: Opportunities for Integrated Water/Energy Policy

Policy frameworks are critical to achieving success based on advances in science and technology. In considering alternative policy strategies, decision-makers should carefully analyze and consider the potential multiple benefits available from integrated strategies.

The United States, like other nations, faces formidable challenges in providing water and energy to its citizens in the face of scarcity, rising costs, security threats, climate change, and much else. We are fortunate to have the scientific and technological capacity, and the institutions of governance, to take on these difficult challenges. Policy formulation, starting with Congress asking penetrating and thoughtful questions, is a critical starting point. From this framework, research and development strategies can be developed to address society's challenges in effective ways.

For the past century, the focus of technological innovation in water systems was on the extraction, storage, and conveyance of water. Huge dams, aqueduct systems, and "appurtenant" facilities were designed, financed, and built to accomplish the task. Major rivers have been entirely de-watered. The costs – economic, environmental, and social – are evident.

Integrated water and energy management strategies, with a focus on vastly improved end-use and economic efficiency for both, and careful consideration of alternative technology opportunities provided by advances in science and technology, can provide significant *multiple benefits* to society. Cost-effective improvements in energy and water productivity, with associated economic and environmental quality benefits, increased reliability and resilience of supply systems (all elements of the "multiple benefits"), are attainable.

It may be worth quoting the California Energy Commission from its *Integrated Energy Policy Report*: "Reducing the demand for energy is the most effective way to reduce energy costs and bolster California's economy."⁵⁴ Consistent with this approach, improvements in efficiency are identified by the California Department of Water Resources as the largest (and in fact the most certain) new water supply for the next quarter century, followed by groundwater recharge and water reuse. The state's Energy Commission noted: "The *2005 Water Plan Update* mirrors the state's adopted loading order for electricity resources."⁵⁵

Methodologies and metrics exist to tap the multiple benefits of integrated water/energy strategies, though they can and need to be improved. The policies required to incentivize, enable, and mandate integrated water and energy policy exist and are being refined to tap ample opportunities to improve both the economic and environmental performance of water and energy systems.

With better information regarding energy implications of water use, and water implications of energy use, public policy combined with investment and management strategies can dramatically improve productivity and efficiency. Potential benefits include improved allocation of capital, avoided capital and operating costs, and reduced burdens on rate-payers and tax-payers. Other benefits, including restoration and maintenance of environmental quality, can also be realized more cost-effectively through policy coordination. Full benefits derived through water/energy strategies have not been adequately quantified or factored into policy.

Public concern regarding environmental costs of diverting and extracting water is another reason for the shift in technology focus from extraction to efficiency. Precipitous declines in populations of fish, and damage to ecosystems around the world, have driven this growing call for more sustainable water systems.

Current technology can provide water supplies through efficiency improvements at substantially *less cost* than the development of new supplies in most areas. As water prices increase to reflect full capital, operating, and environmental costs, it is likely that technology will play an even greater role in providing water efficiency improvements.

Sources

- ¹ American Society of Civil Engineers, Report Card, <http://www.asce.org/reportcard/2005/page.cfm?id=23>
- ² American Society of Civil Engineers, Report Card, <http://www.asce.org/reportcard/2005/page.cfm?id=23>
- ³ *Climate Change 2007: The Physical Science Basis: Summary for Policymakers*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, p.4. <http://www.ipcc.ch/index.htm>
- ⁴ *Climate Change 2007: The Physical Science Basis: Summary for Policymakers*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. <http://www.ipcc.ch/index.htm>
- ⁵ Dettinger, Michael.D., and Dan R. Cayan. 1994. Large-scale atmospheric forcing of recent trends toward early snowmelt runoff in California. *Journal of Climate* 8: 606–23.
- ⁶ California Department of Water Resources, 2006. *Progress on Incorporating Climate Change into Management of California's Water Resources*, http://www.climatechange.ca.gov/documents/2006-07_DWR_CLIMATE_CHANGE_FINAL.PDF
- ⁷ California Global Warming Solutions Act of 2006, (AB32) Section 38501 (a).
- ⁸ Intergovernmental Panel on Climate Change (IPCC) documents at: <http://www.ipcc.ch/index.htm>; Wilkinson, Robert C., 2002. *The Potential Consequences of Climate Variability and Change for California, The California Regional Assessment*, Report of the California Regional Assessment Group for the U.S. Global Change Research Program, National Center for Geographic Information Analysis, and the National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara. Available at: <http://www.ncgia.ucsb.edu/products.html>
- ⁹ See for example: Park, Laurie, Bill Bennett, Stacy Tellinghuisen, Chris Smith, and Robert Wilkinson, 2008. *The Role of Recycled Water In Energy Efficiency and Greenhouse Gas Reduction*, California Sustainability Alliance, available at: www.sustainca.org Also see: California Energy Commission (2005). *Integrated Energy Policy Report*, November 2005, CEC-100-2005-007-CMF; and Klein, Gary (2005). California Energy Commission, California's Water – Energy Relationship. Final Staff Report, Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding, (04-IEPR-01E) November 2005, CEC-700-2005-011-SF.
- ¹⁰ Wilkinson, Robert C. (2000). *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*, Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy Efficiency; California Energy Commission (2005). *Integrated Energy Policy Report*, November 2005, CEC-100-2005-007-CMF; California Energy Commission (2005). *Integrated Energy Policy Report*, November 2005, CEC-100-2005-007-CMF; and Klein, Gary (2005). California Energy Commission, California's Water – Energy Relationship. Final Staff Report, Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding, (04-IEPR-01E) November 2005, CEC-700-2005-011-SF.
- ¹¹ California Energy Commission (2005). *Integrated Energy Policy Report*, November 2005, CEC-100-2005-007-CMF.
- ¹² California Energy Commission (2005). *Integrated Energy Policy Report*, November 2005, CEC-100-2005-007-CMF.
- ¹³ California Department of Water Resources (2005). California Water Plan Update 2005. Bulletin 160-05, California Department of Water Resources, Sacramento, CA.

¹⁴ Klein, Gary (2005). California Energy Commission, California's Water – Energy Relationship. Final Staff Report, Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding, (04-IEPR-01E) November 2005, CEC-700-2005-011-SF.

¹⁵ California Department of Water Resources (2005). California Water Plan Update 2005. Bulletin 160-05, California Department of Water Resources, Sacramento, CA.

¹⁶ Klein, Gary (2005). California Energy Commission, California's Water – Energy Relationship. Final Staff Report, Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding, (04-IEPR-01E) November 2005, CEC-700-2005-011-SF.

¹⁷ Klein, Gary (2005). California Energy Commission, California's Water – Energy Relationship. Final Staff Report, Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding, (04-IEPR-01E) November 2005, CEC-700-2005-011-SF.

¹⁸ Wilkinson, Robert C. (2000). *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*, Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy Efficiency.

¹⁹ California Energy Commission (2006). Public Interest Energy Research - Industrial, Agriculture and Water, <http://energy.ca.gov/pier/iaw/industry/water.html>

²⁰ For a methodology to examine water intensity, see: Wilkinson, Robert C., 2000. *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*, Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy Efficiency.

²¹ This schematic and method is based on Wilkinson (2000) with refinements by Gary Klein, California Energy Commission, Gary Wolff, Pacific Institute, and others.

²² Wilkinson, Robert C. (2000). *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*, Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy Efficiency; QEI, Inc. (1992). *Electricity Efficiency Through Water Efficiency*, Report for the Southern California Edison Company.

²³ QEI, Inc. (1992). *Electricity Efficiency Through Water Efficiency*, Report for the Southern California Edison Company.

²⁴ Metropolitan Water District of Southern California (1996). *Integrated Resource Plan for Metropolitan's Colorado River Aqueduct Power Operations*.

²⁵ California Department of Water Resources (1996). *Management of the California State Water Project*. Bulletin 132-96.

²⁶ Anderson, Carrie (1999). "Energy Use in the Supply, Use and Disposal of Water in California", Process Energy Group, Energy Efficiency Division, California Energy Commission.

²⁷ Burton, Franklin L. (1996). *Water and Wastewater Industries: Characteristics and Energy Management Opportunities*. (Burton Engineering) Los Altos, CA, Report CR-106941, Electric Power Research Institute Report.

²⁸ Metropolitan Water District of Southern California (1996). *Integrated Resource Plan for Metropolitan's Colorado River Aqueduct Power Operations*.

-
- ²⁹ Wilkinson, Robert C. (2000). *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*, Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy Efficiency.
- ³⁰ Park, Laurie, Bill Bennett, Stacy Tellinghuisen, Chris Smith, and Robert Wilkinson, 2008. *The Role of Recycled Water In Energy Efficiency and Greenhouse Gas Reduction*, California Sustainability Alliance, available at: www.sustainca.org
- ³¹ California Energy Commission (2006). Public Interest Energy Research - Industrial, Agriculture and Water, <http://energy.ca.gov/pier/iaw/industry/water.html>
- ³² Burton, Franklin L. (1996). *Water and Wastewater Industries: Characteristics and Energy Management Opportunities*. (Burton Engineering) Los Altos, CA, Report CR-106941, Electric Power Research Institute Report.
- ³³ U.S. Environmental Protection Agency (1998). *Water Conservation Plan Guidelines for Implementing the Safe Drinking Water Act*.
- ³⁴ Miri, Joseph, 1999. "Snapshot of Conservation Management: A Summary Report of the American Water Works Association Survey of State Water Conservation Programs." American Water Works Association
- ³⁵ One of the best sources on water efficiency in the U.S. is Mary Ann Dickinson, Executive Director, Alliance for Water Efficiency, P.O. Box 804127, Chicago, IL 60680-4127. The Alliance web site is: www.allianceforwaterefficiency.org
- ³⁶ California Water Code, Sections 10620 et seq.
- ³⁷ California Urban Water Conservation Council (1991). "Memorandum of Understanding Regarding Urban Water Conservation in California," (First adopted September, 1991).
- ³⁸ Osann, Edward and John Young (1998). *Saving Water Saving Dollars: Efficient Plumbing Products and the Protection of American Water*.
- ³⁹ "Tuas Seawater Desalination Plant □ Seawater Reverse Osmosis (SWRO), Singapore", [water□technology.net/projects/tuas/](http://www.water□technology.net/projects/tuas/), viewed April 23, 2008.
- ⁴⁰ "Seawater desalination to relieve water shortage in China", China Economic Net, Feb. 28, 2006, http://en.ce.cn/Insight/200602/28/t20060228_6217706.shtml.
- ⁴¹ "Perth Seawater Desalination Plant, Seawater Reverse Osmosis (SWRO), Kwinana, Australia", [water□technology.net/projects/perth/](http://www.water□technology.net/projects/perth/)
- ⁴² "Drought-Proof Water Supply Delivering Drinking Water, The nation's first large-scale seawater desalination plant eases Tampa Bay region's drought worries." News release, January 25, 2008, <http://www.tampabaywater.org/whatshot/readnews.aspx?article=131>, viewed April 23, 2008.
- ⁴³ "According to the 2002 State Water Plan, four of the six regional water planning areas with the greatest volumetric water supply needs in 2050 will be regions that have large urban, suburban, and rural populations located on or near the Texas Gulf Coast. These populations could conceivably benefit from a new, significant, and sustainable source of high-quality drinking water." *The Future of Desalination in Texas, 2004 Biennial Report on Seawater Desalination*, Texas Water Development Board, p.ix.
- ⁴⁴ Section 16.060 of the Texas Water Code directs the Texas Water Development Board to "... undertake or participate in research, feasibility and facility planning studies, investigations, and surveys as it considers necessary to further the development of cost□effective water supplies from seawater desalination in the state." The Code also

requires a biennial progress report be submitted to the Governor, Lieutenant Governor, and Speaker of the House of Representatives.

⁴⁵ “The Future of Desalination in Texas, 2006 Biennial Report on Seawater Desalination”, Texas Water Development Board, Executive Summary, pp.iv-v.

⁴⁶ Cooley, Heather, Peter H. Gleick, and Gary Wolff, 2006. *Desalination, With a Grain of Salt*, Pacific Institute for Studies in Development, Environment, and Security, 654 13th Street, Preservation Park, Oakland, California 94612, <http://www.pacinst.org/reports/desalination/index.htm>

⁴⁷ Posidon Resources, <http://www.carlsbaddesal.com/partnerships.asp>

⁴⁸ Hutson, Susan S., Nancy L. Barber, Joan F. Kenny, Kristin S. Linsey, Deborah S. Lumia, and Molly A. Maupin, 2005. *Estimated Use of Water in the United States in 2000*, U.S. Geological Survey, Circular 1268, (released March 2004, revised April 2004, May 2004, February 2005) USGS, P.1. <http://water.usgs.gov/pubs/circ/2004/circ1268/index.html>

⁴⁹ See for example Sandia’s web site at: <http://www.sandia.gov/energy-water/>

⁵⁰ See "Energy Demands on Water Resources Report to Congress on the Interdependency of Energy and Water" U.S. Department of Energy, December 2006, http://www.sandia.gov/energy-water/congress_report.htm

⁵¹ National Energy Technology Laboratory, 2007. “Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements” 2007 Update, DOE/NETL-400/2007/1304, www.netl.doe.gov

⁵² Information and graph are from Dennen, Bliss, Dana Larson, Cheryl Lee, James Lee, Stacy Tellinghuisen, 2007. “California’s Energy-Water Nexus: Water Use in Electricity Generation”, Group Project Report, Donald Bren School of Environmental Science & Management, University of California, Santa Barbara, available at: <http://fiesta.bren.ucsb.edu/~energywater/>

⁵³ Sustainable Water Resources Roundtable, <http://acwi.gov/swrr/>

⁵⁴ California Energy Commission (2005). *Integrated Energy Policy Report*, November 2005, CEC-100-2005-007-CMF.

⁵⁵ Klein, Gary (2005). California Energy Commission, California's Water – Energy Relationship. Final Staff Report, Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding, (04-IEPR-01E) November 2005, CEC-700-2005-011-SF.