Water and Energy: Leveraging Voluntary Programs to Save Both Water and Energy

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March 2008

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Executive Summary

Water and energy are critical resources that affect virtually all aspects of daily life. Ensuring these resources are available in sufficient quantities when and where society needs them entails significant investments in planning, infrastructure development, operations and maintenance. Users of energy and water pay for these investments through their routine utility bills. As water and energy planners assess and undertake policies and programs to maintain the reliability of these systems, meet the growing demand for water and energy, and address scarcity, among other objectives, improving the efficiency in the use of these resources in homes, buildings, and industry is frequently identified as an important strategy. Recent studies project that more than $220 billion is needed to update and expand our water treatment and delivery systems over the next twenty years and more than $400 billion is necessary to meet the growing demand for electricity over the next twenty-five years. The numerous energy and water efficiency measures that can save these resources at costs lower than those for providing new supply and distribution infrastructure can contribute to significant savings.

To date, most significant water efficiency initiatives have been implemented locally and regionally, particularly during periods of droughts. A national water efficiency program that collects and broadly distributes information on water savings policies, strategies, and options could have a significant impact in addressing a growing water supply and infrastructure cost issue. Local and regional programs can leverage the national efforts, to enhance their effectiveness.

Recognizing this need, the U.S. Environmental Protection Agency (EPA) launched the WaterSense® program in June 2006. WaterSense is a voluntary public-private partnership program that seeks to protect the future of our nation's water supply by promoting water efficiency and enhancing the market for water-efficient products, programs, and practices. WaterSense addresses residential and commercial water use. Products and programs that receive the WaterSense label meet water efficiency and performance criteria. As of Fall 2007, the WaterSense program includes specifications for certification programs for irrigation professionals, high-efficiency toilets, residential bathroom sink faucets, and has efforts underway to include showerhead and irrigation controllers.

Energy efficiency efforts have been underway in many areas of the United States for more than a decade and already have provided significant water savings in addition to energy savings. These efforts touch many of the same products, practices, people and institutions that are the focus of local water efficiency efforts. Many of the energy efficiency efforts that are administered by utilities and state energy programs leverage the ENERGY STAR® program which provides a national platform for efficiency efforts, including national outreach and linkages to retailers and product manufacturers. ENERGY STAR was developed by EPA in 1992 and has grown to include more than 50 product categories, new homes, and a range of residential, commercial and industrial energy efficiency practices.

Because energy use and water use are closely intertwined in important ways, energy efficiency initiatives offer opportunities for delivering significant water savings, and similarly, water efficiency initiatives offer opportunities for delivering significant energy savings. Consequently, EPA’s existing voluntary programs can be a valuable resource for helping to advance water and energy efficiency together.

The goal of this report is to illustrate the co-benefits of energy and water efficiency programs and summarize the current and future opportunities to be pursued under the ENERGY STAR and WaterSense programs to save both energy and water. The report provides a summary of water use in the United States, identifies the areas where energy and water are closely intertwined and outlines strategies for delivering additional water savings through energy efficiency efforts, including opportunities with the ENERGY STAR program, and additional energy savings through water efficiency efforts, including those with the WaterSense program. The report concludes with a summary of the potential energy and water savings associated with the ENERGY STAR and WaterSense programs.

Overview of Water Use in the United States

In 2000, about 408,000 million gallons per day (mgd)[1] of water was withdrawn from surface water and groundwater sources in the United States. This water was used for the following purposes (as shown in Exhibit ES-1):

- Nearly half of this water, 195,000 mgd, is used for power plant cooling. After it is used, nearly all of this power plant cooling water is returned to a stream, lake, or ocean fairly close to where it was withdrawn.
- About 34 percent of this water, 137,000 mgd, is used for irrigating crops and other farm uses. About 61 percent of this water is consumed during irrigation, 19 percent is lost during conveyance, and 20 percent is returned to lakes or streams. The portion of irrigation water that is consumed, about 83,000 mgd in 2000, is by far the largest consumptive use of water in the United States. The overwhelming majority of U.S. crop production comes from irrigated fields.
- About 11 percent, 46,900 mgd, is used for residential and commercial purposes. Community water systems withdraw about 43,300 mgd to supply drinking water to residential and commercial customers, and self-supplied water for domestic uses (i.e., water wells at people's homes) added about 3,600 mgd. In total, this water use is about 164 gallons per capita per day (gpcd), 70 percent of which is for residential water use. About 60 percent of residential water use (or 70 gpcd) is for indoor purposes (toilets, showers, baths, sinks, laundry). Customers pay approximately $33 billion a year for this water and an equivalent amount for managing the wastewater that results.
- The remainder of water use is for industrial processes (self supplied), mining, livestock and other miscellaneous uses, accounting for about 7 percent of total water withdrawals.

Looking across the major uses for water shows the following broad trends and concerns for the future:

- Although water use for power plant cooling has been stable in recent years, as the result of shifts in cooling technology, it may increase as the power sector continues to grow.
- Agricultural irrigation is likely to remain stable or decline as improvements in efficiency continue.
- Increasing populations are expected to put pressure on public water supplies.
- The ability of public water systems to meet the needs of the growing population will continue to receive considerable attention. Improved efficiency of residential and commercial water use may be key elements to offset the impacts of this increased demand.

[1] This volume of water is equal to about 1,400 gallons per capita per day (gpcd).

Energy and Water Are Linked

The supply, delivery, and use of water and energy are intertwined in important ways. A better understanding of these relationships can assist in developing strategies that deliver greater energy and water savings and associated environmental benefits. These linkages include:

- Electricity is used to deliver water to residential and commercial customers and to treat the wastewater customers generate. Water supply and wastewater treatment systems typically represent the largest energy expenditures by municipalities that provide these services. Nationally, annual electricity consumption required for water supply and treatment totaled about 30 billion kWh and 7 billion kWh respectively, or nearly one percent of total electricity generation, at a cost of about $3 billion.
- Energy is used to pump irrigation water. In 1998 farms spent about $1.2 billion on energy for irrigation. Electricity use accounted for about two-thirds of the total, or about 10 billion kWh.
- Water is used for cooling in the vast majority of electric power generation in the U.S. today. The availability and quality of cooling water is vital to maintaining efficient electricity production. On average across the country each kWh generated consumes about 0.2 to 0.3 gallons of water, although the rate varies for different cooling system technologies.
- Water and energy are used jointly under many circumstances, particularly where hot water is needed, so that efforts to use one resource more efficiently often help use the other resource more efficiently as well.
- Water and energy substitute for each other under some circumstances, so that efforts to reduce the use of one resource can increase the use of the other resource.

In addition to these direct interactions between water and energy, there are indirect influences.

- When water use is reduced, electricity requirements are reduced *indirectly* as less water needs to be pumped by the water supply system.
- When energy is saved, water requirements are reduced *indirectly* as lower electricity demand means less cooling water required at the power plant.

Opportunities for Energy and Water Efficiency

Although drinking water supplies are only about 11 percent of total water withdrawal, they receive considerable attention because of the importance of adequate supply to support population and economic growth. Additionally, financial pressures on water supply systems and wastewater treatment systems have received significant attention in recent years. Consequently, there is particular interest in ensuring that water resources are used efficiently to not only stretch supplies, but also to help contain delivery and treatment costs.

Enhancing water efficiency among residential, commercial, and industrial customers can contribute significantly to addressing these challenges. Numerous studies show, particularly for residential and commercial customers, that cost effective techniques can reduce typical water use by 20 to 40 percent without reducing the services derived from the water (See Exhibit ES-2 and Exhibit ES-3). Commonly identified strategies include:

- <u>Residential Customers</u>. As consumers change over existing pre-EPAct plumbing fixtures and appliances, they can realize savings of over 20 percent by buying currently available products. By investing in ENERGY STAR and WaterSense products, consumers could save an additional 15 percent.

- Commercial Customers. Savings of about 20 to 40 percent of current baseline water use are possible depending upon the type of commercial establishment. Common strategies include accelerated replacement of toilets that are flushed many times per day with high-efficiency toilets, improved operation of building cooling systems (typically the largest use of water in buildings with such systems); addressing water used to provide cooling for refrigeration as well as industrial processes; and employing resource-efficient products used in water-intensive commercial applications such as commercial kitchens and laundries.

Additionally, improving the efficiency of water supply and treatment operations themselves can help relieve financial pressures. Capturing the significant opportunities to reduce leakage in supply systems not only helps stretch existing supplies, it also reduces operating costs.

Leveraging EPA Programs

There are a number of opportunities for pursuing greater water and energy savings. As an example, recent utility and other efforts across the country to promote resource-efficient clothes washers and dishwashers, leveraging the ENERGY STAR program in many cases, have already helped save over 140 million gallons per day (mgd) of water as of 2006. More broadly, energy efficiency efforts linked to the ENERGY STAR program saved more than 180 mgd of power plant cooling water in 2006. By 2015, the growth of the ENERGY STAR program is expected to save approximately 600 mgd directly, plus an additional 430 mgd of power plant cooling water.

There are significant additional opportunities to leverage ongoing energy efficiency initiatives to capture additional water savings. These opportunities include

- designating additional products that save both energy and water as “resource efficient,” and designing outreach and incentive programs around them with particular focus on energy and water intensive market segments;
- integrating residential water savings opportunities into ongoing home energy audit and retrofit programs;
- integrating water savings opportunities into commercial audit and technical assistance programs; and
- focusing on the energy efficiency and water delivery efficiency of the water supply industry.

EPA’s voluntary programs can be leveraged to provide greater savings of both energy and water in each of these areas, as summarized in Exhibit ES-4. The ENERGY STAR program offers a number of strategies for promoting energy efficiency to the general public, businesses, and industries. Many of these strategies are used by state and utility-based energy efficiency programs that currently spend about $3 billion each year to advance energy efficiency across key market sectors. The new WaterSense program offers new strategies to leverage. The more detailed opportunities include:

- Product Labeling of Water Efficient Products: WaterSense is labeling and promoting the use of high-performing, high-efficiency residential and commercial plumbing fixtures. Several states and water utilities have programs and initiatives promoting and rebating consumers for the installation of these types of products and are in a good position to leverage the WaterSense label to further their efforts. A list of products that are either already covered by the WaterSense program or which are anticipated to be examined for possible coverage under this program is provided in Exhibit ES-4.

- Product Labeling of Products Using Energy and Water: A number of products in the commercial and residential sector use energy and water simultaneously, particularly when they deliver hot water. Products that use both energy and water efficiently, and which meet the performance expectations of consumers, can be promoted with a single product label such as WaterSense or ENERGY STAR as appropriate. This would provide consumers with a single label that communicates a good investment and improved resource efficiency without sacrificing performance. A list of products that use energy and water and which are either already covered by the ENERGY STAR program or which are anticipated to be examined for possible coverage under the ENERGY STAR or WaterSense programs is provided in Exhibit ES-5.

- Existing Homes: Many water utilities, electric utilities, and state energy efficiency programs offer residential audit and retrofit programs which may offer an opportunity for greater outreach on water saving measures such as efficient plumbing fixtures, including toilets, showerheads, and faucet aerators, among other home improvement projects which can include updating appliances as well. In addition, EPA is working with the DOE and HUD on a new initiative for existing homes called Home Performance with ENERGY STAR which may provide a useful delivery mechanism. Significant water savings on the order of 27 gallons per capita per day (approximately 40 percent of a typical households daily water use) can be achieved when pre-EPAct fixtures are replaced with WaterSense and ENERGY STAR appliances, nearly 15 percent greater than if the products just met minimum efficiency standards (see Exhibit ES-2).[2] Home Performance with ENERGY STAR is a whole house retrofit service offered by certified home professionals and backed by a local, credible organization working in partnership with the federal government. Home professionals demonstrate the potential savings to the home owner who is undertaking a variety of home improvement efforts, perform the improvements at the request of the homeowner, and provide third party review of their work. This program is currently underway in key regions of the country and is being expanded to other regions.

- New Homes Construction: Improving the efficiency of the delivery of hot water in new homes offers an opportunity to save energy and water simultaneously and could be explored as a possible measure for an ENERGY STAR home at a future point. Further, EPA's WaterSense program is developing a water-efficient new homes program that establishes criteria and a certification process for certifying the indoor and outdoor water efficiency of a new home.

- Commercial Building Performance: The corporate energy management approach being used by EPA to promote energy efficiency in commercial buildings can be expanded to promote water savings. Key opportunities include:
    - Expanding the energy efficiency rating system developed by EPA to help measure and improve building energy use to incorporate water use and allow for a more unified energy and water assessment. An analysis of commercial and institutional customers in California reports significant water savings potential through the adoption of efficient practices (see Exhibit ES-3).

[2] These savings do not include potential improvements in landscape irrigation practices that may also be achieved.

- o Providing outreach on the suite of energy and water efficient commercial products used in energy and water intensive commercial applications such as commercial kitchens to the many market segments that have commercial kitchens including restaurants, hospitals, schools, and hotels;
  - o Promoting improved performance of building cooling towers through improved efficiency of the heating, cooling, and ventilation system and improved management of the cooling water;
  - o Promoting more efficient plumbing products; and
  - o Addressing water-cooled versus air-cooled cooling equipment such as ice machines.

- The Water Supply and Wastewater Treatment Industry Focus: The water supply and wastewater treatment industries warrant specific attention to capture energy savings opportunities, which will help reduce financial pressures on these industries. An integrated approach to improving energy efficiency and reducing water leakage would offer municipalities the greatest benefits. Such an approach includes facility level benchmarking, dissemination of best practices and enhanced peer exchange.
- Certification Programs for Irrigation Professionals: Commercial and residential outdoor water use in the United States accounts for more than seven billion gallons of water each day, mainly for landscape irrigation. WaterSense's final specifications for certification programs for irrigation professionals address both efficient irrigation system components and services. These specifications will help customers identify professional service providers that embrace and encourage the use of water-efficient practices to enhance performance and efficiency.
- Improved Water Loss Control: As water utilities voluntarily reduce water loss both energy and water savings can be achieved.

Building partnerships around these areas for the ENERGY STAR and WaterSense programs has the potential to achieve significant energy and water savings. Exhibit ES-6 presents the savings for the current ENERGY STAR program and for expanding energy and water efficiency initiatives. As indicated, expanding energy and water efficiency efforts could save significant amounts of water across the country over the next ten years. Expanded energy efforts in terms of intensified promotion of ENERGY STAR clothes washers and dishwashers and improved cooling tower performance in buildings, could save an additional 160 mgd in water savings. Expanded water initiatives such as reductions in water loss and accelerated use of more efficient plumbing products such as EPAct compliant toilets and urinals in the commercial and residential sectors, could provide an additional 270 mgd and 630 mgd in water savings, respectively. When combined with expected savings from ongoing efforts of 600 mgd from the ENERGY STAR program and 1,600 mgd from the natural replacement of EPAct compliant toilets in the residential sector, these combined efforts could provide approximately 3,300 mgd in direct water savings, or the equivalent of the residential indoor water use of approximately 45 million people (see Exhibit ES-6).

These water savings estimates are conservative for two reasons. First, many water savings options were not quantified, including WaterSense labeled products, commercial and industrial process opportunities, and agricultural irrigation improvements. Second, only a portion of the full technical potential of the evaluated options was included, representing what could realistically be accomplished over a period of about 10 years, primarily by focusing on those savings that can be achieved by leveraging major initiatives currently underway.

Exhibit ES-1: Summary of Water Withdrawal and Consumption in 2000

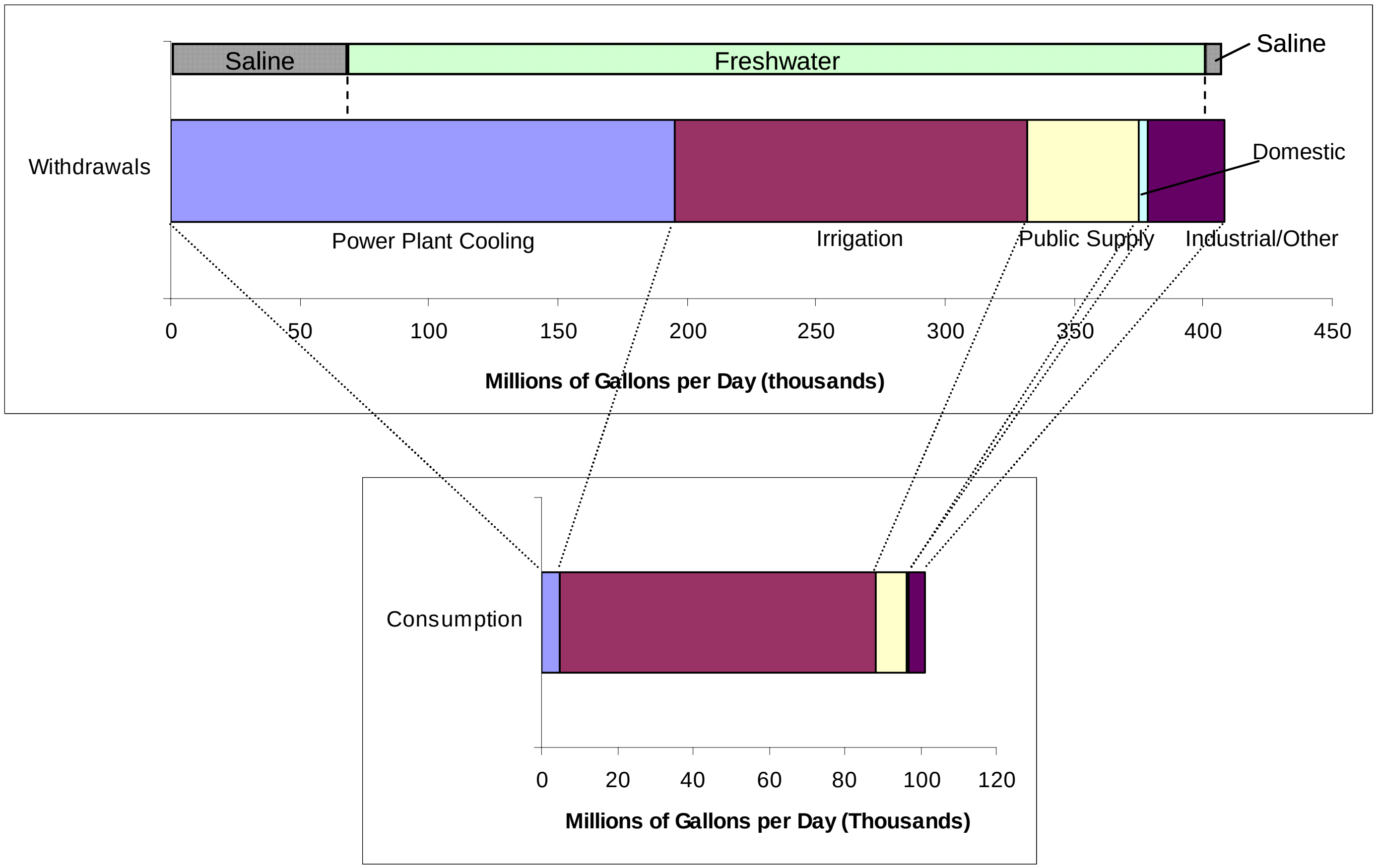
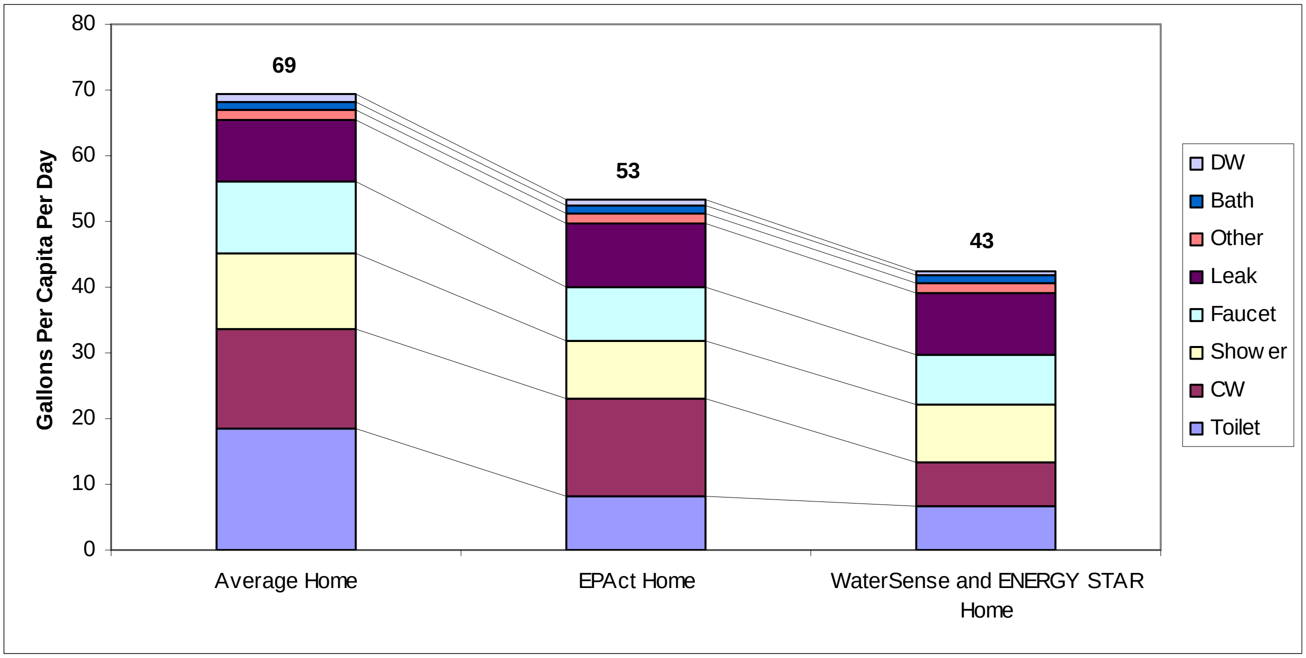
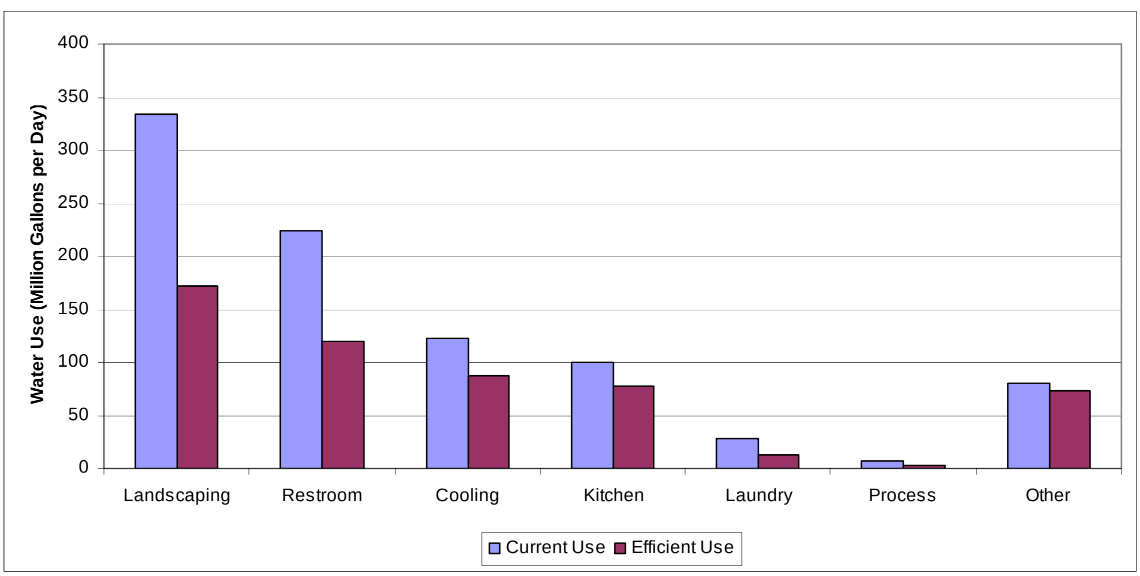


Exhibit ES-2: Water Savings: Retrofitting an Average Home with Water Conserving Fixtures and Appliances[a]



[a] For more information see Section 5.
CW = clothes washer; DW = dishwasher

Exhibit ES-3: Water Savings: Efficient Practices Among Commercial and Institutional Customers in California[a]



[a] For more information see Section 6.

Exhibit ES-4: Opportunities to Leverage Water and Energy Efficiency Programs

Water and Energy Efficiency Opportunities	Opportunities to Leverage Efficiency Programs
Residential	
Water efficient plumbing fixtures (HETs, faucets, showerheads)	• Promote WaterSense labeled plumbing products • Assess and account for embedded energy savings associated with conveyance, distribution, and treatment of water
Water-efficient clothes washers and dishwashers	• Integrate water efficiency specifications into ENERGY STAR appliance labeling, as appropriate
New and existing homes	• Explore new home construction, and home audit and retrofit programs to identify opportunities for enhancement
Water-efficient landscaping	• Promote WaterSense Certification Program for Irrigation Professionals • Integrate water-efficient landscaping messaging into ENERGY STAR Homes outreach to homebuilders and customers
Commercial	
Water efficient plumbing fixtures (HETs, faucets)	• Promote WaterSense labeled plumbing products • Assess and account for embedded energy savings associated with conveyance, distribution, and treatment of water
Water-efficient commercial products, such as clothes washers, dishwashers, steam cookers, others	• Integrate water specifications into ENERGY STAR product labeling • Promote efficient products as part of water and energy efficient commercial buildings initiatives
Water-efficient commercial cooling	• Integrate into high performance building programs
Water-efficient landscaping	• Limited opportunities currently identified to leverage energy efficiency programs
Whole building efficiency	• Integrate water use tracking and management into energy management programs
Industrial	
Improved efficiency of water treatment and waste water treatment systems	• Develop and promote facility level benchmarking, best practices, and enhanced peer exchange

Exhibit ES-5: Status of Labeling Programs for Products that Use Energy and Water

Water Efficiency Opportunities	Status as of Spring 2007
Residential	
Clothes Washers	Updated ENERGY STAR specification effective January 2007. Includes Maximum Water Factor of 8.0.
Dishwashers	Updated ENERGY STAR specification effective January 2007.
High-Efficiency Toilets	New WaterSense specification effective January 2007.
Bathroom Sink Faucets	New WaterSense specification effective October 2007.
Irrigation Control Technologies	New WaterSense specification development process initiated in Spring 2007.
Showerheads	New WaterSense specification development process initiated in Summer 2007.
Commercial	
Commercial Dishwashers	New ENERGY STAR specification effective October 2007.
Ice Machines	New ENERGY STAR specification effective January 2008.
Steam Cookers	ENERGY STAR specification introduced in 2003. In June 2007 EPA provided information on water use of these ENERGY STAR products.
Irrigation Control Technologies	New WaterSense specification development process initiated in Spring 2007.
Autoclaves/Sterilizers	Examine in 2008.
Commercial Clothes Washers	Examine in 2008.
Commercial Toilets and Urinals	Examine in 2008.
Softserve Machines	Examine in 2008.

Exhibit ES-6: Water and Energy Savings Estimates for 2015[a]

Activity	Water Savings (mgd): Direct Savings in Water Supply and Treatment	Water Savings (mgd): Indirect Savings in Power Plant Cooling Water	Direct Energy Savings (million kWh/year)
ENERGY STAR: Expected Activities			
ENERGY STAR products[b]	593[c]	320[b]	257,000[b]
ENERGY STAR buildings	3[d]	110[e]	89,900[e]
Subtotal[f]	**596**	**430**	**346,900**
ENERGY STAR: Potential Expanded Activities			
Intensified residential clothes washer and dishwasher promotion	133	8	6,750
Water supply and wastewater treatment focus	0	3	2,110
Intensified improvement in building cooling tower operations	26	<1	(not estimated)
Subtotal[f]	**160**	**11**	**8,860**
General Water Saving Strategies: Expected Activities			
Natural replacement of toilets to EPAct compliant toilets (residential)—(assuming 95 million people use EPAct toilets)	1,620	1	0
Natural replacement of urinals to EPAct compliant urinals (commercial)	(not estimated)	(not estimated)	(not estimated)
Subtotal[f]	**1,620**	**1**	**0**
General Water Saving Strategies: Potential Expanded Activities			
Reduction in real loss during water supply	270	<1	150
Accelerated replacement of toilets to EPAct compliant toilets (residential)—(assuming an additional 25 million people use EPAct toilets)	430	<1	0
An additional 2 million EPAct toilets and 2 million EPAct urinals (commercial)	200	<1	0
Subtotal[f]	**900**	**1**	**150**
WaterSense: Expected Activities			
• High-efficiency toilets (HETs) • High-efficiency faucets • Certification Program for Irrigation Professionals • Additional labeled products that save water	(under development)	(under development)	(under development)
Total[f]	**3,276**	**443**	**355,910**

[a] For detailed explanation of all assumptions used please see section 7.8.
[b] Includes all ENERGY STAR qualified products, including both EPA and DOE products, such as appliances, consumer electronics, and office equipment.
[c] Direct water savings for all ENERGY STAR products only include residential dishwashers and clothes washers, and exclude other water consuming ENERGY STAR products such as commercial dishwashers, ice machines, and steam cookers for which estimates are 'under development'.
[d] Direct water savings result from improved cooling tower operations.
[e] Direct energy savings and indirect water savings result from all energy efficiency initiatives.
[f] Totals do not include savings from activities that are 'under development' or 'not estimated'. Additionally, totals may not add due to independent rounding.

1. Introduction

Water is a critical resource that affects virtually all aspects of daily life. Historically, populations have settled near reliable sources of clean water. Access to adequate, high-quality water supplies is no less important today. In the United States, water resources are protected by the Clean Water Act, the Safe Drinking Water Act, and other legislation, with the aim of maintaining or enhancing our water resources. Within this regulatory structure, and related legal framework of water ownership and use rights, water resource management decisions address changing and competing demands for water.

The U.S. Environmental Protection Agency, other federal agencies, states, and local governments work to protect the quality and health of our nation's water resources and ecosystems, including working to achieve the following:

- maintain and enhance compliance with safe drinking water standards to protect human health;
- reduce pollution in waters with fish advisories to enhance the safety of fish and shellfish for human consumption;
- restore polluted waters to make them safe for swimming and to maintain healthy watersheds;
- promote healthy coastal waters through better effluent management and control; and
- protect and expand the quality and quantity of wetlands.

Each of the water uses discussed in this report balances the beneficial use of water with potential impacts on water resources.

- Power plant cooling is the largest use of water in the United States. A properly operating cooling system is required to produce electricity efficiently and reliably. Using water for power plant cooling affects local aquatic ecosystems. Even though nearly all power plant cooling water is discharged back to the river or lake from which it was withdrawn, the water intake structures themselves have an impact, as does the reduction in river flow in some cases. The discharge of the water has impacts as well, due to the higher temperature of the water as well as its trace contaminants.
- Agricultural irrigation is the second largest water use in the United States. Irrigation is critical for the production of all our major crops, more than 80 percent of which are produced on irrigated lands. Diverting water for irrigation can affect the flow rates in rivers, which may be needed to maintain ecosystems. Competition between irrigation needs and fish protection requirements has been contentious in various areas for years. Runoff from irrigated fields has also been a concern, as the water is often nutrient rich from fertilizer application, or may contain trace amounts of pesticides used on crops. As a result, runoff controls are typically used to protect surface water resources.
- Public drinking water supply is the third largest use of water. Although the amount of water used for residential and commercial uses is modest compared to power plant cooling and irrigation, this water supports population and economic growth—and consequently is vital to the health of our cities and communities. The concentrated use and discharge of the water (after treatment) can be an important factor in the health of local water resources. Additionally, the discharge of untreated wastewater during heavy rains continues to be of concern in some areas. The costs of maintaining and expanding aging piping networks and treatment facilities are putting a financial strain on the water

supply and treatment infrastructure. The cost and availability of additional water supply to support a growing population are concerns in many areas as well.

Using water efficiently is one component of an overall strategy for balancing the beneficial uses of water with our national goal to protect and enhance environmental quality. Water use efficiency helps existing water supplies serve growing populations, and can help reduce the need for costly expansion of water supply and treatment facilities.

To help identify opportunities to promote water efficiency, this report examines the relationship between water and energy. Like water, energy is a critical resource that affects virtually all aspects of modern life. We are reminded of our reliance on energy during events such as the August 2003 blackout of the northeastern United States and parts of Canada. Since the energy price shocks of the 1970s, the United States has promoted energy efficiency in transportation, buildings, and products, through the use of regulations, building codes, and voluntary programs. As described in this report, the interrelationship between energy and water provides opportunities to promote the efficiency of both resources simultaneously.

- Electricity is used to deliver water for public supply and treat wastewater: Electricity is used to pump and treat water for delivery to users. Prior to being discharged, wastewater is treated in wastewater treatment plants that rely on electricity for pumping and aerating water. Using water more efficiently can reduce the volume of water pumped so that energy requirements of these facilities are reduced. Improved energy efficiency at these facilities can also help relieve the financial pressure on the water supply and treatment industries.

- Energy is used to pump irrigation water: Energy expenditures of about $1.2 billion were reported for on-farm pumping of irrigation water in 1998 (NASS, 1999, p. 40). Electricity costs were about two-thirds of the total, or about $800 million (NASS, 1999, p. 41). More efficient irrigation practices can reduce energy use.

- Water is used to produce electricity: Water is used for cooling in the vast majority of electric power generation in the U.S. today. The availability and quality of cooling water is vital to maintaining efficient electricity production. Energy efficiency that reduces electricity production also reduces water requirements for power plant cooling.

- Water is used in oil refining: Water is a critical input for oil refining, where it is used primarily as part of cooling processes. In fact, more water is used in refineries than crude oil.

- Water and energy are used jointly in products and processes: Water and energy are used jointly under many circumstances. Efforts to use one resource more efficiently often help use the other resource more efficiently as well. Opportunities to use both water and energy more efficiently exist in residential, commercial and industrial applications. Opportunities to improve water and energy efficiency together include:

  - resource-efficient clothes washers use less energy and less water than standard models while maintaining cleaning performance;

  - resource efficient connectionless steam cookers use less energy and less water and provide the same or better cooking capability compared to standard models; and

  - water-efficient pre-rinse spray valves save energy by using less hot water (pre-rinse spray valves are used to rinse dishes in commercial kitchens)—the valves can be designed to maintain cleaning performance.

- Water and energy are substitutes in some processes: Water and energy may substitute for each other under some circumstances, so that efforts to reduce the use of one resource increase the use of the other resource.[3]

Given the inter-related nature of these resources, increased attention is being given to opportunities to improve efficiency of both water and energy use simultaneously. In particular, the combined value of both water savings and energy savings increases the cost effectiveness of some efficiency measures. Given the ongoing and expected continued pressures on the existing water supply and treatment infrastructure, an integrated approach to water and energy efficiency will likely be increasingly important in the future.

The remainder of this paper is organized as follows:

- Section 2 presents an overview of water use in the United States, including recent and expected future trends.
- Section 3 examines energy use the in water supply and wastewater treatment systems.
- Section 4 describes how water is used for electric power production, including power plant cooling.
- Section 5 presents residential water uses, and identifies how water and energy are used together in several products.
- Section 6 reviews commercial and institutional water uses, including methods for examining process water uses; and
- Section 7 summarizes the interrelationship between water and energy, and examines how efficiency programs can provide joint benefits for both resources.

In addition to outlining the relationship between water and energy, this paper also explores where voluntary programs can provide a platform for jointly promoting water and energy efficiency.

[3] One example of the substitution of water for energy is the use of water for cooling in a refrigeration cycle, such as an air conditioner or ice machine. For example, a water-cooled ice machine uses less energy to provide cooling than an air cooled system, which does not use water. However, while installing a water-cooled ice machine may save energy it uses a significant amount of water in the process. EPA decided not to include water-cooled ice machines in its ENERGY STAR specification due to the fact that these machines use more water than air-cooled ice machines (ENERGY STAR, 2007a).

2. Overview of Water Use in the United States

The U.S. Geological Survey (USGS) has reported on U.S. water supplies and uses since 1950, providing a comprehensive picture of how water is withdrawn and used throughout the country. This section first defines three standard terms that are used to describe how water is managed: withdrawal; consumption; and return. Then, an overview of the major uses is provided. This section ends with a summary of the recent trends in water use, including use per capita, as well as expected future trends.

2.1 Water Withdrawal, Consumption, and Return

Several terms are commonly used to describe how water is used, including taking it from its source, using it for some beneficial purpose, and then discharging it. This paper adopts the standard terminology that describes these activities: withdrawal, consumption, and return. These terms have precise meanings, which are important to understand when reviewing water use:

- Water Withdrawal: Water withdrawal is the removal of water from the ground or the diversion of water from a surface water source for use (USGS, 2004, p. 46). The term “offstream use” is also used to mean water that is withdrawn for some use. A surface water source may be a river, lake, or ocean.
- Water Consumption: A portion of the water that is withdrawn may be consumed. Consumption is defined as the water that is “evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment” (USGS, 2004, p. 44). In other words, water is consumed when it is no longer available to be used or returned to a receiving body of water. A “consumptive use” of water is a use that consumes water. A “non-consumptive use” of water is a use that allows the water to be released back to a receiving body of water.
- Return Flow: The “return flow” is the portion of water that is withdrawn but not consumed. More precisely, the return flow is the water that “reaches a ground-water or surface water source after release from the point of use and thus becomes available for further use” (USGS, 2004, p. 45).

By definition, water consumption plus return flow must equal water withdrawal. All three quantities are important for understanding water resource management. The withdrawal of water, even if it is not consumed, can have a significant impact on water resources. Water consumption, of course, reduces the amount of water available for others to use. The return flow may help replenish surface water or groundwater supplies. However, the quality of the return flow and its impacts on the receiving water body must be considered.

Water is withdrawn from groundwater, lakes, streams, and oceans for a variety of uses. The largest water withdrawals in the U.S. are for thermoelectric power plant cooling and irrigation. Only a portion of the water withdrawn for these purposes is consumed, however. For example, about 98 percent of the water withdrawn for power plant cooling is discharged back to a receiving body of water: the return flow equals 98 percent of the withdrawal. Although the quality of the water may be changed (for example, its temperature may be increased and trace contaminants may be added), only 2 percent of the water is consumed (described further in Section 4).

Hydroelectric power, in which turbine generators are driven by falling water, is considered an “instream use” of water (USGS, 1998, p. 54). The water that is used to produce hydroelectric power is immediately available for use downstream. Consequently, it is neither withdrawn nor consumed. Similarly, recreational uses of lakes and rivers, for boating, fishing, swimming, and other activities, are not defined as water withdrawal or consumption. It has been pointed out that the creation of a reservoir causes a substantial increase in evaporation, which may be considered a consumptive use of water because the water is no longer available for use downstream (Torcellini, et al., 2003, p. 3). However, the USGS does not estimate this water consumption, and consequently it is not included in this section.

Throughout this paper, the term “water use” is used generally to refer to activities that involve water withdrawal and/or consumption. The terms “withdrawal” and “consumption” are used for their specific definitions presented above.

2.2 Overview of Water Use: Withdrawal and Consumption

Water in the United States comes from two main sources: surface water sources such as lakes, rivers, and oceans; and groundwater sources from which water is extracted using wells. Surface water sources provide almost 80 percent of the water used in the United States (USGS, 2004, p. 6). Both freshwater and saline water are withdrawn for use.[4] Lakes, rivers, and groundwater provide freshwater. Oceans are the primary source of saline water, although some saline water is also withdrawn from groundwater and lakes. Freshwater accounts for nearly 85 percent of total withdrawals (USGS, 2004, p. 6).

USGS estimates for the year 2000 that the United States withdrew about 408,000 million gallons per day (mgd) (USGS, 2004, p. 7).

Exhibit 2-1 shows the breakdown of water withdrawal for each of eight sectors. As shown in the exhibit, two sectors account for more than 80 percent of total withdrawals: thermoelectric power plant cooling and irrigation. Withdrawals for public water supplies are about 10 percent, and the remaining five uses combine for less than 10 percent of all withdrawals.

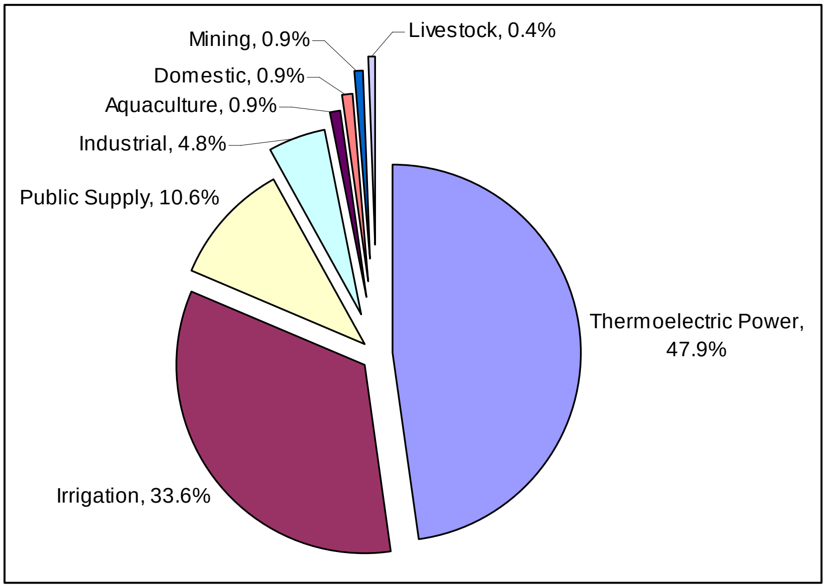
2.2.1 Thermoelectric Power

Almost half of all the water withdrawn in 2000 was for cooling water at thermoelectric power plants. As described in more detail in Section 4, the water is used to condense steam that is used to drive turbines for generating electricity. More than 195,000 mgd are withdrawn for this purpose, including 136,000 mgd of freshwater. The five states with the largest withdrawals for power plant cooling were Texas, California, Florida, Illinois and North Carolina (USGS, 2004, p. 36). However, California and Florida withdraw more than 95 percent of this water from saline sources. The top five states in terms of freshwater withdrawals for power plant cooling are Illinois, Texas, Tennessee, Ohio, and Alabama (USGS, 2004, p. 36) (see Exhibit 2-2).

On average, a small percentage of the water withdrawn for power plant cooling is consumed, on the order of about 1 to 2 percent (see Section 4). This still represents a significant volume of water (2000 – 4000 mgd). Therefore, local and regional impacts of power plant cooling water usage can be significant, in terms of both water consumption and impacts on local water resources.

[4] Saline water is defined as containing 1,000 milligrams per liter or more of dissolved solids (USGS, 2004, p. 2).

Exhibit 2-1: Water Withdrawal by Sector in 2000



Total Withdrawal: 408,000 million gallons per day.
Source: USGS, 2004, p. 7.

Exhibit 2-2: Top States for Water Withdrawal for Power Plant Cooling in 2000

State	Freshwater Withdrawal (mgd)	Saline Water Withdrawal (mgd)	Total Withdrawal (mgd)
Top Five States in terms of Total Withdrawal for Power Plant Cooling *(sorted by total withdrawal)*			
Texas	9,820	3,440	13,300
California	352	12,600	12,900
Florida	658	12,000	12,600
Illinois	11,300	0	11,300
North Carolina	7,850	1,620	9,470
Top Five States in terms of Freshwater Withdrawal for Power Plant Cooling *(sorted by freshwater withdrawal)*			
Illinois	11,300	0	11,300
Texas	9,820	3,440	13,300
Tennessee	9,040	0	9,040
Ohio	8,590	0	8,590
Alabama	8,190	0	8,190
National Total			
All States	136,000	59,500	195,000

Figures may not sum to totals due to independent rounding.
mgd = million gallons per day.
Source: USGS, 2004, p. 36.

2.2.2 Irrigation

Irrigation water use accounts for the second largest amount of withdrawal in 2000, roughly 137,000 mgd or about a third of all water withdrawal (USGS, 2004, p. 7). Uses considered to be irrigation include water that is supplied by irrigation systems in agriculture, as well as pre-irrigation, field preparation, crop cooling, harvesting, dust suppression, leaching salts from roots, and any water lost in irrigation water conveyance. All irrigation withdrawals are freshwater.

Almost 60 percent of irrigation water comes from surface sources, with the remainder from groundwater supplies. The majority of the withdrawals are concentrated in states with large amounts of irrigated land. California, Nebraska, Texas, Arkansas and Idaho alone account for about 53 percent of the irrigated acreage and irrigation water withdrawals (see Exhibit 2-3) (USGS, 2004, p. 21).

Exhibit 2-3: Top States for Irrigated Land in 2000

State	Irrigated Land (000 acres)	Irrigation Water Withdrawal (mgd)
Top Five States in terms of Irrigated Land		
California	10,100	30,500
Nebraska	7,820	8,790
Texas	6,490	8,630
Arkansas	4,510	7,910
Idaho	3,750	17,100
National Total		
All States	61,900	137,000

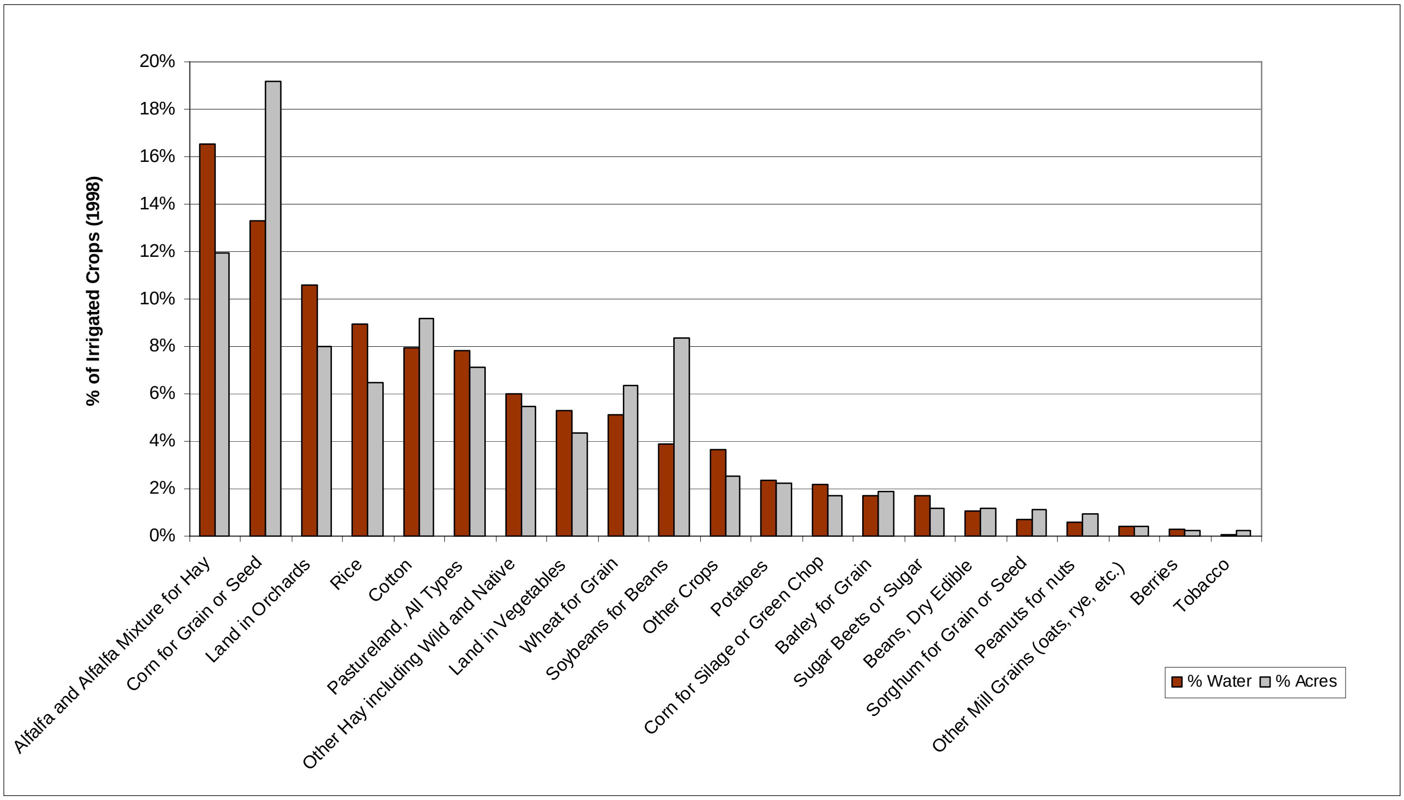
Source: USGS, 2004, p. 21.

Water used for irrigation is often not metered, and consequently the water withdrawal data rely on various types of estimates. For example, withdrawal may be estimated from crop acreage and application rates (USGS, 2004, p. 20). For the year 2000, USGS did not estimate the portion of irrigation water that is consumed, and the portion that is returned to a receiving body. Recognizing that uncertainly exists in the source data and estimates, USGS did make an estimate for 1995, indicating that about 61 percent of irrigation water is consumed, making it the largest consumptive use of water nationally by far (USGS, 1998, p. 32). An additional 19 percent of irrigation water was estimated to be lost to conveyance losses (evaporation and leakage). The return flow was estimated at 20 percent of withdrawal.

The National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture (USDA) periodically collects data on water used for irrigation, including the 1998 Farm and Ranch Irrigation Survey (FRIS) (NASS, 1999). FRIS data show that the top five irrigated crops in terms of water applied in 1998 were: alfalfa for hay; corn for grain or seed; orchards; rice; and cotton. These five crops accounted for about 57 percent of the irrigation water applied in 1998. Exhibit 2-4 shows the portion of applied irrigation water and portion of total irrigated land by crop in that year.

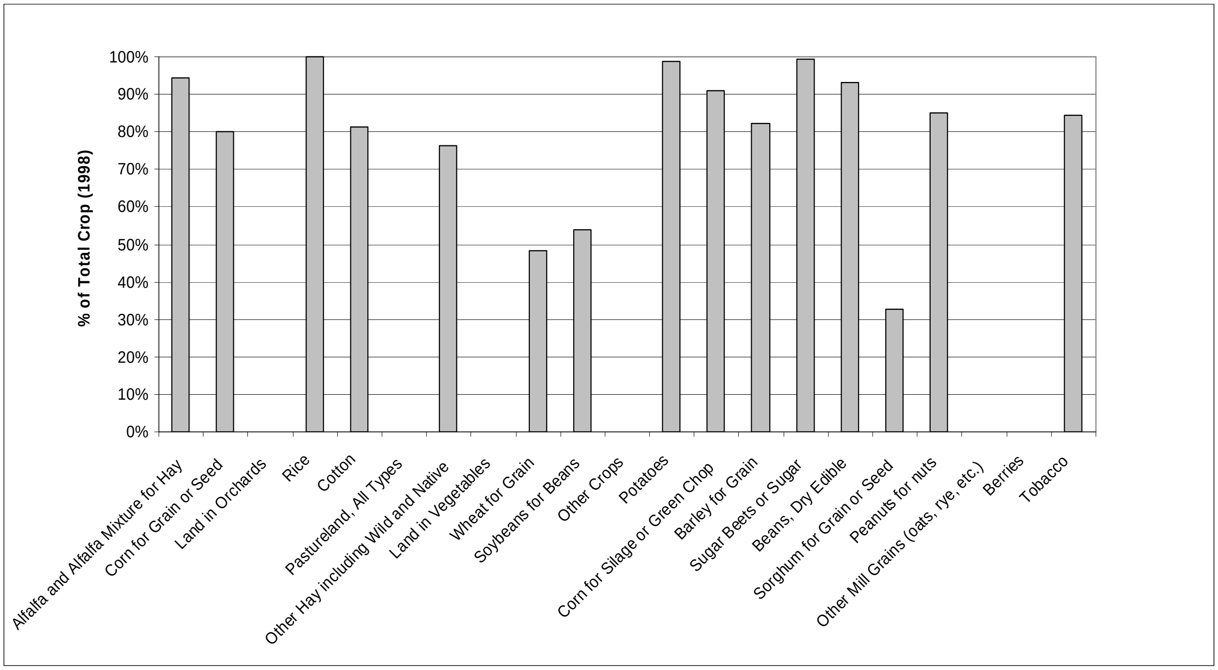
Of note is that for most crops, the overwhelming majority of annual production comes from irrigated lands. Exhibit 2-5 shows the portion of each crop that is produced from irrigated land (versus non-irrigated land). For example, 80 percent of corn is produced from irrigated land. The value of the crops produced is significant. The top five irrigated crops in 1998 had a value of about $48.3 billion.

Exhibit 2-4: Irrigation Water Applied and Irrigated Land by Crop in 1998



Total irrigation water applied for these crops calculated as 77,600 mgd.
Total acres of harvested irrigated land for these crops calculated as 50.1 million acres.
Source: Analysis of data in NASS (1999).

Exhibit 2-5: Portion of Production from Irrigated Land: By Crop for 1998



Units of production vary by crop. No bar is shown for crops for which comparable production data for irrigated and non-irrigated production are not available.
Source: Analysis of data in NASS (1999).

2.2.3 Public Supply

Public supply is the third largest purpose for which water is withdrawn. Described in more detail in Section 3, public supply refers to "systems for the provision to the public of water for human consumption through pipes or, after August 5, 1998, other constructed conveyances, if such system has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least 60 days out of the year" (40 CFR Part 141, 2004, Section 141.2). USGS estimates for 2000 that public supply accounted for withdrawals of 43,300 mgd, or roughly 11 percent of the total (USGS, 2004, p. 13).

Water provided through public supply can be used for any number of purposes, including residential, commercial, or industrial uses. Some public supply may be used for thermoelectric power purposes, although this use is not a significant use of water in this sector. Roughly 242 million people are served by water from public suppliers, and as expected, states with the largest populations drew the greatest amounts of water. Residential water use accounts for about two-thirds of public water supply.

A portion of the water delivered by public water supply systems is consumed, for example through evaporation or consumption by people. The portion that is not consumed is typically discharged to a sewer system. Prior to release to a receiving body of water, the water is treated at a sewage treatment plant as described in Section 3. USGS estimated that about 80 percent of public supply water is returned to receiving bodies of water, with about 20 percent consumed (USGS, 1998, p. 19).

The return flow from wastewater treatment plants in coastal cities is often discharged into the ocean. Although the treated freshwater is returned to a receiving body of water (the ocean in this case), it is not available as a freshwater resource. Consequently, from the perspective of available freshwater supply, the water in the return flow may be considered to be "consumed" because it is no longer available for other freshwater uses.

2.2.4 Remaining Uses

The remaining uses of water account for about 10 percent of total withdrawals.

- Industrial: Nearly five percent of water is withdrawn by industry for use in manufacturing facilities. The water is used for fabrication, processing, washing, diluting, cooling, transporting the product, putting water into the product, or for sanitation needs within a manufacturing facility. Recognizing that public supplies may provide water to industrial customers, the water withdrawal included by the USGS in this sector is the amount that is self-supplied by the companies themselves (USGS, 2004, p. 29). USGS estimated that about 15 percent of this water is consumed, with about 85 percent returned to a receiving body of water (USGS, 1998, p. 19).
- Aquaculture: Less than one percent of water withdrawal is for aquaculture. Typically, finfish or shellfish are produced in water using water for controlled feeding, sanitation, and harvesting procedures. Surface water accounted for about 70 percent of the total of 3,700 mgd of withdrawals in 2000. Idaho uses more than half of the total water in aquaculture in the United States, due to their large fish-hatcheries for commercial sale (USGS, 2004, p. 26).
- Domestic Water Usage: Domestic water usage refers to residential water usage that is supplied primarily by residential wells. This sector is comprised of people who have their own water wells on their properties. Withdrawal for domestic use is less than one percent of total withdrawal, and is about four percent of freshwater groundwater withdrawals.
- Mining: Water is used in mining for the extraction of minerals, accounting for less than one percent of total withdrawals. Coal, iron, sand, gravel, crude oil and natural gas require water in their mining operations for quarrying, milling, adding water and other operations and activities. The total of 3,490 mgd is estimated for the 22 states which require reporting of water uses in mining (USGS, 2004, p. 32). Dewatering to enable mining is not considered a water withdrawal unless the water is put to beneficial use.
- Livestock: Accounting for less than one percent of the total water usage, livestock water consists of the watering of livestock, feedlots, and water associated with the daily operations and other on-farm activities. Other livestock water uses include the cooling of facilities for the animals and products, dairy sanitation, cleaning of facilities, waste disposal and any water loss (USGS, 2004, p. 23). California, Texas and Oklahoma account for almost 50 percent of the total livestock water usage, estimated to be about 1,760 mgd. However, few states require livestock water reporting, so the estimates are created based on animal counts and averages of gallons of water per animal type per day (USGS, 2004, p. 23).

2.2.5 Per Capita Withdrawals by State

Exhibit 2-6 shows the average per capita water withdrawal by state for 1995 for power plant cooling, irrigation, and other uses. The total per capita is shown, along with per capita withdrawal for each category (note changes in scale). As shown in the exhibit, the four states with the highest per capita total withdrawal rates are Wyoming, Idaho, Montana, and Nebraska. These four states withdraw large amounts of water for irrigation and have relatively modest populations. Idaho also has large withdrawal per capita for other uses, as the result of the large amounts of water used for aquaculture. Power plant cooling and irrigation dominate the withdrawals for nearly all states.

2.2.6 Freshwater Consumption

Although USGS did not estimate water consumption for 2000, the data for 1995 include estimates of freshwater consumption. In 1995, freshwater withdrawals were estimated at 341,000 mgd, slightly below the 345,000 mgd estimated for 2000 (USGS, 1998, p. 9 and USGS, 2004, p. 7). Of the total freshwater withdrawal in 1995, 100,000 mgd, or about 29 percent was estimated to have been consumed (USGS, 1998, p. 19). Exhibit 2-7 shows a summary of the water consumption by use. As shown in the exhibit, irrigation and livestock represent the largest component of freshwater consumption (the irrigation and livestock categories were combined in the 1995 USGS data).

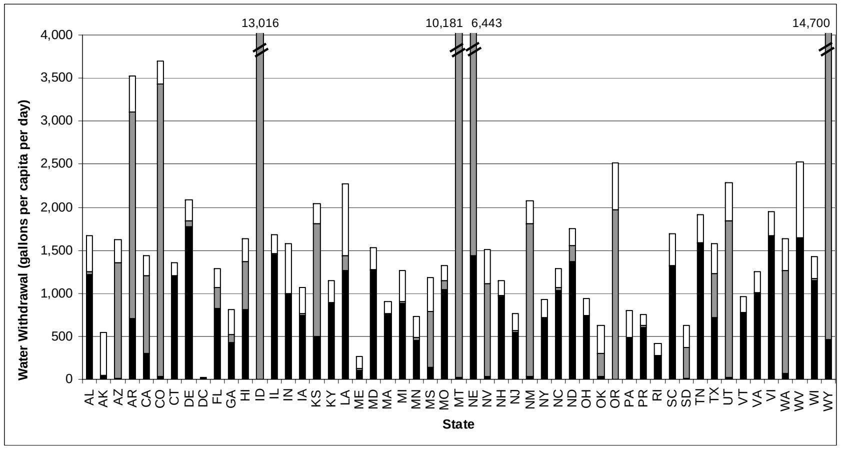
2.3 Trends in Water Use

The USGS data provide an overview of trends in water withdrawals over time. As shown in Exhibit 2-8, total withdrawals increased from 1950 through 1980, and then declined and stabilized. Withdrawals for both power plant cooling and irrigation follow this pattern. The pattern of per capita withdrawals shows declines since 1980.

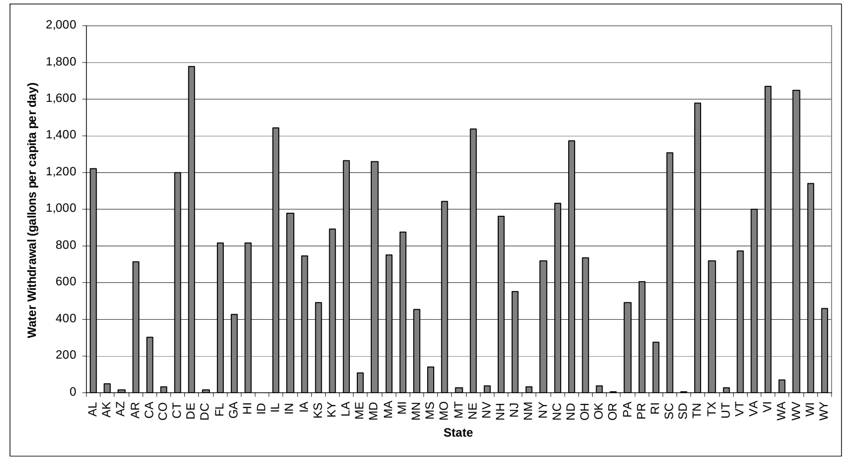
The stabilization of water withdrawals for power plant cooling reflects a shift in cooling system technology from once-through cooling to recirculating cooling systems that use cooling towers (see Section 4). With the continued expansion of electric power production, the withdrawal and consumption of water for power plant cooling may start to increase again. EPRI analyzed future freshwater requirements for power plant cooling and found that under “business as usual” conditions, freshwater consumption could increase by nearly 20 percent from 2000 levels by 2020 (EPRI, 2002, p. 6-4). This increase in water consumption would be a change from the recent past in which water consumption for power plant cooling was relatively flat.

Exhibit 2-6: Per Capita Water Withdrawal by State in 1995: Power Plant Cooling, Irrigation, and Other

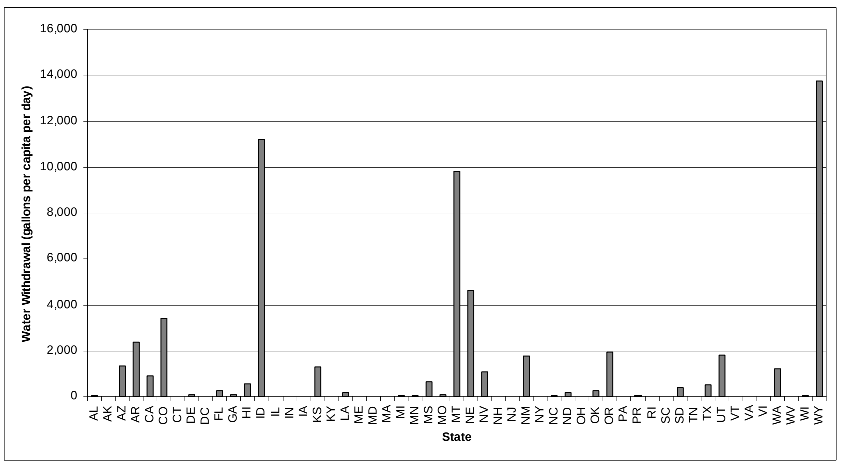
■ = Power Plant Cooling ■ = Irrigation □ = Other Uses



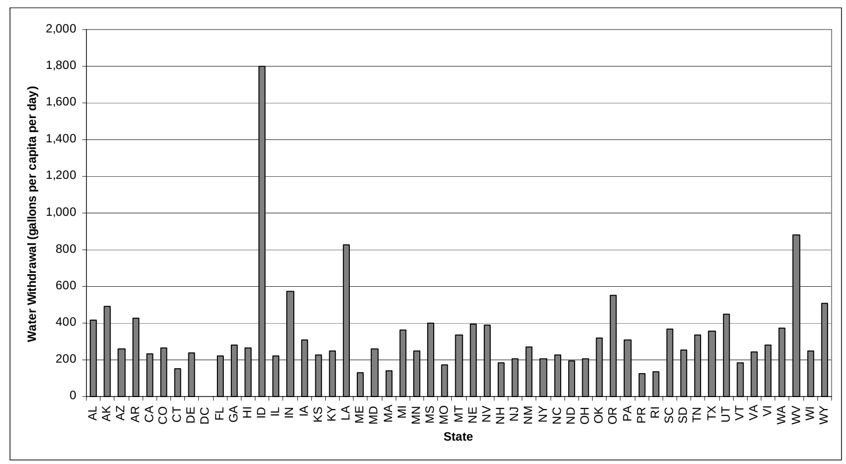
Power Plant Cooling



Irrigation

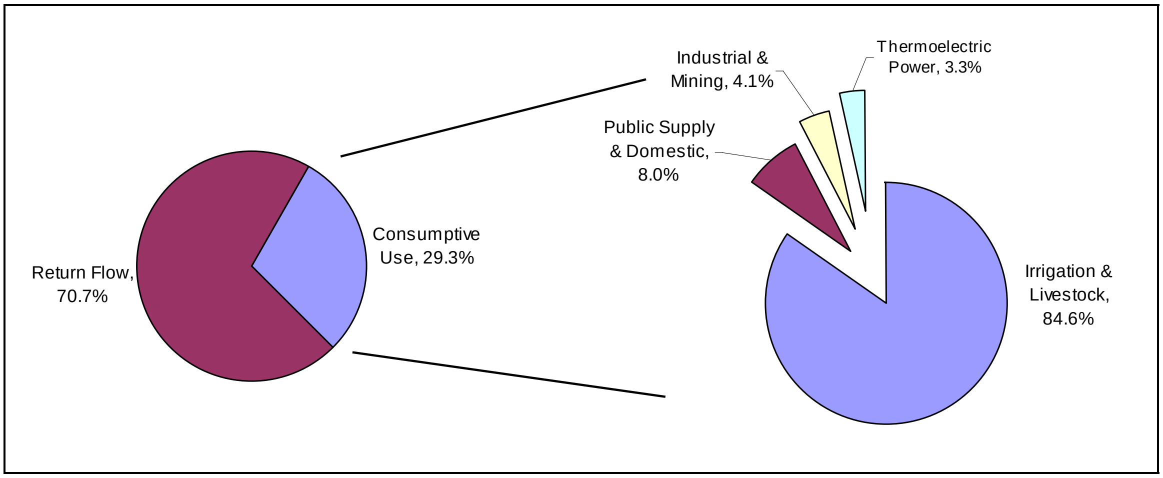


Other Uses



Source: Analysis of data in USGS, 1998.

Exhibit 2-7: Consumptive Use of Freshwater by Sector (1995)



Total freshwater withdrawal in 1995 was 340,000 mgd. Total domestic consumptive use was 100,000 mgd.
Source: USGS, 1998, p. 19.

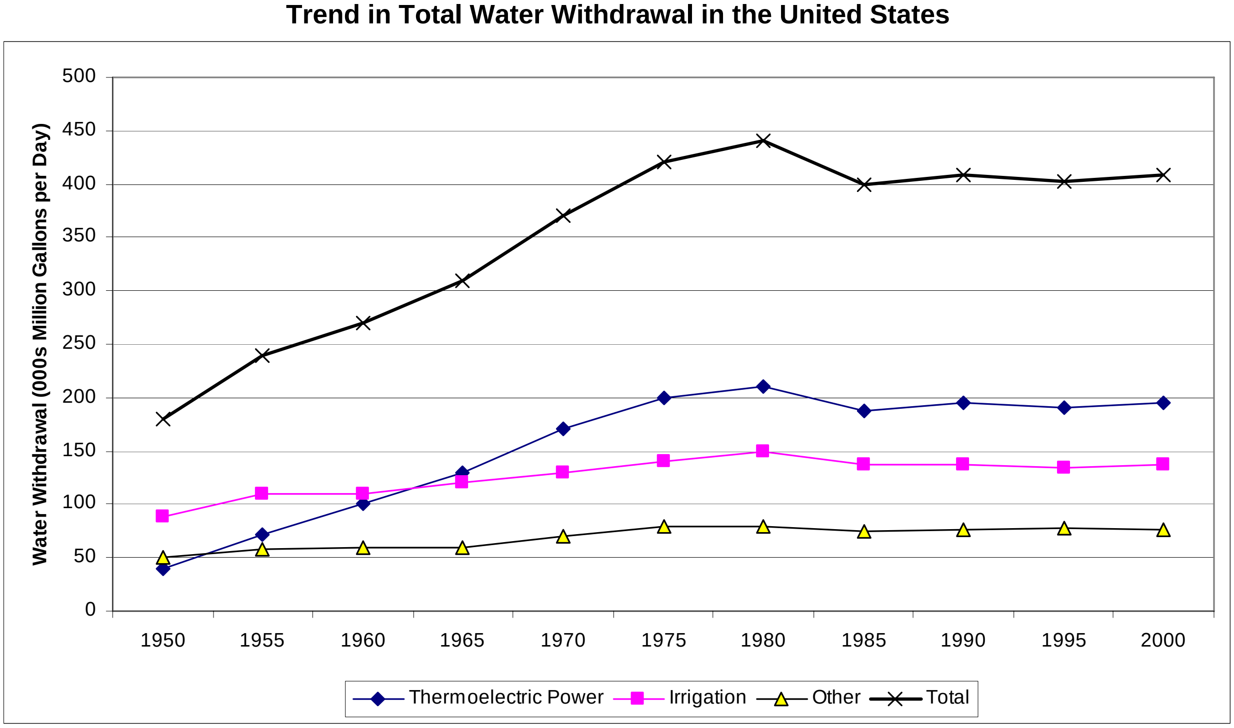
The potential change in freshwater consumption for power plant cooling varies across regions. For example, in the California/Southern Nevada region, the EPRI analysis estimates a large percentage increase in freshwater consumption. The percentage increase is large because in 2000 the water withdrawal for power plant cooling in the California/Southern Nevada region was almost entirely saline (ocean) water (saline water accounted for more than 97 percent of water withdrawal for power plant cooling in California and Nevada, USGS, 2004, p. 36). EPRI estimates that future electricity production in this region will rely more on freshwater supplies, so that freshwater consumption could nearly double from its current (modest) level by 2020. The New England region could also experience a doubling in freshwater withdrawals by 2020, again starting from a modest level in 2000.

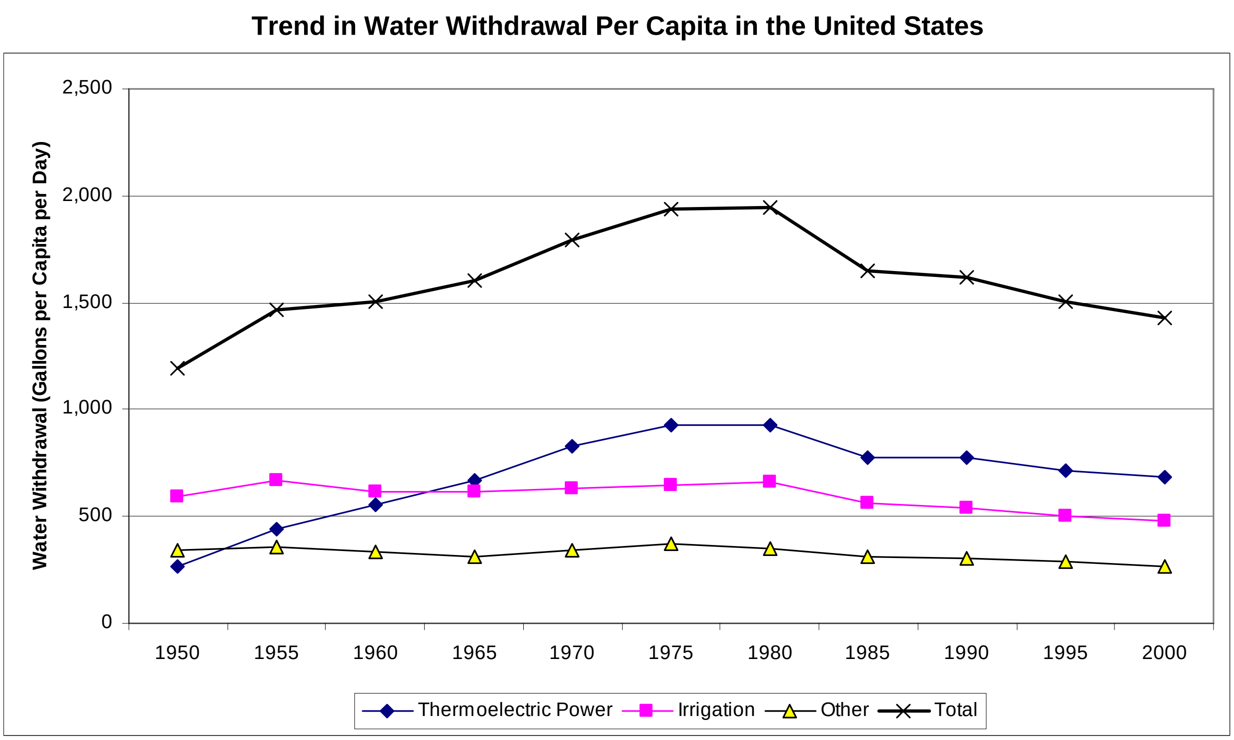
In contrast, the New York and Texas regions could experience small declines in freshwater requirements for power production. In these regions in 2000, freshwater accounted for 45 percent (New York) and 74 percent (Texas) of withdrawals for power plant cooling. Potential shifts in the mix of power generation technologies toward combined cycle units are estimated to be sufficient to reduce freshwater consumption for cooling in these areas.

EPRI's national and regional estimates are both sensitive to assumptions regarding potential changes in the mix of power generation technologies employed in the next 20 years. A massive shift away from coal-fired steam plants to gas-fired combined cycle units could reduce total water consumption for cooling, so that most regions experience a decline in water requirements for power plant cooling (EPRI, 2002, p. 6-5). However, this scenario envisions an 85 percent decline in coal-fired power production and a 14-fold increase in gas-fired combined cycle electricity production (EPRI, 2002, p. 4-2), which would be considered unlikely under current energy and environmental policies.

The trend in water withdrawals for irrigation was driven by the expansion of irrigated acres, particularly through 1980. Much of this increase was experienced in the western states (USGS, 2004, p. 40). While the amount of land under irrigation increased, the rate of water application to irrigated land was declining. After 1980, the reduction in the application rate outweighed the modest increase in land under irrigation, causing the withdrawal rate to decline and then stabilize (Dziegielewski, et al., 2002, pp. ES-4 to ES-6). Marlow (1999) estimated that the

Exhibit 2-8: Trend in Water Withdrawal





Source: USGS, 2004.

reduction in the rate of irrigation water application was due to two primary causes: (1) about 33 to 50 percent of the reduction is associated with a shift in irrigated acreage after 1980 to cooler northern states or humid eastern states in which irrigation requirements are lower; and (2) about 50 to 67 percent of the reduction is due to efficiency gains from improved irrigation technologies and water management practices (Marlow, 1999, p. 7).

With significant competition for water in the west, increases in water use for irrigation are probably not likely. Rather, irrigation use may continue to become more efficient so that additional water is made available for urban requirements. An example of a farmland-to-urban water use shift is the recent program adopted by the Metropolitan Water District (MWD) in California. Farmers in the Palo Verde Irrigation District of Riverside and Imperial counties have agreed to rotate a portion of their cropland in and out of production in order to transfer unused irrigation water to urban Southern California (Business Wire, 2004). The deal will provide about 22 mgd to 100 mgd annually.

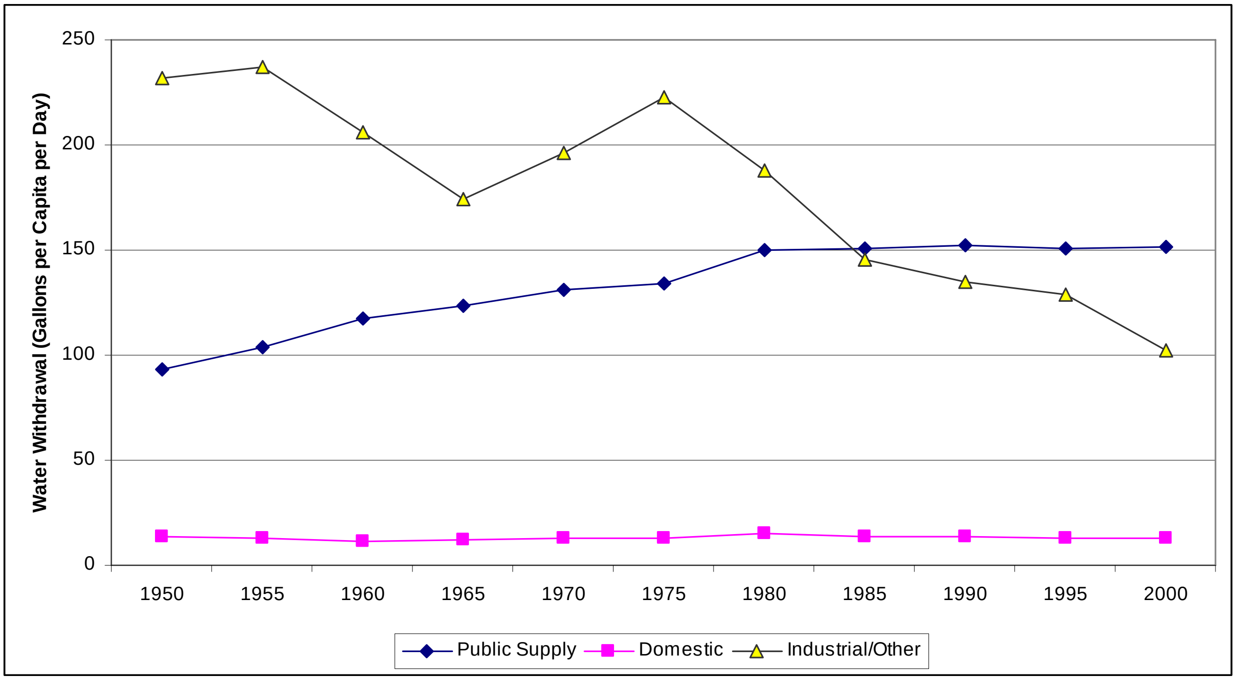
With the U.S. population expected to increase by nearly 20 percent from 2000 to 2020 and nearly 50 percent from 2000 to 2050 (U.S. Census Bureau, 2007b), water withdrawal and consumption for public supply may increase. Three states, California, Texas and Florida, are expected to account for nearly 50 percent of the increase in population through 2025 (U.S. Census Bureau, 2007a). Exhibit 2-9 shows the trend in per capita water withdrawals for purposes other than power plant cooling and irrigation. The trend is shown for three categories: public supply; domestic; and industrial/other. As shown in the exhibit, the trend in water withdrawal per capita for public supply shows an increase through 1980, followed by relatively flat withdrawal per capita for the past 20 years. Water in this category is used primarily for residential and commercial uses. Because population has grown while use per person has remained flat, total withdrawals for public supply increased 27 percent from 1980, reaching 43,300 mgd in 2000 (USGS, 2004, p. 40). If use per capita remains unchanged, population growth will continue to lead to increases in withdrawals for public supply.

As discussed in Sections 5 and 6, substantial opportunities exist for improved efficiency in water use in both residential and commercial applications. For example, the Pacific Institute examined opportunities for conservation and improved efficiency in urban water usage in California (Gleick, et al., 2003). For residential uses, using conservative estimation methods, the conservation potential was found to be nearly 40 percent of current indoor usage, or about 800 mgd in California alone (Gleick, et al., 2003, p. 2). Smart water management policies are proposed to realize the potential savings in California (Gleick, et al., 2003, pp. 6, 13).

In contrast to withdrawals for public supply, withdrawals for industrial use and other miscellaneous uses have declined substantially on a per capita basis over the past 50 years. Dziegielewski, et al. suggests that this decline is driven in part by improvements in efficiency, but more substantially by a shift in industrial activity. In particular, they point to significant reductions in employment in the primary metals industry as an indication of reduced activity in this water intensive industry (SIC 33) (Dziegielewski, et al., 2002, pp. 3-6 to 3-8). USGS (1998, p. 62) makes a similar argument, and also highlights the growth in water recycling among industrial users as a factor reducing the intensity of water use in this sector.

Based on these factors, the outlook for future rates of water withdrawal and use in the U.S. is mixed. Although water use for power plant cooling has been stable in recent years as the result of shifts in cooling technology, it may increase as the power sector continues to grow. Whether water use in the power sector increases depends, in part, on the mix of power generation technologies that is built in the next 20 years. Irrigation is likely to remain stable or decline as improvements in efficiency continue. Increasing population has the potential to put pressure on public water supplies. Although public supply accounts for only about 10 percent of total water withdrawals, the ability of public water systems to meet the needs of the growing population will continue to receive considerable attention as water supply is necessary for life and economic growth. Improved efficiency of residential and commercial water use is expected to help offset the impacts of this increased demand.

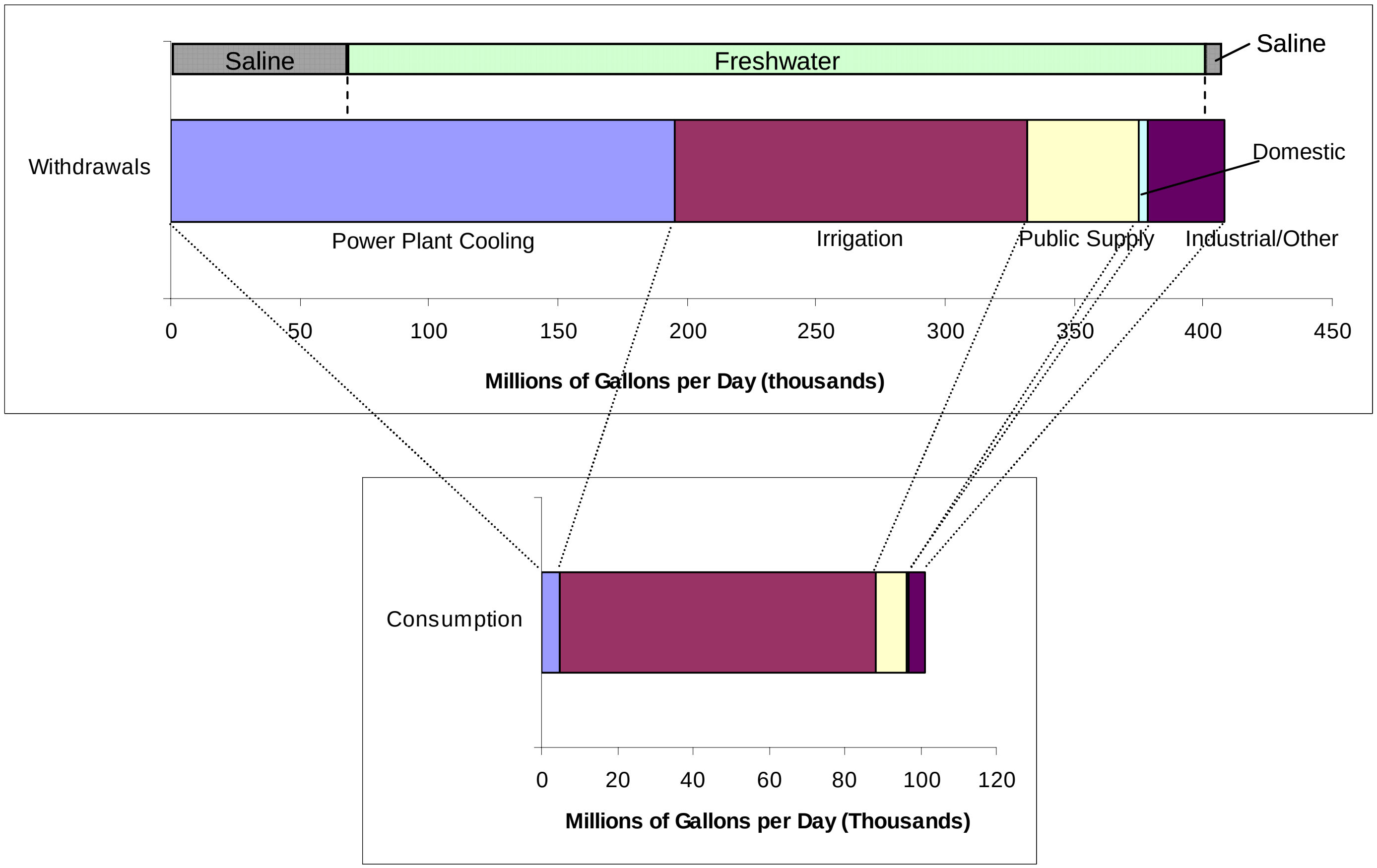
Exhibit 2-9: Trend in Water Withdrawal per Capita for Public Supply, Domestic, and Industrial/Other



Source: USGS, 2004.

Exhibit 2-10 summarizes recent rates of water use and expected future trends. The top bar shows water withdrawals divided by major category: power plant cooling, irrigation, public supply, domestic, and industrial/other. Saline water is used for a portion of power plant cooling and industrial uses. The bottom bar shows water consumption (note the change in scale). Irrigation uses account for the overwhelming majority of annual consumption.

Exhibit 2-10: Summary of Water Withdrawal and Consumption in 2000



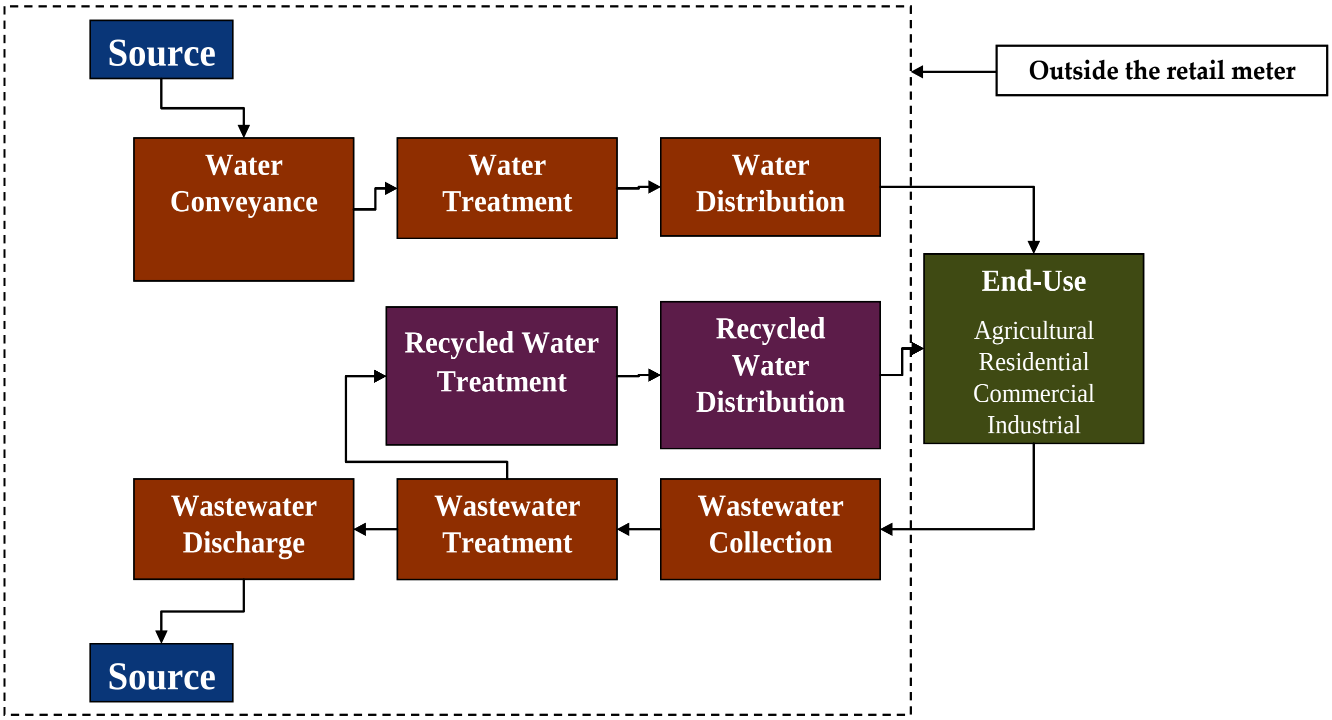
Category	Trend in Water Use
Power Plant Cooling	Expected to increase with growth in the power sector. Trend sensitive to the mix of generation technologies built.
Irrigation	Expected to remain stable, and possibly decline with improved efficiency of use.
Public Supply and Domestic	Expected to increase with increases in population. Reductions in per capita use required to stabilize future use.
Industrial/Other	Trend sensitive to changes in industrial activity. Recycling has reduced use.

Source: USGS (1998) and USGS (2004).

3. Water Supply and Wastewater Treatment Systems

Water supply systems provide potable water throughout the United States, serving residential, commercial, institutional, and industrial customers. In most communities, municipal wastewater collection and treatment services are also provided, in which sewer systems are used to collect wastewater that is treated at wastewater treatment plants prior to discharge. These two industries, water supply systems and wastewater treatment systems, are significant components of our water system infrastructure. Exhibit 3-1 provides an overview of a common water use cycle.

Exhibit 3-1: Water Use Cycle



Source: CEC, 2005, p. 7.

Water supply and wastewater treatment are also significant users of energy. In many communities, the energy requirements for water supply and treatment are the largest energy expenditures for the municipality. Information on opportunities for improving energy efficiency at water supply and treatment facilities has been developed and disseminated in various programs. Nevertheless, there appear to be significant opportunities for continued improvement at many facilities. This section first examines water supply systems, and then wastewater treatment systems. Within each subsection, background information is provided on each industry, followed by an assessment of energy use and potential energy savings. The potential for water savings is also examined.

3.1 Water Supply Systems

This section discusses water supply systems. First the industry is described, followed by a summary of the processes used in supplying water. Then, the energy intensity of water supply systems is estimated, along with a review of opportunities to improve energy efficiency. This section concludes with a discussion of water delivery efficiency, “unaccounted for water,” and water savings opportunities.

3.1.1 Water System Industry

The U.S. EPA maintains an official database of all public drinking water systems using information collected and submitted by the states: Safe Drinking Water Information System/Federal (SDWIS/Fed) (USEPA, 2001a). Based on the most current SDWIS/Fed data, there are approximately 161,000 public drinking water systems in the United States, which are defined as: “systems for the provision to the public of water for human consumption through pipes or, after August 5, 1998, other constructed conveyances, if such a system has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least 60 days out of the year” (40 CFR Part 141, 2004, Section 141.2).

Public water systems are often divided into three types for purposes of describing their characteristics (40 CFR Part 141, 2004, Section 141.2):

- Community Water System: A public water system that serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.
- Non-Transient Non-Community Water System: A public water system that is not a community water system and that regularly serves at least 25 of the same persons over six months per year. Some examples are schools, factories, office buildings, and hospitals which have their own water systems.
- Transient Non-Community Water System: A public water system that is not a community water system and that does not regularly serve at least 25 of the same persons over six months per year. Examples are a gas station or campground where people do not remain for long periods of time.

Exhibit 3-2 shows the approximately 161,000 systems by type, size, and number of people served. As shown in the exhibit, community water systems serve a population of more than 273 million.[5] The approximately 3,900 large and very large community water systems (those serving more than 10,000 people) serve a total of about 221 million. Most people in the U.S. receive their water from these large community systems.

Exhibit 3-3 shows the number of systems and people served by water source. As shown in the exhibit, most people served by community water systems get their water from surface water sources (68 percent). However, about 75 percent of the 53,000 community water systems have groundwater as their sole or principal source.

To support the Agency’s regulatory development and implementation efforts, EPA periodically conducts a survey of community water systems (USEPA, 2002a). The most recent survey, conducted in 2000, received responses from 1,246 system operators covering the full range of sizes in terms of populations served (USEPA, 2002a, p. 3). The data collected in the survey apply only to community water systems, and do not include the non-community systems (transient and non-transient). The survey results include the following:

- The overwhelming majority of large community water systems are publicly owned (USEPA, 2002a, Table 3). About 85 percent of the systems serving more than 10,000

[5] The total populations served listed in Exhibit 3-2 and Exhibit 3-3 sum to more than the total national population. This occurs for two reasons. Some people are served part of the year by transient systems (such as camp grounds) as well as by the community water system at their place of residence. These people are consequently counted twice. Also, the population served includes those served directly (i.e., retail water customers) as well as those served through the sale of water to other public water suppliers (i.e., wholesale customers) (USEPA, 2002a, p. 3). The inclusion of wholesale customers also contributes to double counting.

people are publicly owned, and about 91 percent of systems serving more than 100,000 people are publicly owned. Overall, however, the number of systems is split evenly between public and private ownership: 51 percent are privately owned and 49 percent are publicly owned (USEPA, 2002a, p. 8).

- Of the 51 percent of the systems that are privately owned, 27 percent are for-profit and 34 percent are not-for-profit (USEPA, 2002a, p. 8). The remaining 39 percent of the private systems are ancillary, meaning the water supply is not the primary purpose of the business, such as a mobile home park which has its own water system. These systems tend to serve small populations and often do not bill customers for water (USEPA, 2002a, p. 8-9).
- More than 90 percent of the total water produced is controlled by publicly owned systems (USEPA, 2002a, p. 10).
- In 2000, residential customers accounted for two-thirds of retail water deliveries, while commercial, industrial, agricultural, and other non-residential customers account for the balance. The average residential connection (which is typically a residential household) received about 325 gallons per day, while the average non-residential customer received nearly 1,700 gallons per day (USEPA, 2002a, p. 10).
- Fifty percent of the water produced comes from surface sources, 30 percent comes from the ground and 20 percent of the water is purchased from other entities following treatment (USEPA, 2002a, p. 8).

Exhibit 3-2: Water Systems by Number of People Served

Water System Type		System Size by Population Served					Total
		Very Small 500 or less	Small 501-3,300	Medium 3,301-10,000	Large 10,001-100,000	Very Large >100,000	
Community Water Systems	# systems	30,417	14,394	4,686	3,505	361	53,363
	Pop. Served	5,010,834	20,261,508	27,201,137	98,706,485	122,149,436	273,329,400
	% of systems	57%	27%	9%	7%	1%	100%
	% of pop	2%	7%	10%	36%	44%	100%
Non-Transient Non-Community Water Systems	# systems	16,785	2,786	97	16	2	19,686
	Pop. Served	2,327,575	2,772,334	506,124	412,463	279,846	6,298,342
	% of systems	85%	14%	0%	0%	0%	100%
	% of pop	37%	44%	8%	7%	4%	100%
Transient Non-Community Water Systems	# systems	85,366	2,657	96	29	4	88,152
	Pop. Served	7,315,647	2,602,706	528,624	619,248	12,269,000	23,335,225
	% of systems	97%	3%	0%	0%	0%	100%
	% of pop	31%	11%	2%	3%	53%	100%
Total Number of Systems		**132,568**	**19,837**	**4,879**	**3,550**	**367**	**161,201**

See text for definitions of the water system types.

Source: USEPA (2004b).

Exhibit 3-3: Water Systems by Water Source

Water System Type		System by Water Source		Total
		Groundwater	Surface Water	
Community Water Systems	# systems	41,499	11,864	53,363
	Pop. served	86,348,074	186,981,326	273,329,400
	% of systems	78%	22%	100%
	% of pop	32%	68%	100%
Non-Transient Non-Community Water Systems	# systems	18,908	778	19,686
	Pop. served	5,568,192	730,150	6,298,342
	% of systems	96%	4%	100%
	% of pop	87%	12%	100%
Transient Non-Community Water Systems	# systems	86,061	2,091	88,152
	Pop. served	10,527,089	12,808,136	23,335,225
	% of systems	98%	2%	100%
	% of pop	45%	55%	100%
Total Number of Systems		**146,468**	**14,733**	**161,201**

Groundwater systems = groundwater and purchased groundwater.
Surface water systems = surface water, purchased surface water, groundwater under the direct influence of surface water, and purchased groundwater under the direct influence of surface water.
Source: USEPA (2004b).

The majority of the revenue earned by community water systems comes from water sales, which in 2000 accounted for $33 billion, or 85 percent of total water system revenues of $39 billion (USEPA, 2002a, pp. 15-16). Water is typically sold on the basis of the amount of water used. Other sources of revenue, which are typically not based on consumption, include: development fees, connection fees, fines and other payments. Residential customers provided the majority of water sales revenue across systems of all sizes (USEPA, 2002a, p. 16). Exhibit 3-4 presents the distribution of revenue sources, along with the distribution of water sales revenue by customer type.

As of 2000, the annual revenue for all water systems exceeded their annual expenses of $32.2 billion. Nevertheless, in 2000 about 30 to 40 percent of water systems reported operating deficits (USEPA, 2002a, p. iv), with smaller systems tending to be more likely to be operating with deficits or losses (USEPA, 2002a, p. 37).

Expenses incurred by water systems are divided into three types:

- operations and maintenance (O&M) accounts for 70 percent of expenditures;
- interest and repayment of debt equals 20 percent; and
- non-routine expenses, including capital investments make up 10 percent.

For O&M, an average of 38 percent of the budget is for employee costs, with the remaining required for other operational requirements. However, as systems become larger, O&M accounts for a smaller portion of the budget (USEPA, 2002a, p. 17-18).

Capital spending by community water systems is currently averaging about $10 billion annually. Almost half of this sum is spent on the replacement and upkeep of distribution and transmission lines or pipes. Projects involving treatment accounted for about 20 percent of this spending.

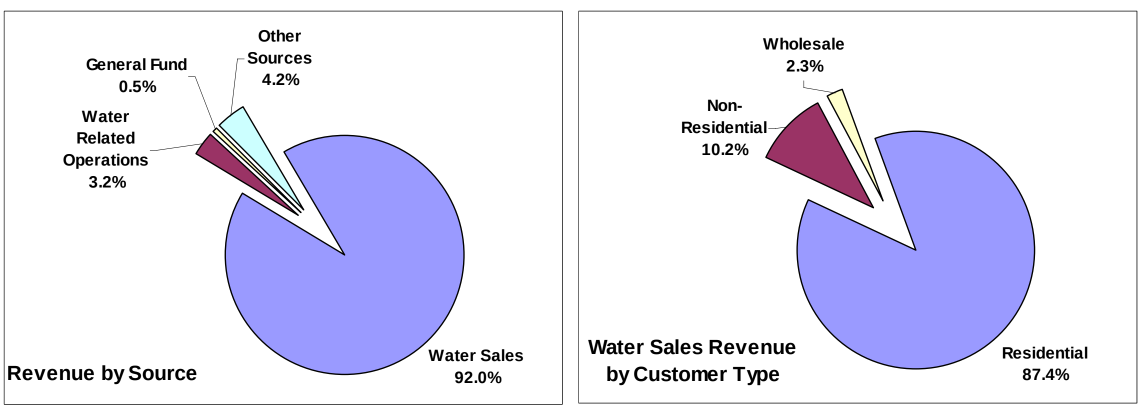
Exhibit 3-5 details the areas where capital spending is focused for both public and privately owned community water systems (USEPA, 2002a, p. 19).

Several studies have examined whether a quantifiable gap exists between projected drinking water investment needs and available resources. EPA estimated needs expected over the twenty year period of 2000 to 2019 and found that a significant funding gap could develop if the current level of spending does not increase at a real rate of growth of 3 percent each year (above the rate of inflation) (USEPA, 2002a, p. ES-1). This real increase in expenditures is estimated to be needed for several reasons:

- Systems are aging: Pipes often have life cycles that last upwards of 50 to 100 years, but aging pipes require increasing amounts of maintenance and (eventually) replacement.
- Population shifts and increases: Water systems will need to increase capacity to handle increases in the U.S. population (expected to be 325 million by 2020), as well as continued migration to certain areas of the country, such as the southwest. Recent trends show a stable level of per capita use of public water supply, indicating that population growth will lead to increased water use (USGS, 2004, p. 40).
- Current treatment may not be sufficient: New treatment requirements have been proposed that will require additional investment. Deterioration of intake water quality may also contribute to increased treatment needs.

Based on the 1999 Drinking Water Infrastructure Needs Survey, the capital investment needed was estimated at $150.9 billion over 20 years, including $78.7 billion for transmission and distribution pipelines and related infrastructure, $63 billion for treatment systems, storage systems, and water supplies, and $9.3 billion to comply with future regulations (USEPA, 2002c, p. 30). This assessment was adjusted upward to $209.3 billion to account for under-reporting of needs by survey respondents (USEPA, 2002c, p. 30).[6] Converting the estimates from 1999 dollars to 2001 dollars yields $218 billion.

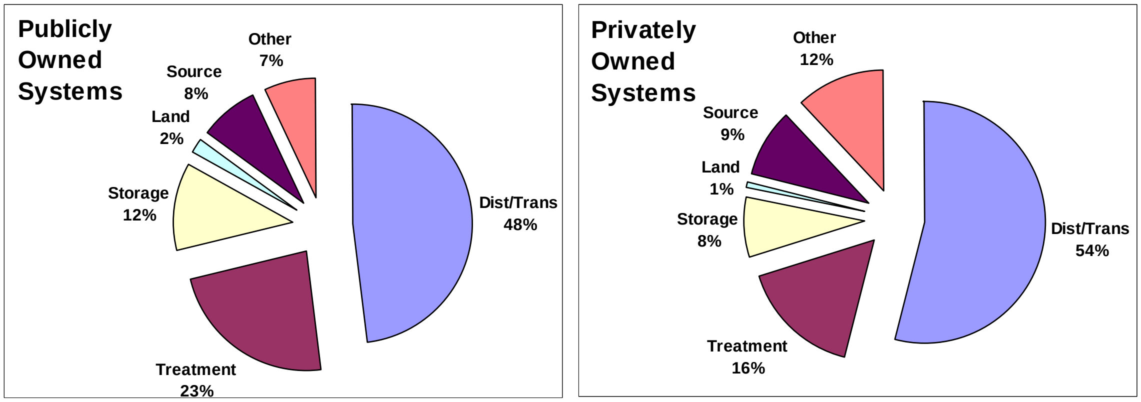
Exhibit 3-4: Revenue by Source and Water Sales Revenue by Customer Type



Source: USEPA (2002b), Table 51 and Table 52.

[6] Adjusted figures are: $115.6 billion for transmission and distribution pipelines and related infrastructure, $84.4 billion for treatment systems, storage systems, and water supplies, and $9.3 billion to comply with future regulations (1999 dollars) (USEPA, 2002c, p. 31).

Exhibit 3-5: Type of Capital Expense by Ownership



Source: USEPA (2002b), p. 19.

AWWA's May 2001 study of investment needs also estimated significant resource requirements, totaling $250 billion over the next 30 years for pipe replacement and system expansion (AWWA, 2001). The Congressional Budget Office (CBO, 2002) conducted an independent estimate of investment needs and compared the figures to previously published values. Because the CBO analysis examined expected costs as financed, as opposed to total capital costs, the figures are not comparable to those presented here. However, the study concludes that investment requirements in the period of 2000 to 2019 may average $11.6 billion to $20.1 billion per year (CBO, 2002, p. ix). It further states that the higher figure represents an increase of nearly $10 billion in annual expenditure above the 1999 level.

Based on these assessments, water supply systems are expected to continue to be under financial pressure to increase capacity, comply with water quality requirements, and keep rates as low as possible.

3.1.2 Typical Water Supply Processes

The vast majority of water is supplied to cities and communities from surface water (rivers and lakes), groundwater wells, and desalination of salt water or the recycling of wastewater (Burton, 1996, p. 3-2). In California, the use of recycled water is rapidly gaining support as a water supply. The adjacent textbox provides an overview of recycled water use in California. Surface water supplies require treatment and disinfection prior to distribution due to the impurities acquired from surface runoff. This runoff can create mineral deposits, muddy silt and debris in streams and plant and algae growth. Disinfection is also required because surface water is the primary disposal point for wastewater (Burton, 1996, p. 3-2).

Recycled Water Use in California

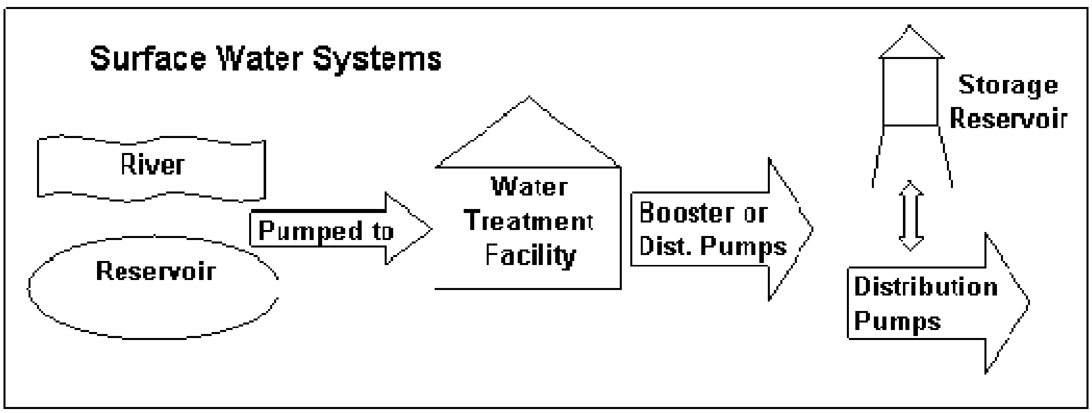
In California the fastest growing new source of water in the state is not a new source, rather it is the use of recycled water from wastewater systems. Faced with increasingly stringent requirements governing the disposal of wastewater and limited water supplies, many agencies are now installing additional treatment facilities that can purify wastewater to the point where it can be substituted for freshwater in many applications, including power plant cooling and landscape irrigation. The primary benefit of increasing the use of recycled water, from an energy perspective, is the displacement of other, more energy-intensive water supplies. Since recycled water is often a by-product of existing secondary and tertiary wastewater treatment processes, it is the least energy-intensive source in the state's water supply (Source: CEC, 2005, p. 28).

Groundwater is created when rain water or other sources percolate into the soil. While passing through the ground, water comes into contact with a number of substances which are readily soluble, resulting in higher levels of 'hardness' and increased mineral concentration in the water. Most groundwater is only treated with disinfection. However, groundwater contamination from industrial, agricultural or other sources can lead to the need for extensive treatment of groundwater prior to consumption (Burton, 1996, p. 3-3).

Exhibit 3-6 and Exhibit 3-7 show the process of obtaining and distributing surface water and groundwater, respectively. As shown, the primary task is transporting the water from one place to another. The typical process for surface water treatment includes (see Exhibit 3-8):

- raw water is screened to remove debris and contaminants;
- water is often pre-oxidized using chlorine or potassium permanganate to kill pathogenic organisms and eliminate taste and odor;
- aluminum sulfate (alum) and/or polymers are added to aid in the coagulation and flocculation of colloidal particles,[7] which are then removed by sedimentation (when available) and filtration; and
- the water is disinfected to kill any remaining organisms and provide a disinfectant residual throughout the distribution system to prevent growth of further organisms.

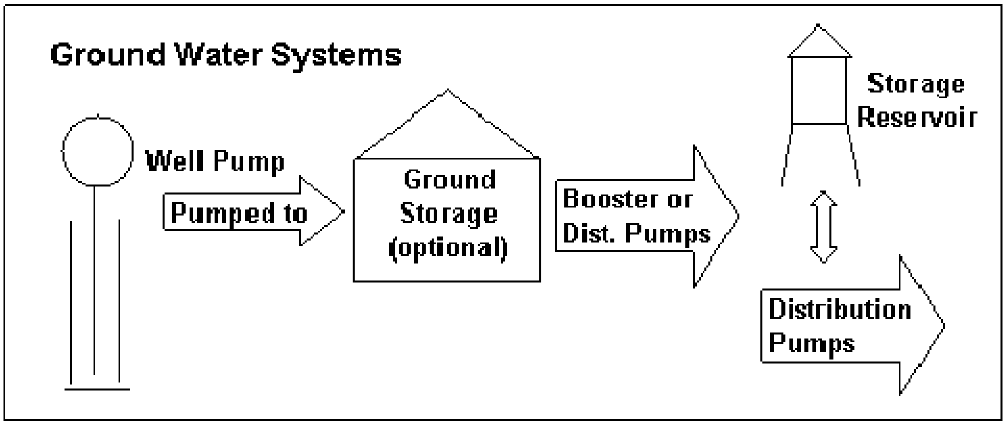
Exhibit 3-6: Surface Water Distribution



Source: Burton (1996), p. 3-3.

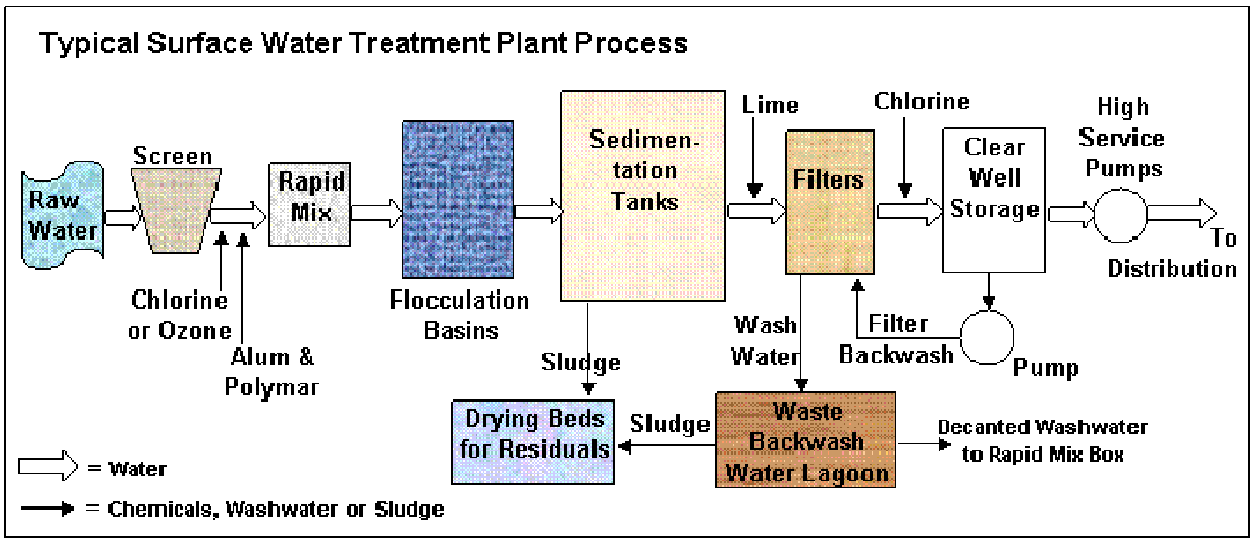
[7] Colloidal particles are fine particles that must be removed from the water by coagulation.

Exhibit 3-7: Groundwater Distribution



Source: Burton (1996), p. 3-3.

Exhibit 3-8: Surface Water Treatment Processes



Source: Burton (1996), p. 3-7.

The treatment process for groundwater is less complicated than that of surface water, consisting primarily of pumping the water to the surface and chlorinating for disinfection and removal of odor and taste. Exhibit 3-9 lists the portion of community water systems that reported using disinfection alone versus disinfection with additional treatment processes. As shown in the exhibit, 55 percent of groundwater systems report using disinfection only. In contrast, only 11 percent of surface water plants report using this amount of treatment.

Exhibit 3-9: Percentage of Plants Using Various Treatment Processes

Treatment Practice	Groundwater Plants	Surface Water Plants
Disinfection Only	55%	11%
Disinfection and Other Treatment	45%	89%

Disinfection and other treatment may include: chemical addition, ion exchange, activated alumina, aeration, filtration (various types), and softening.
Source: USEPA (2002b), p. 12.

3.1.3 The Energy Intensity of Water Supply and Opportunities to Improve Efficiency

EPRI estimated electricity consumption at about 30 billion kWh for public water systems in the year 2000 (EPRI, 2000, p. 2-4). The pumping of water is the primary consumer of energy, including pumping to deliver untreated water to a treatment plant, deliver treated water to customers, and to clean water filters. In California, water pumping is the single most significant use of electricity in the state, using seven percent of the total usage. Electricity costs can compose anywhere between 20 and 80 percent of a water utility's total operating budget (Business Wire, 2001).

An often-cited source of energy intensity estimates for water supply systems is the EPRI-funded study *Water and Wastewater Industries: Characteristics and Energy Management Opportunities* (Burton, 1996). This study reviewed data on energy consumption in various processes to produce estimates of electricity usage in "generic" water supply plants ranging from 1 mgd to 100 mgd (Burton, 1996, p. 3-28).

Using the basic schematic shown in Exhibit 3-6, and including the processes presented in Exhibit 3-8, a surface water supply system would have an estimated total electricity consumption of 1,400 to 1,500 kWh per million gallons of water supplied (Burton, 1996, p. 3-30). This total includes the pumping of the raw water to the treatment plant, the treatment of the water, and the pumping of the water for distribution. The energy intensity was estimated to vary slightly by the flow rate of the plant (see Exhibit 3-10).

Burton (1996) estimated electricity consumption for groundwater systems at about 1,824 kWh per million gallons of water. Pumping accounts for 99 percent of the estimated requirement, with the chlorination process requiring less than 1 percent of the electricity needed (Burton, 1996, p. 3-30).

Exhibit 3-10: Electricity Consumption for Surface Water Treatment Plants

Water Supply Plant Size	Electricity Consumption (kWh/million gallons)	Portion of Energy Used for Pumping
1 mgd	1,483	89%
5 mgd	1,418	93%
10 mgd	1,406	94%
20 mgd	1,409	94%
50 mgd	1,408	91%
100 mgd	1,407	94%

Source: Burton (1996), p. 3-30.

Of note is that energy requirements can vary significantly with local circumstances. Pumping from deep groundwater wells requires more energy than pumping from shallow wells. Variations in topography may necessitate pumping to higher elevations in some areas. Alternatively, surface water may be delivered in part by means of gravity, thereby having lower energy requirements for collecting the raw water prior to treatment. Several examples of the energy intensity of water supply are as follows.

- The Madera Valley Water Company reported using about 1.27 million kWh to deliver about 519 million gallons of water in 1993, for an energy intensity of about 2,400 kWh per million gallons (CEC, 2003a). This system serves 1,600 residential customers with groundwater drawn from within their distribution system.
- The Iowa Association of Municipal Utilities (IAMU) conducted a detailed survey and analysis to assess energy consumption at water supply plants (IAMU, 2002).

Approximately 300 plants provided data from which the energy intensity of their operations could be calculated. The average energy intensity was about 2,770 kWh per million gallons of water (IAMU, 2002, p. 11). Nearly all the water systems in the survey were groundwater systems, with only eight systems listed as surface water (IAMU, 2002, p. 9). The treatment processes used at the responding plants are consistent with the pattern discussed above, with less treatment being performed at the groundwater based plants (see Exhibit 3-11). It should be noted that all the treatment plants in the survey are very small, with all but five of the respondents serving fewer than 10,000 people.

Exhibit 3-11: Treatment Processes Used by Iowa Drinking Water Source

	Primary Water Source (Number of respondents)			
Treatment Performed	**Deep Wells (157)**	**Shallow-Deep Wells (33)**	**Shallow Wells (109)**	**Surface Water (8)**
Disinfection	96%	100%	95%	100%
Fluoridation	34%	30%	53%	88%
Iron Removal	62%	15%	46%	75%
Chemical Sedimentation	41%	48%	39%	100%
Cation/Anion Exchange	24%	21%	24%	38%
Byproduct Management	18%	18%	16%	88%

The survey did not define “Shallow” or “Deep” wells. Respondents self-identified their well depths. Some respondents indicated both Shallow and Deep wells and are listed as “Shallow-Deep.”
Source: IAMU (2002), p. 10.

- The American Water Works Association performed a study in 2003 called *Best Practices for Energy Management*. In that study, sixteen water utilities reported their volume of water delivered per unit of energy used. The results showed a large degree of variability, which could be due to any number of characteristics unique to the individual utilities. Nevertheless, the majority of the utilities reported figures similar to the numbers from Burton (1996) presented above, averaging about 1,500 kWh per million gallons of water (AWWA RF, 2003, p. 27).
- An overall study of California’s water systems found that approximately 9,000 kWh per million gallons is required to transport State Water Project water to Southern California on average, and 6,000 kWh per million gallons is required to pump water through the Colorado River Aqueduct to Southern California (Wilkinson, 2000, p. 6). This level of energy use is noted as being uniquely intensive, and unlikely to be observed in other locations in the U.S. Exhibit 3-12 shows the embedded upstream and downstream energy from each aspect of the water use cycle in California.
- Recently, the American Water Works Association Research Foundation (AWWA RF) conducted a study to develop an energy index for water utilities (AWWA RF, 2007). Surveys were distributed to water utilities serving populations of greater than 10,000. Eighty-five percent of U.S. community water systems serve populations of 10,000 or more. The final data analysis included responses from 125 water utilities, which indicated that energy usage varies between 324 to 2,360 kWh per million gallons.

Exhibit 3-12: Embedded Upstream and Downstream Energy Use in California

Aspect of Water Use Cycle	Northern California kWh/MG	Southern California kWh/MG
Water Supply and Conveyance	2,117	9,727
Water Treatment	111	111
Water Distribution	1,272	1,272
Wastewater Treatment	1,911	1,911
Regional Total	5,411	13,022

Source: CEC (2006), p. 22

Because the energy requirements for water supply are substantial, a variety of investigations have been conducted to identify opportunities to improve efficiency and/or reduce operating costs. Efforts have focused on pumping because it accounts for the overwhelming majority of energy consumption. Most methods to improve efficiency or reduce costs at water supply facilities can be grouped into the following categories (AWWA RF, 2003, p. 2-1, 2).

- Maintenance and Operations: The use of the existing infrastructure can be optimized through the testing and maintenance of pumps, as well as the regular repair of motors. Strategically using the available storage capacity can reduce the amount of pumping required during peak time periods when electricity prices may be higher than off-peak.
- Improving equipment efficiency: By installing energy-efficient motors and pumps, facilities can save between 15 to 30 percent compared to standard motors and pumps. Improvements can also be found in upgrading computer control systems.

Burton recommends similar energy management options for reducing costs (Burton, 1996, p. 3-32). High-efficiency equipment and effective control can improve efficiency so that less electricity is required to satisfy the same pumping need. Using storage effectively can not only reduce peak load requirements, but can enable pumps to operate in their most efficient ranges more often, thereby also improving efficiency.

A benchmarking study completed in 2003 involving 24 utilities nationwide recommended strategic energy management planning and implementation. From the perspective of asset performance, it was recommended that utilities optimize existing process operations, adjust operations so equipment runs in an efficient range, maintain equipment, and include energy efficiency in equipment decisions. Finally, the study suggested that operations managers use historical and real-time energy use data when making operations decisions (AWWA RF, 2003, pp. 1, 37).

A case study of the Southwest Water Utility (SWWU), which put the areas for improvement listed above into practice, found the following to be particularly important (AWWA RF, 2003, p. 156-159):

- Optimized Pumping Design: Benefits are achieved through the ability to reduce pumping energy demand by selecting the optimum number of pumps to operate. The choice of the number of pumps to operate and which pumps to operate is made by matching the required flow rates with the efficient operating ranges of the individual pumps.
- Planning Pump Operations: Planning efforts provide several components for increased efficiency, including optimum reservoir levels, pumping station plans, and total storage. Focusing on the proper storage requirements and adequate operating plans allow for optimum efficiency for the whole system.

Exhibit 3-13 lists examples of successful efforts to improve the energy efficiency of water supply through process optimization, improved maintenance, and the installation of high-efficiency equipment. The potential national savings from cost-effective practices have not been estimated. An average five percent savings on overall electricity usage in the water supply industry would translate into annual savings of about 1.5 billion kWh based on total annual electric consumption of 30 billion kWh.

Compared to the examples in Exhibit 3-13, five percent may be a conservative estimate. Larger municipal water systems, with full-time professional engineering staff, may have optimized their systems to a large degree. Smaller systems, with fewer technical resources, are likely to have been slower to adopt advancing measures and could potentially see improvements of 30 percent or more. The lack of an effective energy intensity benchmark against which to assess current performance limits the ability to estimate the potential national improvement in energy efficiency across the industry.

3.1.4 Improving Water Delivery Efficiency: Water Loss Control

While improving the energy efficiency of water supply can reduce the energy intensity of the process, opportunity also exists to improve the efficiency of water delivery itself. In particular, a significant amount of water is lost through leakage and other factors. Reducing losses during delivery not only helps conserve water, it also reduces the amount of energy required to operate the system.

Exhibit 3-13: Example Water Supply Energy Efficiency Improvements

New Jersey. The New Jersey American Water Company installed variable-frequency drives (VFDs) on various pumping applications to help control motor and equipment speed. With the installation, they were able to improve their operational control, increase standby power, and provide better control of water withdrawal from storage. They estimate their annual savings at about $228,000 and project paybacks for their four sites ranged from two to eighteen months (EPRI, 1997, p. 3-4).

Pleasanton, California. The City of Pleasanton, California developed an operations and maintenance program for their water system which included the installation of energy-efficient pumps and motors. In the first 16 months of the program, they estimated savings of over $90,000, or 34 percent of their annual energy cost. Ongoing efforts to improve their operations have continued to yield reductions in energy billing (EPRI, 1997, p. 7-3).

Madera Valley, California. Madera Valley Water Company reported significant energy savings from the use of variable frequency drives (VFDs) and programmable logic controllers (CEC, 2003a). The VFDs and controllers enabled the operators to distribute water more evenly throughout the pressure zone, and allowed them to reduce the zone's pressure differential from 22 to 5 psi. They report annual savings of 15 percent in energy cost despite a 22 percent increase in water delivery.

Southern California. Given the importance of energy used for pumping, Southern California Edison (SCE) provides pump test services to their agriculture and water supply electricity customers. The program is credited with not only identifying energy efficiency improvement opportunities, but with helping to promote the adoption of improved maintenance practices (SCE, 1998, p. 3-9). Part of the success of the program is attributed to improved information being available to help select efficient motors and pumps to meet their needs (SCE, 1998, p. 5-18 to 5-19). Energy savings estimates for the program are not currently available, however.

Discussion of water loss and estimates of water leakage often refer to information about "unaccounted for" water. Unaccounted for water is typically taken to be the difference between water produced (as measured by meters at the supply facilities) and metered water use (water sales and non-revenue water use as measured by customer meters or estimated for nonmetered activities). Expressed as a percentage of water production, unaccounted for water is typically calculated as (Lahlou, 2001, p. 2):

$$\text{Unaccounted for Water (\%)} = \frac{(\text{Production} - \text{Metered Use}) \times 100\%}{\text{Production}}$$

where Production and Metered Use are expressed in common units such as millions of gallons (or millions of gallons per day).

Unaccounted for water has been criticized as an inadequate metric of the performance of water supply systems, as well as a misleading indicator of the amount of water that is lost due to leakage or other factors (AWWA, 2003, p. 67). Not all water calculated to be unaccounted for is in fact lost or leaked. Unaccounted for water can be attributed to the following causes (AWWA, 1999, p. 28-31):

- Accounting error – Discrepancies between production and metered use occur due to inaccurate billing cycles, misread meters, improper calculations or computer programming errors.
- Unauthorized connections – This occurs accidentally in cases where a connection is listed as inactive, but water is still extracted from it. This occurs deliberately when a customer taps into a main to avoid paying for water.
- Malfunctioning distribution-system controls – Water loss may result from improper application, malfunctioning, or improperly set system controls such as valves.
- Reservoir seepage and leakage – Loss resulting from tears in linings, bottoms or walls, or storage tanks or ponds.
- Evaporation – Clearwells and reservoirs that are open to the atmosphere lose a certain amount of water to evaporation.
- Reservoir overflow – Reservoirs can overflow when the control valve, normally set to prevent the tank from overflowing, is faulty or missing.
- Unauthorized water use – Usually occurs when individuals vandalize fire hydrants.
- Leaks – Losses from leaks that are both visible and non-visible in distribution and transportation pipes.

Authorized un-metered use can also be counted as unaccounted for water if the quantity is not estimated and added to the metered usage. Authorized un-metered uses typically include firefighting and firefighter training, the flushing of mains, storm drains, and sewers, and street cleaning. Authorized un-metered use may also include water provided for schools, landscaping and irrigation in public areas, decorative public water facilities, swimming pools, construction sites, and water quality testing and processing at water treatment plants (AWWA, 1999, p. 19-27).

Exhibit 3-14 shows estimates of unaccounted for water for community water systems by size. Although the average is roughly 8.4 percent, unaccounted for rates vary substantially among water providers. The differences may in part be due to variations in the methods used to define and measure unaccounted for water. Different state agencies have various definitions for unaccounted for water, with most differentiating between metered and un-metered water.

Exhibit 3-14: Unaccounted for Water by System Size: Community Water Systems

		System Size by Population Served					
		Very Small 500 or less	Small 501-3,300	Medium 3,301-10,000	Large 10,001-100,000	Very Large >100,000	Total
Community Water Systems	# systems	30,417	14,394	4,686	3,505	361	53,363
	Unaccounted For Water	2.8%	9.1%	11.4%	9.4%	7.4%	8.4%

Source: Analysis of data in USEPA (2002b).

Some states have reporting requirements for unaccounted for water based on the percentage found during their water accounting efforts. For example, the Massachusetts Department of Environmental Protection requires that if a system has 15 percent or greater water loss or uses 100,000 gallons per day with any percentage of unaccounted for water, the system must report the loss and submit plans to correct the problem. The percentage threshold required to report loss varies from state to state and by agency. Exhibit 3-15 is an example of some of the agency standards for reporting unaccounted for water.

There is currently a movement among state and regional agencies to refine the definitions, measurements and standards used to evaluate water loss (Beecher, 2002, p. 4, 27). The AWWA Water Loss Control Committee has recommended a standard set of water accounting definitions, and has proposed that the term “unaccounted for” water no longer be used. Rather, the committee recommends that all water be accounted for in a systematic way so that useful operating metrics can be estimated.

Exhibit 3-16 presents a summary of the recommended water accounting relationships. Accounting for the water resource is done in terms of authorized consumption, apparent losses, and real losses. The real losses are leaks. Apparent losses are due to unauthorized consumption and metering and data inaccuracies. Apparent losses are not inefficiencies in the use of the water resource, but rather represent water for which no revenue is collected. AWWA (2003) recommends that the financial accounting for the water be organized to work with the resource accounting so that the implications of real water losses and non-revenue water for system finances can be assessed.

Exhibit 3-15: Selected State Standards for Reporting Unaccounted for Water

State	Agency	Reporting Standard
Arizona	Department of Water Resources	10% (large), 15% (small)
California	Urban Water Conservation Council	10%
Florida	Southwest Florida Water Management District	12% or less
Florida	St. Johns River Water Management District	10%
Georgia	Environmental Protection Division	Less than 10%
Indiana	Department of Environmental Management	10 – 20%
Kansas	Kansas Water Office	15%
Kentucky	Department of Energy	15%
Louisiana	Department of Environmental Quality	15%
Massachusetts	Department of Environmental Protection	15%
Minnesota	Department of Natural Resources	10%
Missouri	Department of Natural Resources	10%
North Carolina	Division of Water Resources	15%
Ohio	Public Utility Commission and Environmental Protection Agency	15%
Oregon	Water Resources Division	10 – 15%
Pennsylvania	Public Utility Commission	20%
Pennsylvania	Bureau of Water and Wastewater Management	10 – 15%
Rhode Island	Water Resources Board	10 – 15%
South Carolina	Public Service Commission	7.50%
South Carolina	Department of Health and Environmental Control	10%
Texas	Water Development Board	10 – 15%
Texas	Natural Resources Conservation Commission	20%
Washington	Department of Health	20% (10% proposed)
West Virginia	Public Service Commission	15%
Wisconsin	Public Service Commission	15% (large), 25% (small)
Delaware River Basin Commission	Delaware River Basin Commission	15%

Source: Beecher (2002), p. 13.

Exhibit 3-16: Standard Water Audit Format

<table>
<tr><th colspan="2">Resource Accounting</th><th>Financial Accounting</th><th>Activities/Causes</th></tr>
<tr><td rowspan="9">Total Water Supply</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Revenue Water</td><td>Billed metered consumption</td></tr>
<tr><td>Billed un-metered consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled metered consumption</td></tr>
<tr><td>Unbilled un-metered consumption</td></tr>
<tr><td rowspan="2">Apparent Losses</td><td rowspan="5">Non-revenue Water</td><td>Unauthorized consumption</td></tr>
<tr><td>Customer meter inaccuracies and data errors</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on mains</td></tr>
<tr><td>Leakage and overflows at storage</td></tr>
<tr><td>Leakage on service connections to customer meter</td></tr>
</table>

Source: Adapted from AWWA (2003), p. 72.

Using these accounting definitions, AWWA (2003) recommends that the volume of real losses be reported, rather than a percent loss or percent unaccounted for. The volume of water loss should be compared to a system-specific estimate of unavoidable annual real losses (UARL) to assess how well the system is being operated. The UARL can be calculated from system parameters, such as miles of main and number of service connections, and represents the minimum level of leakage that could exist if all possible leak reduction activities were successfully in place (AWWA, 2003, p. 72). AWWA calls the ratio of real losses to UARL the Infrastructure Leakage Index (ILI).

Lower ILI values indicate more resource efficient systems. Recognizing that there are costs associated with reducing leakage rates, the AWWA defines the “economic leakage level” (ELL) as the target ILI for systems to shoot for (AWWA, 2003, p. 72). The ELL will be system-specific, depending on the particulars of the system infrastructure, resource costs, and costs of leak detection. While methods are under development to standardize ELL calculations, AWWA recommends that systems calculate their ILI using water audits. Additionally, AWWA observes that ILI values above eight are almost certainly higher than any expected value of ELL, and that actions to reduce leakage should be intensified if a water audit indicates an ILI of eight or more (AWWA, 2003, p. 75).

A water audit identifies the amount of water that is lost and what that loss costs a utility. As summarized in Exhibit 3-17, the process involves checking the accuracy of records and control equipment, as well as recommending programs designed to reduce distribution system losses (AWWA, 1999, p. 1). Following the audit, the supplier analyzes the value of the losses and what it may cost to implement potential corrective and preventive measures. A plan for how to attack the problem is then put into place based on need and financial viability (AWWA, 1999, p. 5-10).

Exhibit 3-17: Overview of a Water Audit

Steps for Performing a Water Audit to Assess the Causes of Real Water Losses

The first step in the water audit process is to choose a time period that allows the analysis and evaluation of total water system use—this is usually at least one year. Also important is to choose an official unit of measure, such as gallons. The following tasks are then performed:

- Measure the Supply – Identifying and mapping the sources, measure the water from each source and calculate total supply.
- Measure Authorized Metered Use – Identify all the metered uses and calculate the total from available records.
- Measure Authorized Un-metered Use – Identify un-metered uses and estimate the total amount based on activity information.
- Assess Meter Accuracy – Estimate the accuracy of the supply and usage meter data to estimate the contribution of meter accuracy on the apparent discrepancy between supply and use.
- Calculate Water Losses – Calculate the total apparent water loss and estimate the amount of unaccounted for water by type of loss (e.g., unauthorized un-metered use and leakage).
- Analyze Audit Results – Evaluate the value and cost of reducing losses, such as through enhanced leak detection and repair. Compute the Infrastructure Leakage Index and intensify leak reduction efforts if the ILI is high.

AWWA (2003) recommends a four-component approach to control real losses (AWWA, 2003, p. 77):

- Pressure management: lower operating pressures can reduce leakage rates, particularly from small leaks.
- Pipeline materials management: selection, installation, and maintenance of pipeline materials.
- Active leakage control: regular inspection of mains and connections for leakage.
- Leak repair: timely and high quality repairs of leaks.

Many leaks are highly visible and readily identified and repaired. Non-visible leaks, however, may remain unknown for extended periods of time. According to one analysis, most underground, non-visible leaks remain undetected an average of two years, and many examples exist of leaks that are never detected (AWWA, 1999, p. 35). A leak detection program may be undertaken to uncover the non-visible leaks that would otherwise persist over time.

Underground leaks are a major cost for municipalities. The actual cost of these leaks can be determined in numerous ways and is based on the cost of water in the area. For an individual leak, the amount lost in a given period of time, multiplied by the retail value of the water will provide a dollar amount (Lahlou, 2001, p. 1). Examples of the reported costs of leaks include the following.

- The City of Beverly Hills had a ½ inch leak in an underground steel main for an estimated duration of two years. Flow from the leak was calculated at 53 gallons per minute, losing almost 56 million gallons of water, valued at $43,000 (AWWA, 1999, p. 35).
- The Walnut Valley Water District found a leak in a mainline estimated to be losing 12 gallons per minute. The 2-year duration cost the district almost 13 million gallons of water at approximately $9,600 (AWWA, 1999, p. 36).
- The City of Santa Clara found a leak in a main that was flowing into an adjacent sewer at 98 gallons per minute. Water lost from the leak during the estimated 2 years was over 100 million gallons, costing $47,000 (AWWA, 1999, p. 36).

To reduce these water losses, leak detection can reduce the time prior to the leak being discovered. The cost of leak detection includes the cost of both equipment and personnel and may range from $75 to $300 per mile of main (performed by utility staff) or from $150 to $500 per mile of main when conducted by contractors. These costs do not include leak repair costs, which would be expected to be incurred once the leak was detected in any case (AWWA, 1999, p. 2).

While saving money by reducing water loss is the primary benefit gained from leak detection programs, additional benefits exist that are more difficult to quantify, including the following (AWWA, 1999, p. 3 and Lahlou, 2001, p. 2):

- *Increased knowledge of the distribution system:* Personnel become more familiar with the distribution system, allowing for a quicker response to future emergencies.
- *More efficient use of existing supplies:* The reduction of water loss helps to conserve water supplies and defers the need for finding new sources.
- *Improvements in public health and property:* In locating a leak before it damages property, water suppliers also maintain public health and safety.
- *Improved public relations:* In addition to preventing property damage, the detection could improve environmental conditions and increase firefighting capabilities.

- *Reduction of legal liability:* The supplier shields themselves from legal issues with a decrease in property damage and public health concerns.
- *Less disruption for customers:* Leak detection can prevent the shutdown of water supplies to consumers.
- *Reduced risk of contamination:* If a leak is letting water out, there is a possibility that certain type of contaminants could also be coming into the supply.

In 2003, Western Resource Advocates looked at water supply and demand management programs in 13 urban communities in the Southwestern U.S. (WRA, 2003). Seven of the 13 communities reported that they implement leak detection and repair programs. As shown in Exhibit 3-18, five of the seven communities showed reductions in unaccounted for water between 1994 and 2001. The reductions were about 6.6 gallons per capita per day, or about 2,400 gallons per capita per year. Overall, average unaccounted for water was reduced from 9.1 percent to 6.7 percent on average. Two communities showed an increase in unaccounted for water during this period. Tempe, which reported an increase of 6 gallons per capita per day in unaccounted for water, reported that in 2002 they intensified their leak detection and repair program to cover their entire system rather than only its oldest portions (WRA, 2003, p. 170).

Exhibit 3-18: Reductions in Unaccounted For Water in Communities with Leak Detection and Repair Programs

City	UAF Water (Gallons/capita-day)				UAF Water %		
	1994	2001	Change	% Change	1994	2001	Change
Denver, CO	14	9	-5	-36%	6.3%	4.4%	-1.9%
El Paso, TX	24	17	-7	-29%	11.6%	10.2%	-1.4%
Grand Junction, CO	47	24	-23	-49%	18.2%	10.3%	-7.9%
Highlands Ranch, CO	2	9	7	350%	1.1%	4.7%	3.6%
Las Vegas, NV	31	14	-17	-55%	9.4%	4.6%	-4.7%
Phoenix, AZ	30	23	-7	-23%	12.4%	9.7%	-2.7%
Tempe, AZ	8	14	6	75%	3.0%	4.5%	1.5%
Average	22.3	15.7	-6.6	-29%	9.1%	6.7%	2.4%

Source: WRA, 2003.

Another example of the benefits of reducing leakage is the savings achieved by the Philadelphia Water Department. In 2000, the Department implemented rigorous water audit practices based on the International Water Association format (AWWA, 2003, pp. 72). Through pipeline replacement, improved leak detection, faster repairs, and improved accuracy in billing, the city recovered about 10.5 million gallons a day of real and apparent losses, saving about $9.8 million in lost water costs over five years (Ghezzi, 2005). A portion of these savings is associated with energy savings due to reduced pumping and treatment of real losses.

On a national level, it is premature to estimate the potential reduction in leakage that could be achieved through intensified leak management. Following the restructuring of the water industry in the United Kingdom in 1989, steps were taken to reduce real water losses. Systematic methods for managing leakage have reportedly reduced by 85 percent the leakage that exceeds the UARL, bringing ILI values to less than two in many cases (AWWA, 2003, pp. 68, 75). The potential to reduce leaks in the United States is likely to be at least as large as existed in the U.K. prior to restructuring. For purposes of estimating potential, we assume that leaks could be reduced by an amount equal to one percent of total water delivery, or about 550 mgd. If the current leak rate is about 10 percent, this improvement of one percent is a 10 percent reduction in total leaks. Based on total energy consumption of 30 billion kWh per year, this leak reduction would save 300 million kWh per year.

3.2 Wastewater Treatment

This section discusses wastewater treatment systems. First the industry is described, including a summary of the processes used to treat wastewater. Then, the energy intensity of water treatment is estimated, along with a review of opportunities to improve energy efficiency.

3.2.1 Wastewater Treatment Industry

Municipal wastewater is collected and treated in most communities throughout the United States. The facilities that treat municipal wastewater prior to discharge are called wastewater treatment plants, and because nearly all of the plants are owned by public institutions (municipalities or specially designated districts), they are often referred to collectively as Publicly Owned Treatment Works (POTWs). The primary purpose of POTWs is to treat wastewater to a degree that allows its discharge into surface or groundwater or that enables its reuse. The type of treatment performed varies with local conditions and water quality needs. POTWs typically treat wastewater from residential, commercial, and institutional sources. Industrial wastewater often has special treatment needs, so that in many cases, industrial wastewater is treated at the industrial facility prior to its discharge into the sewer system. Once in the sewer system, it flows to the POTW where it is treated as part of the overall municipal waste stream. In other cases, industrial wastewater is treated completely at the industrial site and is not discharged into the sewer system.

Approximately 16,000 POTWs were operating in the United States in 2000. Comprehensive data describing the basic operating characteristics of these plants are collected periodically by the U.S. EPA through a survey of water quality programs and projects eligible for funding under the Clean Water State Revolving Fund (USEPA, 2003b, p. xiii). Exhibit 3-19 lists the number of wastewater treatment plants by state and size, and Exhibit 3-20 lists the number of people served and total flow rate. In 2000, about 210 million people were served by POTWs. The approximately 1,600 plants with flows greater than 2.5 million gallons per day (mgd) served about 167 million people, or about 105,000 people per plant on average. Twenty-two plants serve more than 1 million people each, with flow rates typically above 100 mgd. The 14,500 plants that reported flows of less than 2.5 mgd served a total population of about 42.8 million, with an average of about 3,000 people served per plant. The average flow rate per person increases with plant size, from about 98 gallons per person per day (gal/person-day) for the smallest plants to more than 200 gal/person-day for the largest plants (see Exhibit 3-20).

Driven by the Clean Water Act and its regulatory requirements, substantial progress has been made in the past 30 years to provide adequate wastewater treatment. The minimum level of treatment currently required is “secondary treatment,” which is defined in terms of the concentration and removal of two conventional pollutants: biochemical oxygen demand (BOD_5) and suspended solids (USEPA, 2003b, p. Glossary-4). The number of facilities providing less than secondary treatment declined from 4,800 in 1972 to 868 in 1992, and further declined to just 47 in 2000 (USEPA, 2003b, pp. 3-3 to 3-4). Most of the remaining facilities providing less than secondary treatment have received or asked for waivers from the requirement. Advanced treatment, exceeding the requirements of secondary treatment, is provided by nearly 5,000 plants to reduce concentrations of non-conventional pollutants, including nitrogen and phosphorus.

Exhibit 3-21 shows the treatment processes that are typically used at the two principal types of wastewater treatment plants: those without activated sludge treatment and those with activated sludge treatment. For both types of plants, raw untreated wastewater is collected by the sewer system. At the treatment plant, the wastewater is screened and grit is removed. Primary settling is used to remove the settleable solids. At plants without activated sludge treatment, the wastewater is often treated using trickling filters: the wastewater flows over a filter medium with a large surface area. Treatment occurs through biological action. The wastewater then goes through secondary settling, and is disinfected prior to discharge. The biosolids collected in the settling tanks are typically thickened, and may be treated using anaerobic digestion prior to disposal. As discussed below, anaerobic digestion is not commonly used in trickling filter treatment plants.

Plants with activated sludge treatment are capable of handling higher pollutant loadings. Activated sludge treatment tanks use biological action to treat the waste, and can be designed to include nitrification (conversion of ammonia to nitrate). Additional treatment processes may include the addition of chemicals and filtration prior to disinfection and discharge. As with trickling filter plants, activated sludge plants may include anaerobic digestion of biosolids.

Information regarding the financial characteristics of wastewater treatment plants is available from the Association of Metropolitan Sewerage Agencies (AMSA) periodic survey of its members. AMSA's most recent survey, conducted in 2001 and published in 2002, obtained responses from 126 wastewater treatment agencies, with 458 plants serving approximately 87 million people (AMSA, 2002). Although the survey is not a statistical representation of all POTWs, it provides insight into industry's finances and operating issues. The agencies that responded have a total average daily flow of about 12,500 mgd, accounting for about 40 percent of the national average daily treatment as computed by EPA (USEPA, 2003b).

As shown in Exhibit 3-22, user fees account for the majority (57 percent) of the $12 billion in revenue received by the agencies that responded to the AMSA survey. Federal and state grants accounted for a relatively small portion of revenue, as did the State Revolving Fund for loans (SRF). Comparison with previous AMSA surveys indicates that this pattern of revenue sources has been consistent for the past 10 years. One key trend noted in the study is a continuing increase in long term debt held by the respondents (AMSA, 2002, p. 6).

Exhibit 3-19: Number of Wastewater Treatment Plants by State and Size

	Average Daily Flow Rate (millions of gallons per day)					
State	**<0.5**	**0.5-2.5**	**2.5-7.5**	**7.5-30**	**30-75**	**>75**
Alabama	148	84	25	13	2	0
Alaska	34	7	3	0	1	0
American Samoa	1	1	0	0	0	0
Arizona	104	42	12	5	1	1
Arkansas	265	57	13	1	0	0
California	318	131	63	47	7	7
Colorado	230	55	9	7	1	1
Connecticut	31	30	22	7	1	0
Delaware	10	5	2	0	1	0
District of Columbia	0	0	0	0	0	1
Florida	82	96	69	24	6	1
Georgia	219	83	28	17	2	1
Guam	3	2	1	0	0	0
Hawaii	8	5	6	1	1	0
Idaho	133	26	8	2	0	0
Illinois	525	127	35	29	0	3
Indiana	254	95	31	15	4	3
Iowa	643	61	15	4	1	0
Kansas	576	37	15	5	1	0
Kentucky	147	56	14	5	1	1
Louisiana	243	68	33	7	2	2
Maine	100	27	11	2	0	0
Maryland	92	36	12	8	1	1
Massachusetts	44	52	16	10	2	1
Michigan	268	90	20	12	5	1
Minnesota	458	38	13	4	0	1
Mississippi	230	55	10	4	1	0
Missouri	546	76	12	8	4	0
Montana	179	19	4	2	0	0
Nebraska	432	23	6	3	1	0
Nevada	37	9	2	1	1	0
New Hampshire	57	20	7	1	0	0
New Jersey	52	54	26	18	4	2
New Mexico	35	16	6	0	1	0
New York	350	140	50	25	10	9
North Carolina	204	85	25	13	1	0
North Dakota	271	8	4	1	0	0
Ohio	524	144	59	21	8	4
Oklahoma	409	54	17	5	2	0
Oregon	137	46	15	7	2	0
Pennsylvania	454	209	60	12	1	4
Puerto Rico	5	14	6	4	1	0
Rhode Island	5	6	7	3	0	0

	Average Daily Flow Rate (millions of gallons per day)					
State	**<0.5**	**0.5-2.5**	**2.5-7.5**	**7.5-30**	**30-75**	**>75**
South Carolina	86	67	22	10	1	0
South Dakota	264	13	1	1	0	0
Tennessee	144	67	24	6	5	0
Texas	937	300	73	32	9	6
Utah	69	18	7	6	2	0
Vermont	63	15	3	0	0	0
Virgin Islands	8	2	1	0	0	0
Virginia	152	43	9	16	3	0
Washington	149	56	19	13	2	1
West Virginia	143	54	9	4	0	0
Wisconsin	488	77	17	8	1	1
Wyoming	66	12	5	0	1	0
Grand Total	**11,432**	**3,013**	**982**	**449**	**101**	**52**

Source: USEPA, 2003c.

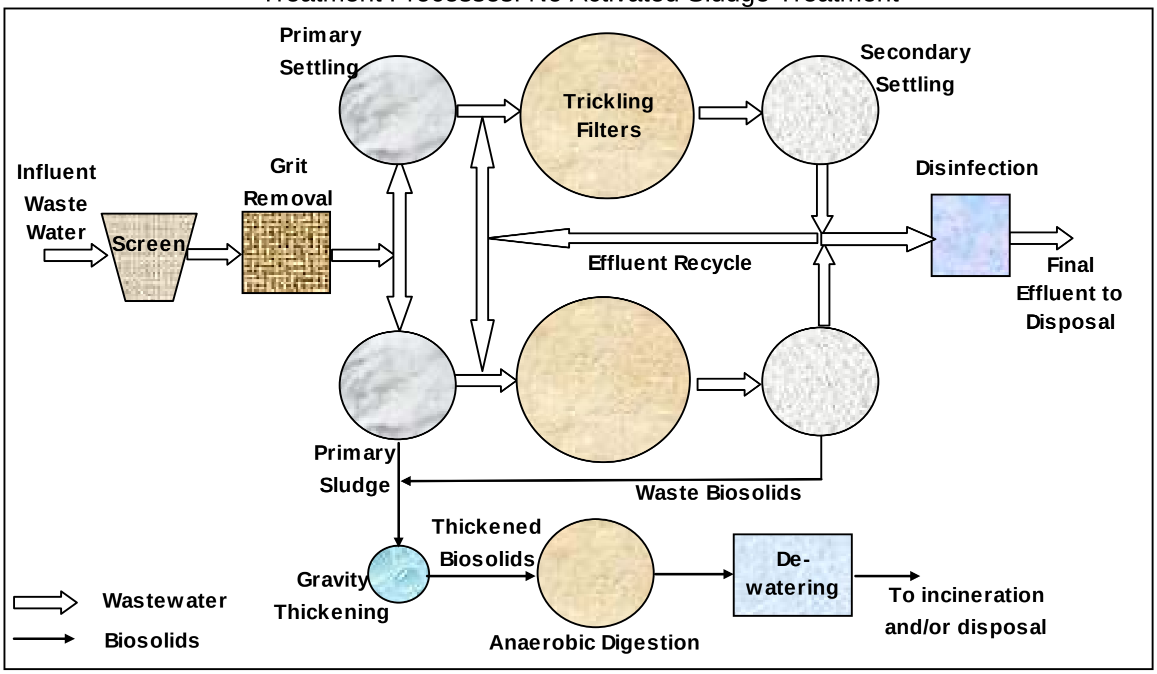
Exhibit 3-20: Population Served by Wastewater Treatment Plant Size

	Average Daily Flow Rate (millions of gallons per day)						
	<0.5	**0.5-2.5**	**2.5-7.5**	**7.5-30**	**30-75**	**>75**	**Total**
Number of Plants	11,432	3,013	982	449	101	52	16,029
Total Population Served (millions)	15.0	27.8	33.6	47.4	35.2	51.3	210.3
Population/Plant	1,314	9,213	34,251	105,597	348,897	985,839	13,120
Total Reported Flow (mgd)	1,472	3,363	4,161	6,105	4,692	10,484	30,275
Average Flow/Plant (mgd)	0.13	1.1	4.2	13.6	46.4	201.6	1.9
Flow/Person (gal/day per person)	98	121	124	129	133	204	144

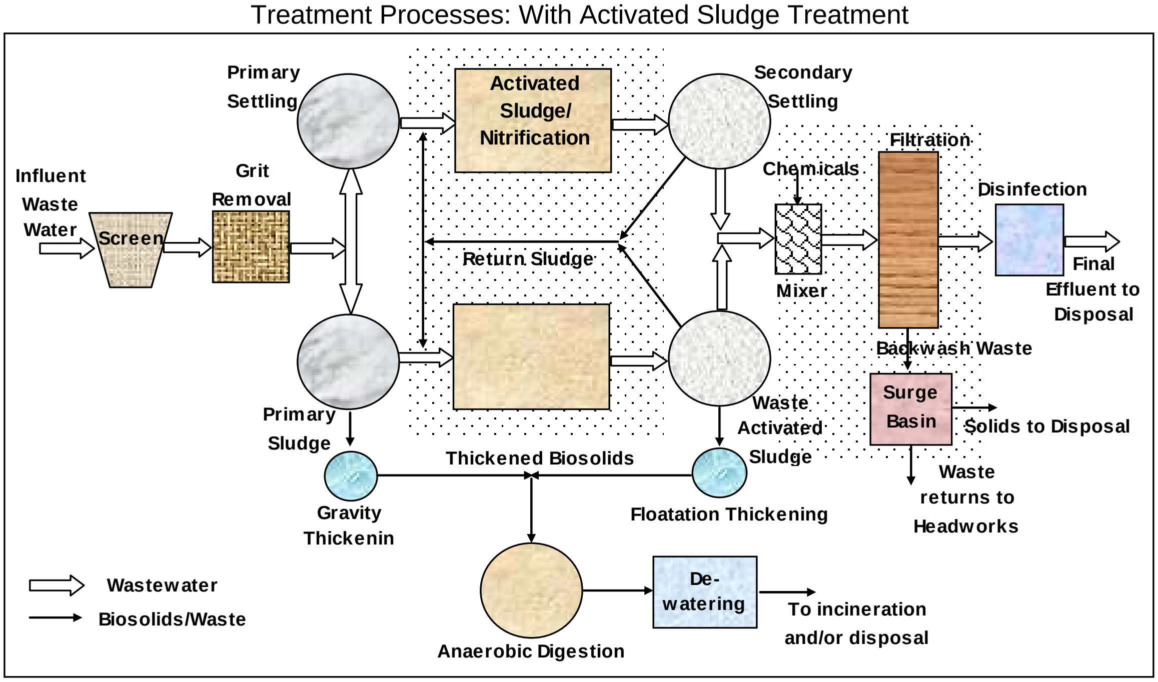
Source: Analysis of data from USEPA (2003b).

Exhibit 3-21: Typical Processes at Wastewater Treatment Plants

Treatment Processes: No Activated Sludge Treatment



Treatment Processes: With Activated Sludge Treatment



Source: From Burton, 1996, pp. 2-23 and 2-25.

Exhibit 3-23 shows that the largest expenditure for wastewater treatment plants is for operation and maintenance (37 percent) followed by debt service (20 percent). Total expenditures among the AMSA survey respondents was about $12 billion, or about $2,800 per million gallons of water treated. Using this cost per million gallons to extrapolate to the entire industry, total expenditures would be on the order of 30,275 mgd x 365 days x $2,800/million gallons = $31 billion per year. In making this extrapolation it must be recalled that the AMSA survey is not representative of the industry as a whole, and in particular small plants are under-represented in their data.

While considerable investment has been made to construct wastewater treatment capacity, additional investment is needed to maintain progress. As part of the U.S. EPA Clean Watersheds Needs Survey report for 2000 (EPA, 2003b. p. 3-1), states identified $57.2 billion in needed investment in secondary and advanced wastewater treatment. An additional $54.1 billion in investment is needed for wastewater collection and conveyance systems (primarily sewer improvements). Finally, $50.6 billion was identified for correcting problems with sewer systems that combine storm runoff with wastewater.[8]

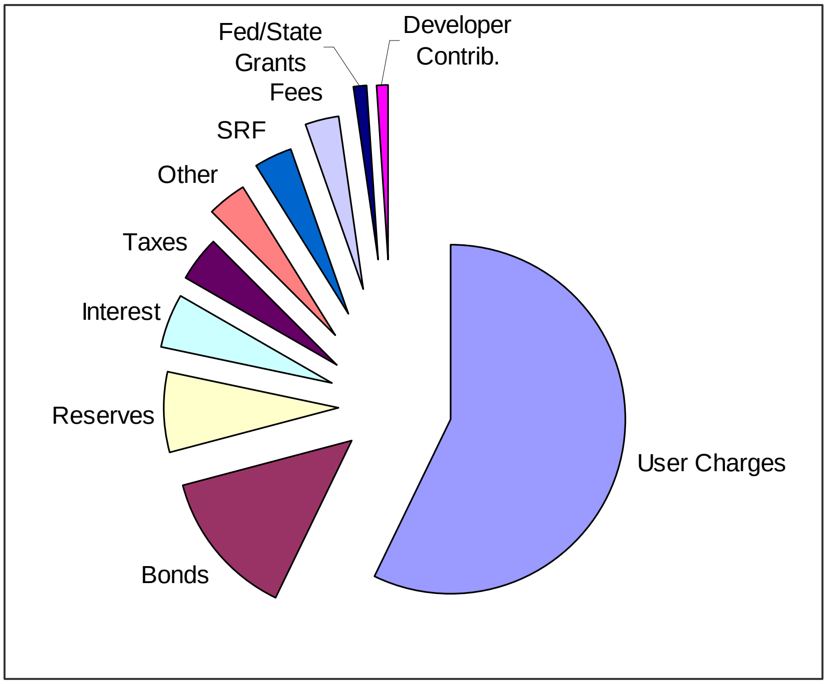
The Congressional Budget Office (CBO, 2002) conducted an independent estimate of investment needs and compared the figures to previously published values. Because the CBO analysis examined expected costs as financed, as opposed to total capital costs, the figures are not comparable to those presented here. However, the study concludes that investment requirements in the period of 2000 to 2019 may average $13 billion to $20.9 billion per year (CBO, 2002, p. ix). It further states that the higher figure represents an increase of about $10 billion in annual expenditure above the 1999 level. An analysis of investment requirements by the U.S. EPA produced results consistent with these estimates (USEPA, 2002c). Consequently, POTWs will likely remain under financial pressure to meet current standards, maintain existing systems, and expand to meet growing needs.

Of note is that while the majority or households are connected to sewers and are served by POTWs, a sizable minority use onsite wastewater treatment systems. The U.S. Census Bureau's American Housing Survey for 2001 reports that 21 percent of the 105.4 million year-round occupied housing units used a septic tank, cesspool, or chemical toilet (AHS, 2002, Table 1A-4). These systems are used in about 51 percent of seasonally-occupied housing units. The prevalence of onsite treatment varies by state, with nine states reporting for 1990 (the most recent state-level data available) that more than 40 percent of households use onsite treatment: Maine; New Hampshire; Vermont; West Virginia; Kentucky; North Caroline; South Carolina; Mississippi; and Alabama (see Exhibit 3-24).

The operation and maintenance of onsite treatment systems are typically left to homeowners. System failures have been identified as an important problem, not only affecting homeowners, but also affecting groundwater quality or other environmental resources (USEPA, 2002c, pp. 1-4 to 1-5). Nevertheless, the improved design and use of onsite wastewater treatment is an alternative to continued expansion of sewers and POTWs in some areas.

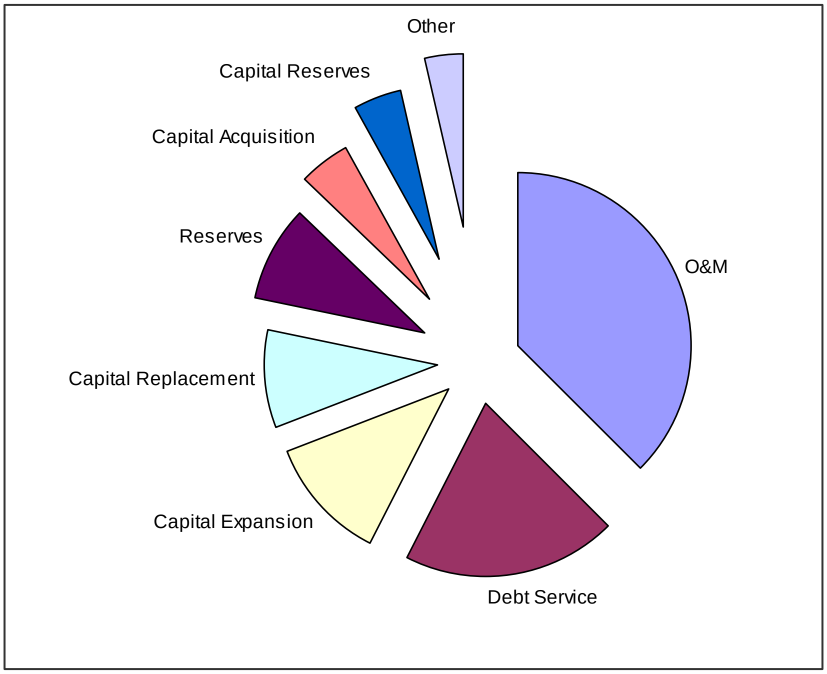
[8] Earlier-built sewer systems collect storm water runoff and wastewater in a combined sewer system. During periods of heavy rainfall, the combined flow can overload the wastewater treatment plant such that untreated wastewater must be discharged along with the storm water runoff.

Exhibit 3-22: Wastewater Treatment Plant Revenue Sources: AMSA Survey



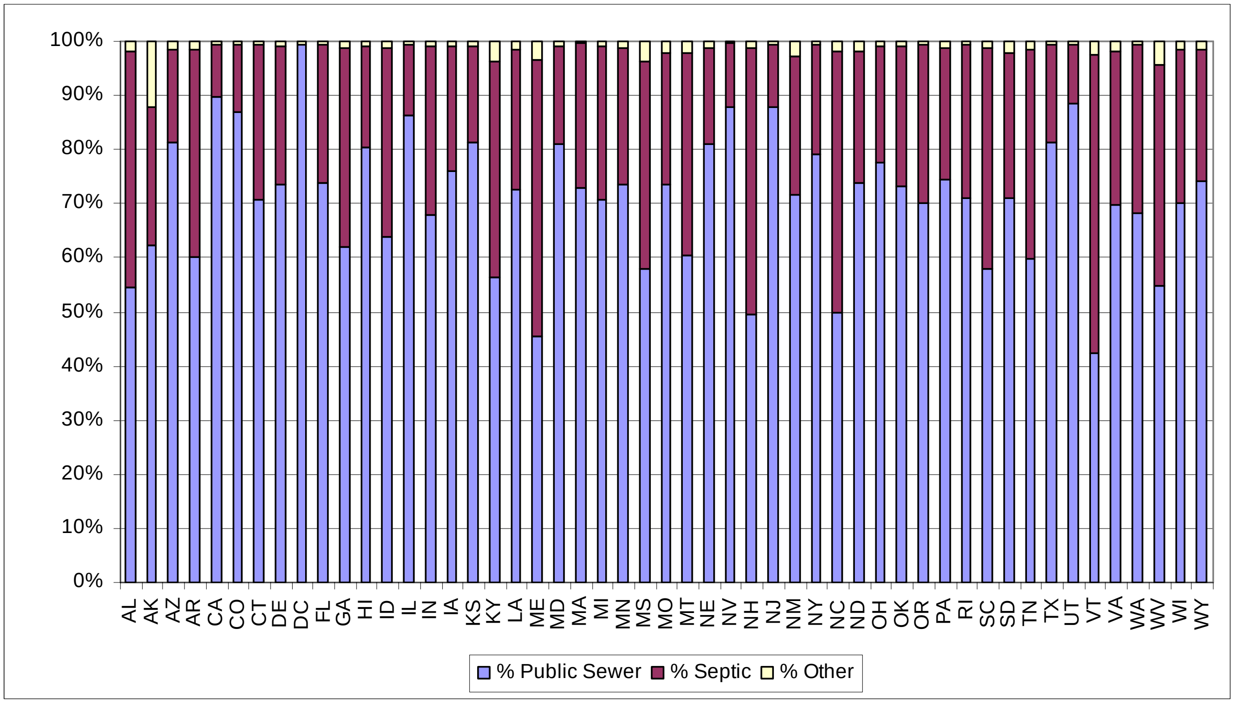
Source: AMSA (2002).

Exhibit 3-23: Wastewater Treatment Plant Expenditures: AMSA Survey



Source: AMSA (2002).

Exhibit 3-24: Prevalence of Onsite Wastewater Treatment for Households by State (1990)



% Sewer = percent of households connected to sewer service.
% Septic = percent of households reporting onsite treatment using septic tank, cesspool, or chemical toilet.
% Other = percent of households reporting other treatment systems.
Source: U.S. Census, 2004a.

3.2.2 The Energy Intensity of Wastewater Treatment

It has been well recognized that wastewater treatment plants consume significant amounts of energy, including electricity, natural gas, fuel oil and biogas. As the number and complexity of POTWs have grown, increased attention has been paid to energy requirements and opportunities to improve efficiency and recover usable energy from treatment processes.

An often-cited source of energy intensity estimates for wastewater treatment is the EPRI-funded study *Water and Wastewater Industries: Characteristics and Energy Management Opportunities* (Burton, 1996). This study reviewed data on energy consumption in various treatment processes to produce estimates of electricity usage in "generic" treatment plants ranging from 1 mgd to 100 mgd (Burton, 1996, p. 2-36). The generic plant types can be divided into two main types: those without activated sludge treatment and those with it (see Exhibit 3-21 above and accompanying text). Of those plants with activated sludge treatment, Burton defines three types, with increasing levels of treatment capability.

- activated sludge treatment and no advanced treatment or nitrification;
- activated sludge treatment with advanced treatment and without nitrification; and
- activated sludge treatment with advanced treatment and with nitrification.

Exhibit 3-25 presents the energy intensity estimates. For each treatment plant type, the energy consumption in kWh per million gallons of treated water is presented for a range of plant flow rates. For all the plant types, the energy requirement per million gallons of water treated is estimated to decline for larger plants. For plants above 10 mgd the estimates include potential energy recovery from biogas produced during anaerobic digestion of biosolids. The top area of the bars (lighter shading) represents the electricity that could be offset from the use of biogas.

As shown in the exhibit, increasing levels of treatment require additional energy. A 10 mgd activated sludge plant without advanced treatment is estimated to require about 1,200 kWh per million gallons. An activated sludge plant with advanced treatment and nitrification of the same size is estimated to required about 1,800 kWh per million gallons, or about 50 percent more.

Using these figures, along with the 1996 characterization of POTWs from EPA's survey, EPRI estimated total electricity consumption at POTWs at about 21 billion kWh in 2000, or about 1,800 kWh per million gallons of water treated (EPRI, 2000, p. 3-8).[9] This energy intensity reflects an average across the various treatment types and plant sizes, and no allowance for onsite electricity generation from biogas was included (EPRI, 2000, p. 3-6).

The New York State Energy Research and Development Authority (NYSERDA) estimated that municipal wastewater treatment plants used about 1.5 billion kWh in 1995 to treat an average of 3,500 mgd in New York (NYSERDA, 1995a, p. 1). The implied energy intensity is about 1,200 kWh/million gallons. In a study for The Northwest Energy Efficiency Alliance (NEEA), Quantum Consulting estimated that municipal wastewater treatment plants consume about 997 million kWh annually to treat about 1,500 mgd in the Pacific Northwest (Quantum, 2001, p. 3-8). The implied energy intensity is about 1,821 kWh/million gallons. Quantum estimated that the energy consumption at the 20 largest plants, which account for 1,000 mgd of treatment was about 400 million kWh, or about 1,100 kWh/million gallons (Quantum, 2001, p. 1-2).

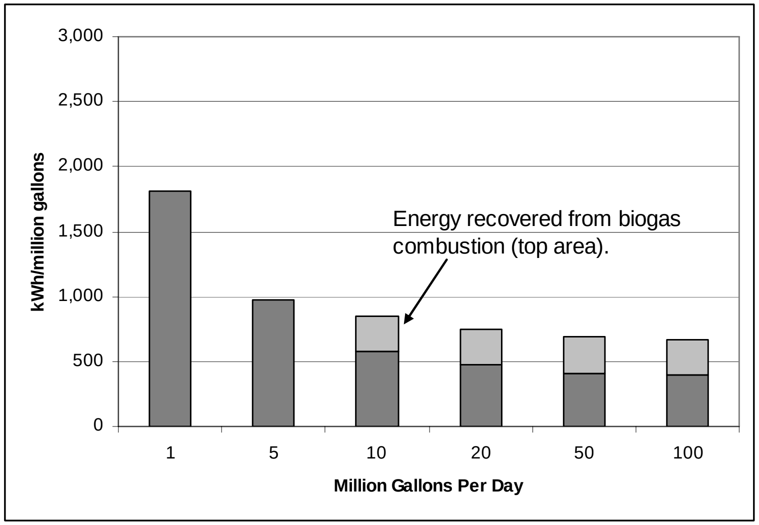
The Iowa Association of Municipal Utilities (IAMU) conducted a detailed survey and analysis to assess energy consumption at wastewater treatment plants (IAMU, 2002). A total of 343 plants provided data showing the average energy consumption was 1,150 kWh/million gallons for the wastewater treatment plants and an additional 420 kWh/million gallons for pumping as part of wastewater collection (i.e., sewer pumping stations) (IAMU, 2002, executive summary). The average energy consumption for the treatment plants reported by IAMU is significantly affected by the mix of treatment processes used in the plants included in the study. Additionally, all the treatment plants in the survey are very small, with nearly all of the respondents serving fewer than 10,000 people.

[9] Average energy consumption is estimated as:

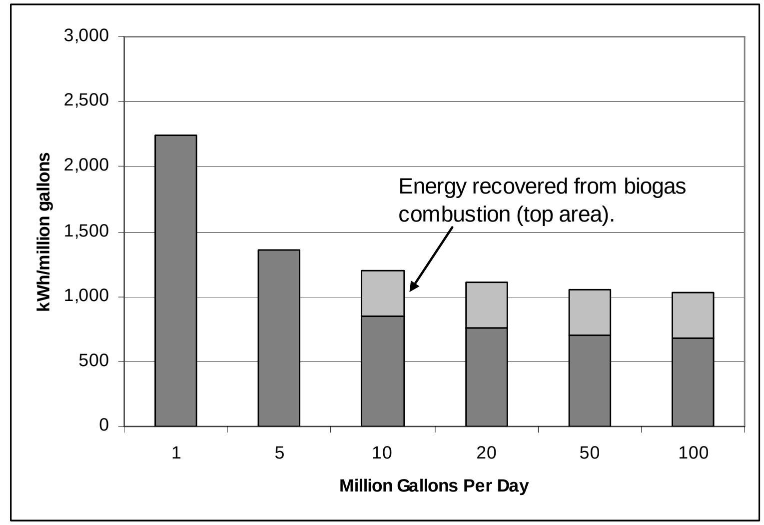
21 billion kWh / [32,175 mgd x 365 days] = 1,788 kWh/million gallons.

Exhibit 3-25: Electricity Consumption at Typical Wastewater Treatment Plants

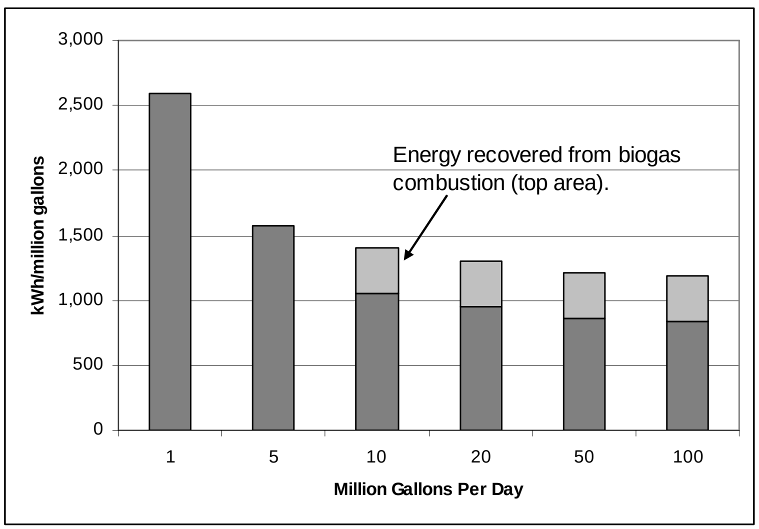
Trickling Filter Plant



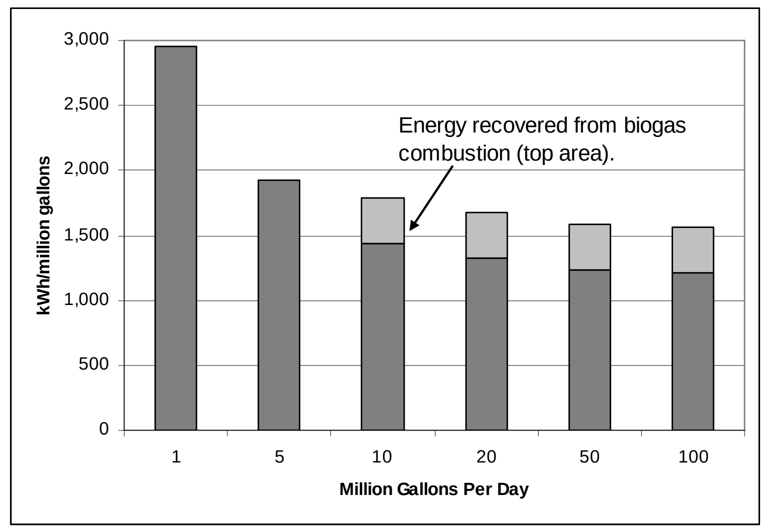
Activated Sludge Plant



Activated Sludge and Advanced Treatment without Nitrification



Activated Sludge and Advanced Treatment with Nitrification



Source: Burton (1996).

In the Iowa study, only 10 percent of the respondents (34 plants) reported the use of activated sludge treatment, while 76 percent reported the use of ponds and lagoons (IAMU, 2002, p. 30). The survey showed that significantly more electricity was used in plants that included activated sludge treatment, which is consistent with other sources reviewed (e.g., Burton, 1996). Exhibit 3-26 shows the range of reported energy consumption in the IAMU study by treatment process type. As shown in the exhibit, most of the respondents report using non-aerated facultative lagoons, which they report as having about one-third the energy requirements of plants using activated sludge processes.

Nationally, activated sludge treatment is much more prevalent than observed in the Iowa survey. Analysis of the facility data from USEPA (2003b) shows that about 34 percent of all plants have activated sludge treatment (many of which also have various types of advanced treatment as well). The larger plants have a higher prevalence of activated sludge treatment, so that about 70 percent of the total national flow is treated in plants with activated sludge treatment (see Exhibit 3-27). With this national perspective, the average electricity consumption reported in the IAMU study is biased downward because of the relatively infrequent use of activated sludge treatment among the respondents.

The AMSA survey discussed above collected information on the cost of electricity consumed at plants, although not the amount of electricity in kWh. Recognizing that electricity rates can vary across plants, we can make a rough estimate of the energy consumed using an average commercial electricity rate of $0.077/kWh.[10] The average electricity expenditure reported was about $113 per million gallons of treated water, which implies an energy intensity of about 1,500 kWh per million gallons. Of interest is that the implied energy intensity varies significantly among the AMSA survey respondents. As shown in Exhibit 3-28, the estimated energy consumption varies from less than 1,000 kWh per million gallons to more than 3,000 kWh per million gallons.

In addition to the treatment processes used at a plant, another factor that may contribute to the variation in energy intensity is the amount of pollutants that must be removed from the waste stream. Exhibit 3-29 shows that for the data in the AMSA survey, little correlation exists between the energy intensity of the treatment and the amount of BOD removed per million gallons of treated water. Further investigation is warranted to understand whether and to what extent the treatment energy requirements are affected by the pollutant loading.

Exhibit 3-26: Total Electricity Consumption Reported by Process Type in Iowa Plants

Treatment Process	Electricity Used (kWh/million gallons)	# of Respondents
Activated Sludge	3,250 to 4,400	19
Trickling Filter	750 to 1,400	27
Activated Sludge + Trickling Filter	1,250 to 3,100	4
Rotating Biological Contactor	3,200	4
Non-aerated Facultative Lagoon	300 to 1,400	130
Aerated Facultative Lagoon	1,550 to 1,800	62

All estimates are for the entire electricity requirement of the plants. All plants serving less than 10,000 people. Fewer than 343 respondents listed because not all respondents included complete energy data.
Source: IAMU (2002), p. 33.

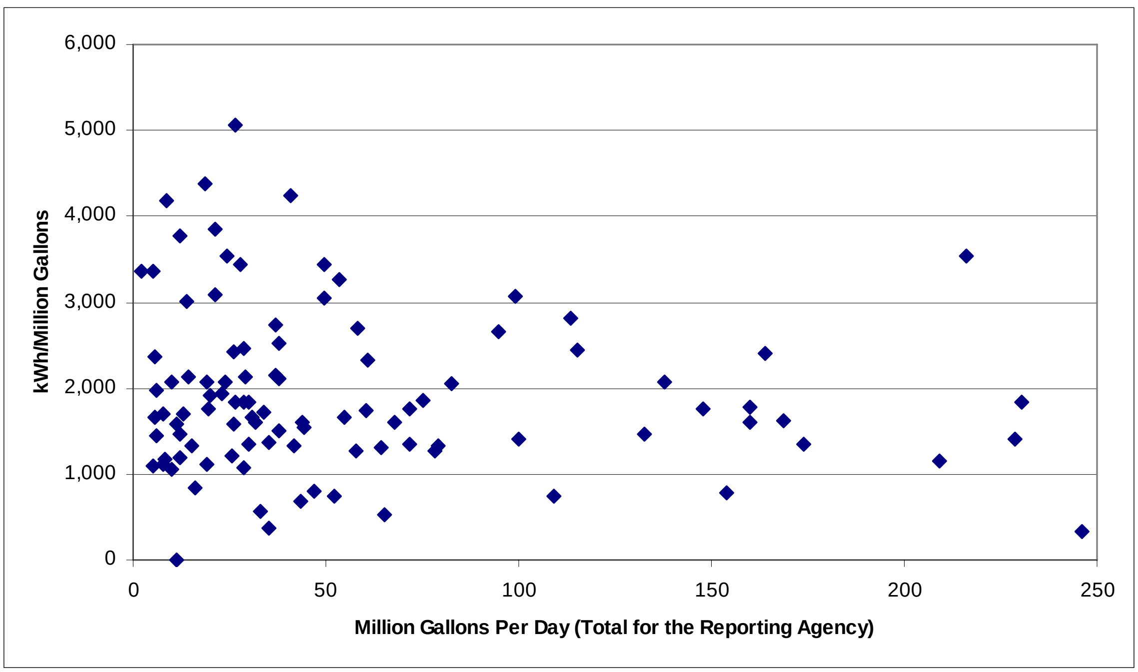
[10] The average electricity rate for commercial customers as reported by the Energy Information Agency for 2002 (EIA, 2005a).

Exhibit 3-27: Portion of Plants with Activated Sludge Treatment: National Estimate

	Average Daily Flow Rate (millions of gallons per day)						
	<0.5	**0.5-2.5**	**2.5-7.5**	**7.5-30**	**30-75**	**>75**	**Total**
Number of Plants	11,432	3,013	982	449	101	52	16,029
% of Plants with Activated Sludge Treatment	25%	49%	64%	76%	82%	79%	34%
Total Reported Flow (mgd)	1,472	3,363	4,161	6,105	4,692	10,484	30,275
% of Flow with Activated Sludge Treatment	32%	52%	65%	78%	82%	72%	70%

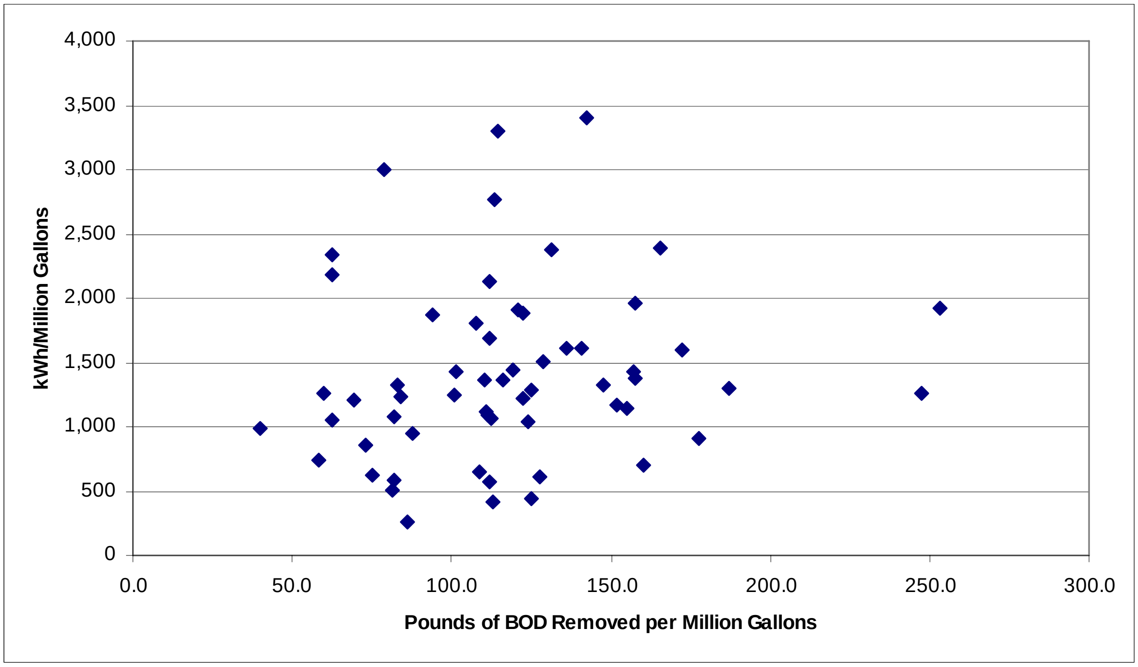
Source: Analysis of data from USEPA (2003b).

Exhibit 3-28: kWh per Million Gallons Treated Estimated from the AMSA Survey



Source: Analysis of data in AMSA (2002).

Exhibit 3-29: Energy Intensity Versus BOD Removal from AMSA Survey



Source: Analysis of data in AMSA (2002).

3.2.3 Principal Electricity Uses at Wastewater Treatment Plants and Opportunities for Improved Energy Efficiency

Although the energy intensity estimates reviewed above vary somewhat, they all indicate that energy consumption by wastewater treatment plants is significant. As a result, there has been considerable investigation to identify the major uses of electricity in wastewater treatment plants and to develop guidance and strategies for improving efficiency. The Water Environment Federation (WEF) has assembled a comprehensive review of the major uses of energy in wastewater treatment plants along with recommendations for improving efficiency (WEF, 1997). Additional reviews and guidance include:

- EPRI guidance documents on energy audits and energy efficiency retrofits (EPRI 1994 and 1998);
- NYSERDA technology assessment and energy reference guide (NYSERDA, 1995a and 1995b); and
- various USEPA publications including an energy audit manual with supporting data (USEPA, 1986).

While each treatment plant is unique, it is generally the case that *aeration* and *pumping* are the two most important uses of electricity. At plants that include activated sludge treatment (which are 70 percent of the plants with flows exceeding 2.5 mgd), aeration is typically the dominant use of electricity. As discussed above and summarized in Exhibit 3-27, 70 percent of the national wastewater flow is treated at plants with activated sludge treatment. NYSERDA (1995a) found that aeration accounts for 67 percent of electricity usage at plants that include activated sludge treatment, with pumping accounting for 21 percent. The data in Burton (1996) indicate that aeration accounts for about 30 to 55 percent of electricity use at plants with activated sludge treatment, depending on size and other processes also employed. Exhibit 3-30 summarizes the role of aeration and pumping in wastewater treatment.

Anaerobic digestion, a process used to stabilize organic sludge, can also be an important user of electricity. Organic matter is digested under conditions without oxygen at temperatures of about 90°F to 95°F (WEF, 1997, p. 127). Unlike other wastewater treatment processes, anaerobic digestion has the potential to be a net energy producer. The biogas (methane) produced during anaerobic digestion can be recovered and used to produce electricity. The waste heat from the electricity production is typically more than is needed to heat the digester (WEF, 1997, p. 127). If the biogas is not recovered and used, the process can be a significant energy consumer because of the heat required to keep the digester at temperature.

Analysis of the data in USEPA (2003b) indicates that anaerobic digestion is less prevalent than activated sludge treatment (see Exhibit 3-31), with 52 percent of flow being treated at the 19 percent of the plants with anaerobic digestion. The data also show that utilization of the biogas from anaerobic digestion is relatively uncommon, with only 15 percent of the flow being treated at plants that report using this energy recovery technology (see Exhibit 3-31). An assessment of the factors that limit energy recovery from anaerobic digestion is needed to understand better how to take advantage of this potential energy source.

Various other processes use electricity in wastewater treatment plants. Among these are lighting and space conditioning requirements, which are similar to the needs in other commercial and industrial buildings.

Despite the significant energy requirements at wastewater treatment plants, energy issues are only one of the many competing priorities that must be handled by plant operators. Plant operators focus primarily on ensuring that plants meets effluent quality requirements and on keeping operating costs in line with expectations. Capital improvements are undertaken to increase capacity to handle increasing loads as well as to enhance the ability to comply with permit requirements. The expertise of plant personnel is primarily in ensuring that the plant operates to meet its permit and effluent requirements, and is less focused on energy analysis and assessment.

Exhibit 3-30: Aeration and Pumping

Aeration is fundamental to the biological treatment of wastewater. Dissolved oxygen is required to stabilize organic material (i.e., remove BOD) as well as to nitrify and denitrify the waste stream. Aeration is also used to promote mixing to keep solids in suspension. There are two main types of aeration systems (WEF, 1997):

- diffused air systems blow air into the water using blowers and diffusers; and
- mechanical aerators thrash the water surface to drive in air bubbles and typically consist of an impeller driven on a vertical or horizontal shaft.

The efficiency of aeration systems can vary considerably, depending on the design of the equipment, how it is operated, and how it is maintained. Considerable energy savings have been achieved through evaluations and modifications of aeration system operations.

Pumping is used to move water and solids through treatment plants. Most features affecting pump system efficiency are determined during design and construction, including pipe configurations and changes in elevations. Nevertheless, there are some operation and maintenance practices that can be implemented to improve efficiency. Because of the complexity of factors affecting pumping efficiency, considerable effort can be required to identify improvements (WEF, 1997, p. 63).

Exhibit 3-31: Portion of Plants with Anaerobic Digestion and Digester Gas Utilization: National Estimate

	Average Daily Flow Rate (millions of gallons per day)						
	<0.5	0.5-2.5	2.5-7.5	7.5-30	30-75	>75	Total
Number of Plants	11,432	3,013	982	449	101	52	16,029
% of Plants with Anaerobic Digestion Treatment	10%	36%	49%	54%	48%	71%	19%
% of Plants with Digester Gas Utilization	0%	2%	6%	10%	10%	35%	1%
Total Reported Flow (mgd)	1,472	3,363	4,161	6,105	4,692	10,484	30,275
% of Flow with Anaerobic Digestion Treatment	16%	38%	49%	55%	47%	63%	52%
% of Flow with Digester Gas Utilization	1%	3%	6%	12%	10%	29%	15%

Source: Analysis of data from USEPA (2003b).

Consequently, despite the efforts mentioned above to understand and improve energy efficiency, there appears to be a relative lack of attention given to energy issues at many plants. The AMSA survey provides evidence that energy management is not a high priority for most plant operators. When asked whether "responding agencies used benchmarks to evaluate their utility performance, and if so, which benchmarks are used," 64 of the 132 responding agencies said that they use one or more performance benchmarks, and four agencies indicated that they were developing a benchmarking system (AMSA, 2002, p. 19). Only one respondent mentioned energy cost per million gallons treated (AMSA, 2002, p. 139).

The five most frequently listed benchmarks were:

- Total Cost Per Million Gallons (or 1,000 Gallons) Treated (37 respondents);
- Total Cost Per Dry Ton Biosolids Disposed or Beneficially Reused (10 respondents);
- O&M Costs Per Mile Sewer Pipe - Cleaning, Repair, Replacement, and/or Installation (10 respondents);
- Number of Overflows/Pump Station Bypasses - Per Year/Month or Per Mile (8 respondents); and
- Number of NPDES Permit Violations/Near Misses (8 respondents).

These survey results are consistent with the views of plant operators reported by Quantum regarding the most important criteria for making equipment purchase decisions. Criteria listed by respondents as "very important" were: operating costs; ease of operation; ability to handle increased flow; reliability; regulator-approved; used at other regional facilities; and payback period (Quantum, 2001, p. 4-5). Energy efficiency fell into the category of "somewhat important" as a criterion for making equipment purchase decisions.

This relative lack of attention on energy use is probably driven by the fact that energy costs are only about 10 percent of operating costs. Nevertheless, there is ample evidence that significant cost-effective energy efficiency improvements can be made. While recognizing again that each plant poses unique challenges and opportunities, the two areas mentioned most often are aeration and pumping.

Due to variations in flow rates and aeration requirements, many aeration systems are not optimized for operating conditions encountered. Within the constraints of the basic facility design, case studies demonstrate that aeration systems can be reconfigured and controlled to improve energy efficiency by impressive amounts.

Because wastewater flows and BOD concentrations vary both during the day and across days, improved aerator control to better match aeration with oxygen requirements can improve energy efficiency. Using dissolved oxygen (DO) probes, operators can adjust the systems, or automated control systems can adjust aeration rates in real time (WEF, 1997, pp. 110-111). The California Process Optimization Program (CalPOP), which is focusing on improving efficiency in wastewater treatment plants, has implemented multiple projects focusing on aeration efficiency (CalPOP, 2008), including the following:

- Riverbank Wastewater Facility (1.5 to 4.0 mgd): Based on the monitoring from a newly installed DO monitoring system, selected aerators could be turned off. Energy use was reduced an average of 18 percent, saving $20,000 annually.
- Avenal Wastewater Facility (1.7 mgd): A DO monitoring system was added to an existing control system to match aeration needs to measured DO levels. A variable frequency drive (VFD) was installed on the one aerator that runs continuously so that the control system could throttle the speed of the aerator. The second aerator is only run as needed during high demand for DO. Annual savings are estimated at 15 percent of energy use, or $38,000.
- Nipomo Wastewater Aerated Lagoon (1 mgd): Based on DO monitoring, the aerator manifold was reconfigured so that only two of three 50 hp blowers need to operate simultaneously. Blower usage was reduced by one third.
- Red Bluff Wastewater Facility (2.5 mgd): DO monitoring identified over-aeration. The existing control system was re-set to reduce aeration costs 25 percent.

Another aspect of aeration to examine is how efficiently the system is dissolving oxygen in the wastewater. Improving the oxygen transfer efficiency (OTE) will reduce the aeration energy requirement. Careful selection and use of diffusers that create fine bubbles can improve OTE compared to coarse bubble aerators, and reduce energy requirements (WEF, 1997, p. 115). Care must be taken to maintain the diffusers to prevent fouling, however. Exhibit 3-32 lists case histories of OTE improvements with fine pore diffusers. USEPA (1999) also lists examples of the use of this technology.

Improving pumping efficiency requires site-specific data on the variability of pumping requirements and other factors affecting load. Efficient motors and VFDs are often mentioned, along with proper sizing of pumps to meet varying needs (e.g., NYSERDA, 1995b). The California Energy Commission (CEC) reports several case studies of savings from these technologies, including the Encina Wastewater Authority (36 mgd). In their project they report saving $21,000 per year through the use of VFDs and $15,000 per year through the use of high-efficiency motors (CEC, 2003b). East Bay Municipal Utility District (EBMUD) reports saving $273,000 annually through the use of high-efficiency pumps and motors with VFDs (CEC, 2003b). These savings were estimated to be about 50 percent of the facility’s baseline pumping costs.

Exhibit 3-32: Example Case Studies of the Use of Fine Pore Diffusers

Plant (capacity)	Technology	Cost	Payback
Frankenmuth, MI (18 mgd)	Ceramic disc diffusers	$190,000	Not reported
Glastonbury, CT (3.6 mgd)	Rigid porous plastic diffusers	$28,000	2 years
Green Bay, WI (52.5 mgd)	Ceramic disc diffusers	Not reported	4.5 years
Hartford, CT (60 mgd)	Fine pore dome diffusers	$600,000	<2 years
Ridgewood, NJ (3 mgd)	Fine pore diffusers	Not reported	10-11 years
Wittier Narrows, CA (15 mgd)	Disc and dome diffusers	Not reported	2.8 years
Cleveland, WI (0.2 mgd)	Porous plastic plate fine pore diffusers	$11,500	5 years
Plymouth, WI (1.65 mgd)	Ceramic disc diffusers	$220,000	11 years
Renton, WA (72 mgd)	Perforated flexible membrane tube diffusers	$380,000	4 years

Source: WEF (1997), pp. 115-120.

Quantum reports that 60 percent of facilities in the Pacific Northwest currently use variable speed drives, and 30 percent would consider using them (Quantum, 2001, p. 4-6). The extent to which these energy efficiency measures are deployed nationally has not been assessed.

To estimate potential national cost-effective energy savings at wastewater treatment plants, we can make some assumptions. Our assumptions are in agreement with the estimates for wastewater treatment plant energy consumption as indicated in the recently completed AWWA RF study (2007). First, we consider the aeration requirements at plants with activated sludge treatment:

- Electricity use for aeration is significant at plants with activated sludge treatment. Based on Burton (1996), aeration requires at least 500 kWh per million gallons of water treated. Based on other data discussed above, the aeration requirements may be as high as 50 percent of total energy use. Because the total energy use for plants with activated sludge processes are higher than the average, the aeration requirements could be about 1,000 kWh per million gallons, based on 50 percent of a 2,000 kWh of total energy use. We use a range of 500 to 1,000 kWh per million gallons for purposes of making this order of magnitude estimate.
- Improved aeration control is likely achievable at most plants. The largest plants may have already implemented automated controls, but even when controls are in place, improvements are typically possible (WEF, 1997, p. 110). We can assume conservatively that on average a 10 percent efficiency improvement can be achieved in a cost effective manner. In the case studies we note that the savings were larger.
- The total wastewater flow at plants with activated sludge treatment is about 21,000 mgd (see Exhibit 3-27).

Using these figures, the energy efficiency potential from improved aeration at activated sludge facilities is:

Savings = 500 to 1,000 kWh/million gallons x 10% improvement x 21,000 mgd x 365 days
= 383 to 766 million kWh per year from improved aeration systems.

Next, we can look at the pumping requirements at all plants. We have less evidence regarding the savings potential for pumping. The pumping energy requirements are on the order of 150 kWh per million gallons (Burton, 1996). Recognizing that not all pumping situations are suitable for improved efficiency, we assume a 2 percent average efficiency improvement. Using these assumptions, the total savings across all facilities is:

Savings = 150 kWh/million gallons x 2% improvement x 31,275 mgd x 365 days
= 34 million kWh per year from improved pumping systems.

At $0.077/kWh, these combined savings are worth about $32 to $62 million annually. Additional characterization and evaluation is needed to improve these estimates. However, based on the information available, they are a reasonable order of magnitude estimate.

Energy recovery from the use of digester gas may also be valuable. Based on the statistics from USEPA (2003b), it appears that there is significant untapped potential. No estimate of the energy recovery is made at this time, however.

3.3 Linkage Opportunities with Energy Efficiency Programs

Energy efficiency programs provide resources for capturing untapped energy efficiency opportunities at both water supply and wastewater treatment systems. Conditions in these industries that suggest an energy efficiency effort tailored to them could result in significant energy savings include:

- cost effective energy efficiency improvements appear to be available that are not being undertaken due to informational or other barriers;
- there appears to be a lack of recognized energy performance benchmarks against which system operators can evaluate their energy performance and motivate action; and
- energy costs are substantial in the water supply and wastewater treatment industries.

Section 7 discusses resources available from energy-efficiency programs.

4. Power Generation

No sector demonstrates the interconnected nature of water and energy more than the electric power industry. In 2002, more than 4,500 power plants produced electric power throughout the United States. The overwhelming majority of water used in the industry is for cooling steam that is used to produce power. As described in Section 2, water withdrawal for power plant cooling is the largest single use of water in the U.S., estimated at 195,000 million gallons per day (mgd) (USGS, 2004, p. 6). Approximately 70 percent of the water withdrawal comes from freshwater sources, totaling about 136,000 mgd. This withdrawal is about equal to all the freshwater withdrawn for irrigation (the second largest use), and is more than three times the total withdrawal for public water supplies (USGS, 2004, p. 6).

While the amount of water withdrawn is substantial, water consumption is a small fraction of the total. On average, most of the water is returned to the lake, river, or harbor from which it was withdrawn, with about two percent of the water being consumed (USGS, 1998, p. 48). The amount of consumption varies significantly across facilities, depending primarily on the type of cooling system used.

The importance of water supplies for power plant siting, and the impact of power plant water use on surrounding water resources, have received considerable attention over the past 30 years. Water withdrawal and discharge are regulated by the Clean Water Act, under which regulatory requirements continue to be examined and revised (e.g., USEPA, 2001c). Most recently, the competing requirements for increasing both power production and water supply, particularly in the water-limited but rapidly growing southwest, have been highlighted (Hewlett Foundation, 2003). Consequently, there is considerable interest in opportunities to reduce the water requirements for power production.

This section first summarizes the principal uses of water at power plants. Then, we calculate the amount of water withdrawn and consumed to estimate the water intensity of electricity production. The potential role of dry cooling is discussed as a means of reducing water consumption by new electric power plants. Finally, this section concludes with an estimate of the impact of energy efficiency on water consumption by power plants.

4.1 Water Uses at Power Plants

4.1.1 Power Plant Cooling Water

Electric power generation uses water in several ways and varying amounts depending on the type of generation technology and cooling system employed (CEC, 2002, p. 1-3). Water is used primarily for condensing steam, which is referred to as power plant cooling. The basic process is shown in Exhibit 4-1. A boiler or other heat source is used to produce steam, which is used to turn a turbine. The turbine turns the generator, which produces electricity. After turning the turbine, the steam must be condensed back to water. A condenser is used to transfer the heat from the steam to cooling water. The condensed water is pumped back to the boiler to start the cycle again.

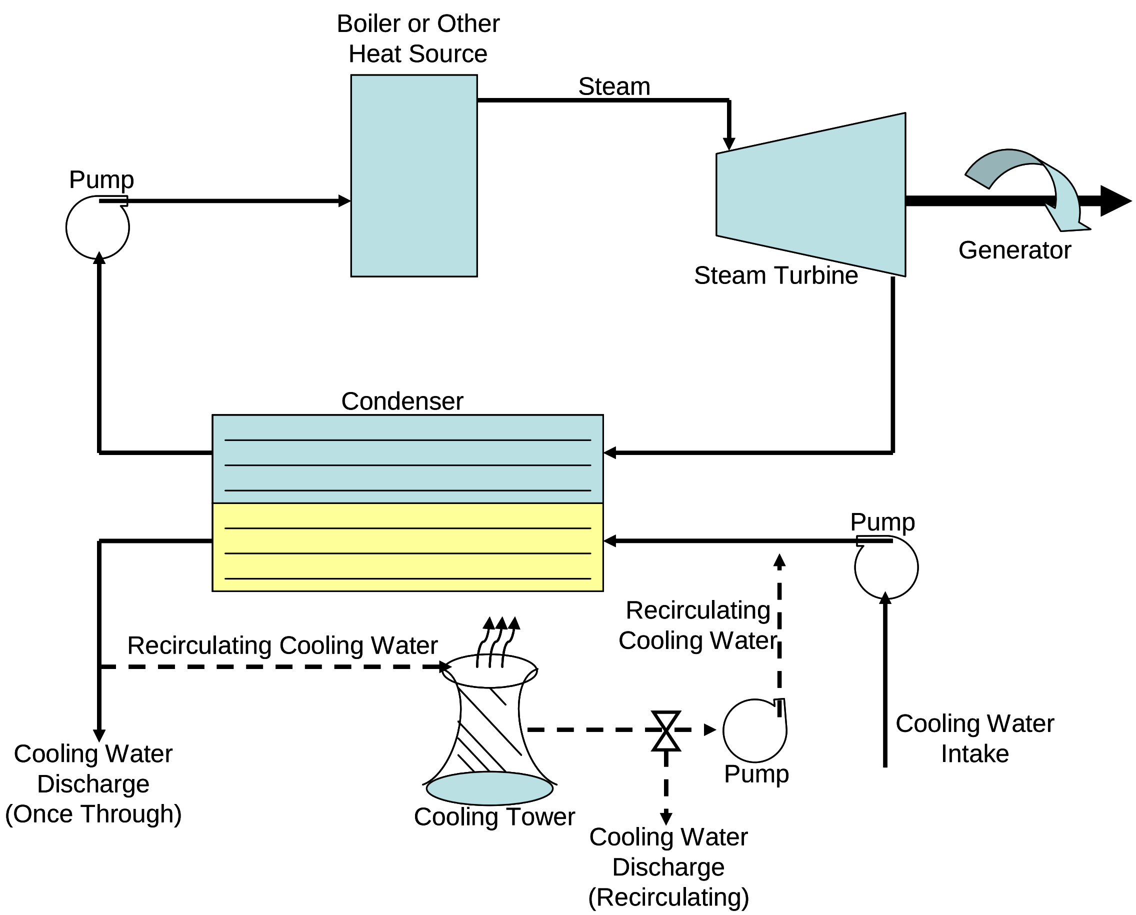
Cooling water systems are configured in two types: once-through and recirculating.

- <u>Once-Through Systems</u>. In cooling systems that only use water once—i.e., once-through systems—the cooling water is drawn from a source such as a river, lake or ocean. The cooling water takes the heat that is transferred from the steam in the condenser and is discharged, typically back to its source. The cooling water typically increases by about 20°F (CEC, 2002, p. 2-4), and can increase by more than 30°F (CEC, 2001, p. 27).

- Recirculating Systems. Some cooling systems recirculate the cooling water. As shown with dashed lines in the exhibit, the recirculated cooling water is typically cooled using a cooling tower. The cooled water can then be pumped back to the condenser to pick up heat. In some cases a cooling pond is used in place of a cooling tower.

Condensing steam in the condenser is a critical component of the power plant. A properly operating condenser, with cooling water at the appropriate temperature, prevents backpressure from building up at the turbine. If backpressure builds up, a 5 to 10 percent reduction in electricity production can occur (USEPA, 2001c, pp. 3-9 to 3-12). If the backpressure rises to unacceptable levels, the plant must be taken off line. Consequently, care is taken to ensure that the cooling system operates properly.

Exhibit 4-1: Typical Cooling Water Configurations



Once-through cooling systems withdraw very large amounts of water, and discharge virtually all the water back to its original source. Prior to the enactment of the Clean Water Act, once-through cooling was the dominant choice for power plant design (Micheletti and Burns, undated, p. 3). Following the requirement that best available technologies be used to minimize the environmental impact of cooling water use, recirculating systems became the standard cooling method for newly constructed power plants (Micheletti and Burns, undated, p. 2). Recirculating systems withdraw much less water, but a portion of the water is evaporated in the cooling tower.

Nearly all the power plants in the United States that use steam turbines use either once-through or recirculating cooling water systems (or a combination of both). The steam may be produced by coal, gas, nuclear energy, or other fuels. In nearly all cases, however, cooling water is used to condense the steam. About two-thirds of the utility electric power plant capacity in the U.S. is steam generation (analysis of data in EIA, 2008) and about 85 percent of recent U.S. electricity production was from steam (EPRI, 2002, p. vii). Consequently, cooling water is commonly used to condense steam at power plants in the U.S.

About 22 percent of electric power generating capacity is combustion turbines in which fuel (typically natural gas) is burned directly in a turbine.[11] Because steam is not used in the process, cooling water is not used to condense steam. Nearly one-third of this combustion turbine capacity is configured in combination with a steam turbine to provide a "combined cycle" power plant. In this configuration, fuel is burned directly in the combustion turbine to turn a generator. The exhaust from the turbine is hot, so it can be used to produce steam.

In Exhibit 4-1, the hot exhaust from the combustion turbine would be the heat source for the steam. Once the steam is produced, the process of using the steam to produce electricity is as depicted in the exhibit. Consequently, in combined cycle power plants, cooling water is used on the steam portion of the power production, but not on the combustion portion.[12]

The remaining electric power capacity in the U.S. is made up of hydroelectric power (about 10 percent) and other miscellaneous sources. Cooling water is not used in these other plants.

4.1.2 Other Uses of Water at Power Plants

Water is used at electric power plants for several purposes in addition to cooling water for condensing steam, including the following (CEC, 2002, p 1-4):

- Steam: The water for producing steam must be replaced periodically.
- Emissions Control: Water is used in some NOx control systems.
- Auxiliary Equipment Cooling: Water may be used to cool various pieces of equipment. Chief among the cooling applications can be intake air cooling for combustion turbines. Intake air to the combustion turbine may be cooled to prevent loss of power output of the turbine, particularly during hot weather (TICA, 2008).
- Plant Maintenance and Personnel Needs: Water is used for cleaning and related uses, as well as for toilets, showers, drinking water, and other personnel needs.

Although these water uses are small compared to cooling water withdrawals, they can comprise up to nearly one-third of total water consumption at individual combined cycle power plants with recirculating cooling systems (CEC, 2002, p. 1-4).

One study recently examined whether hydroelectric power is an important consumer of water (Torcellini, et al., 2003). Water flowing through turbines and into the river is not considered a consumptive use of water because the water is immediately available for other uses. However, the authors examined the increased evaporation associated with converting a flowing stream to a reservoir. When viewed in this way, the creation of a reservoir causes a substantial increase in evaporation, which may be considered a consumptive use of water because the water is no longer available for use downstream (Torcellini, et al., 2003, p. 3). The amount of increased

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[11] A combustion turbine is similar to a jet engine, in which fuel is combusted to turn the turbine directly without the use of steam.

[12] Gas-fired combined cycle power plants are increasingly the design of choice of new plant construction. By virtue of using the waste heat from the combustion cycle, they are more efficient than traditional steam plants. Additionally, by using natural gas, they have lower air emissions than typical coal-fired plants.

evaporation was calculated to be significant, with total water consumption more than double the consumption for power plant cooling water.[13]

It is important to recognize that dams and reservoirs have wide ranging impacts on the local environment, as well as diverse benefits in terms of water supply, recreation, and flood control. It is inappropriate to assign 100 percent of the evaporative consumption of water from reservoirs solely to electric power production. For purposes of this report, we acknowledge that these evaporative losses are significant, but do not address them further.

As mentioned above, once-through cooling systems increase the temperature of the cooling water prior to its discharge. The increased water temperature can increase the amount of evaporation from the receiving body of water (EPRI, 2002, p. 3-2). These incremental evaporative losses can be significant, and may be considered a consumptive use of water from these plants even though the consumption does not occur on site.

4.2 The Rate of Water Consumption at Power Plants

4.2.1 Cooling Water Consumption at Power Plants

The rate of water consumption in power plants is typically expressed in terms of water use per unit of electricity produced, or gallons per kWh. While various studies have examined water use from power plant cooling, the underlying data on water withdrawal, discharge, and use originate from the Energy Information Administration (EIA) Form 767. Using this form, power plants with capacities of 100 MW or more report their annual water use for power plant cooling. These data can be compared to the power generation reported by the same plants on Form 767 to calculate water use per kWh.

The Form 767 data for 2002 show considerable variability.[14] The data include the following:

- Water withdrawal, discharge and consumption are reported for each cooling system in units of cubic feet per second. These data represent annual average values.
- The type of cooling system is identified, including once-through versus recirculating systems.
- A single power plant may have multiple cooling systems, so that a single power plant may have both once-through and recirculating cooling systems.
- A single power plant may have multiple generating units. The electricity generation data reported in Form 767 include only the generation at those units for which cooling water is used. The generation data do not include, for example, generation from combustion turbines that do not use cooling water, but are located at the same power plant.

The total dataset provided information on 1,625 cooling systems at 734 different power plants. These observations were summarized into plants with once-through systems, recirculating systems, and mixed systems (in which both once-through and recirculating types are reported). Exhibit 4-2 shows the estimates of water withdrawal per kWh generated for once-through and recirculating systems. As shown in the exhibit, the withdrawal rate for once-through systems is

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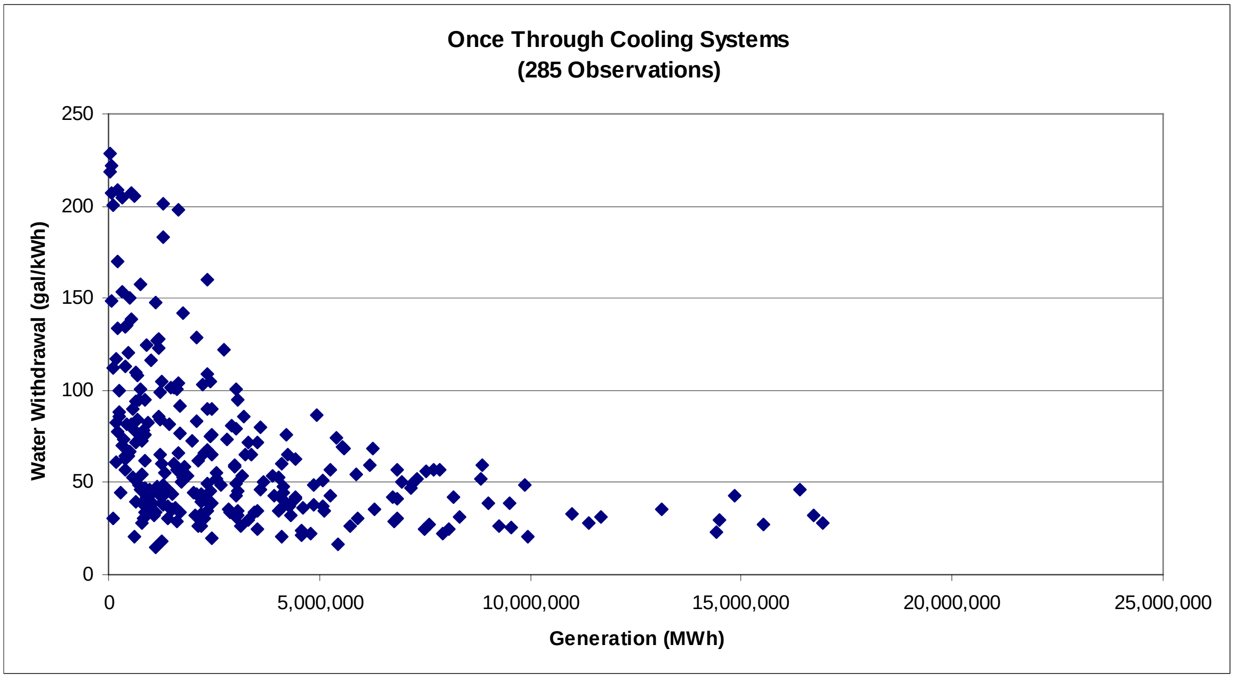
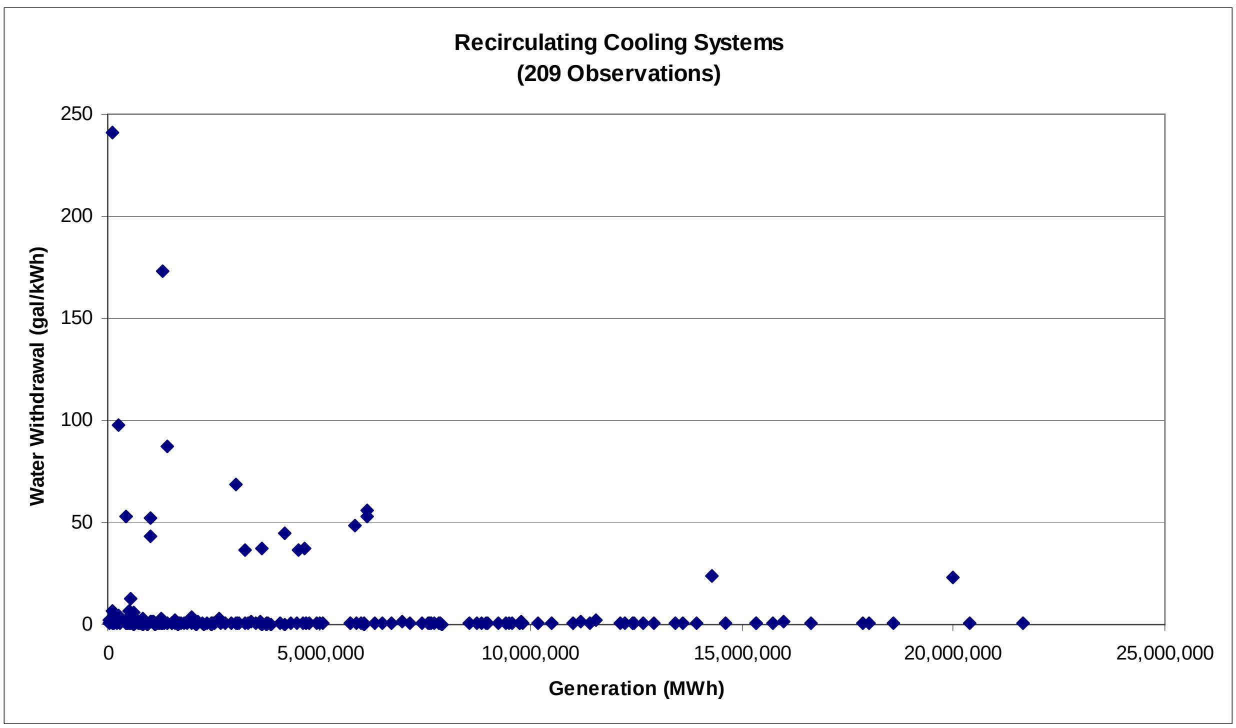
[13] The comparison here is for water consumption, not water withdrawal. The increased evaporation due to reservoirs was estimated to be more than double the water consumption associated with power plant cooling. As discussed in the text, only a small fraction of the water withdrawn for power plant cooling is in fact consumed.

[14] Some apparent data entry errors were identified by comparing 2002 data with 2000 and 2001 data for the same plants. One significant data edit performed was the replacement of water withdrawal and consumption values of 1706 cubic feet per second with 17.6 for one power plant (#6139, in Texas) based on comparison with previous years.

much larger than for recirculating systems, ranging from 15 gallons per kWh to more than 200 gallons per kWh. By comparison, the withdrawal rates for recirculating systems are nearly all below 10 gallons per kWh.

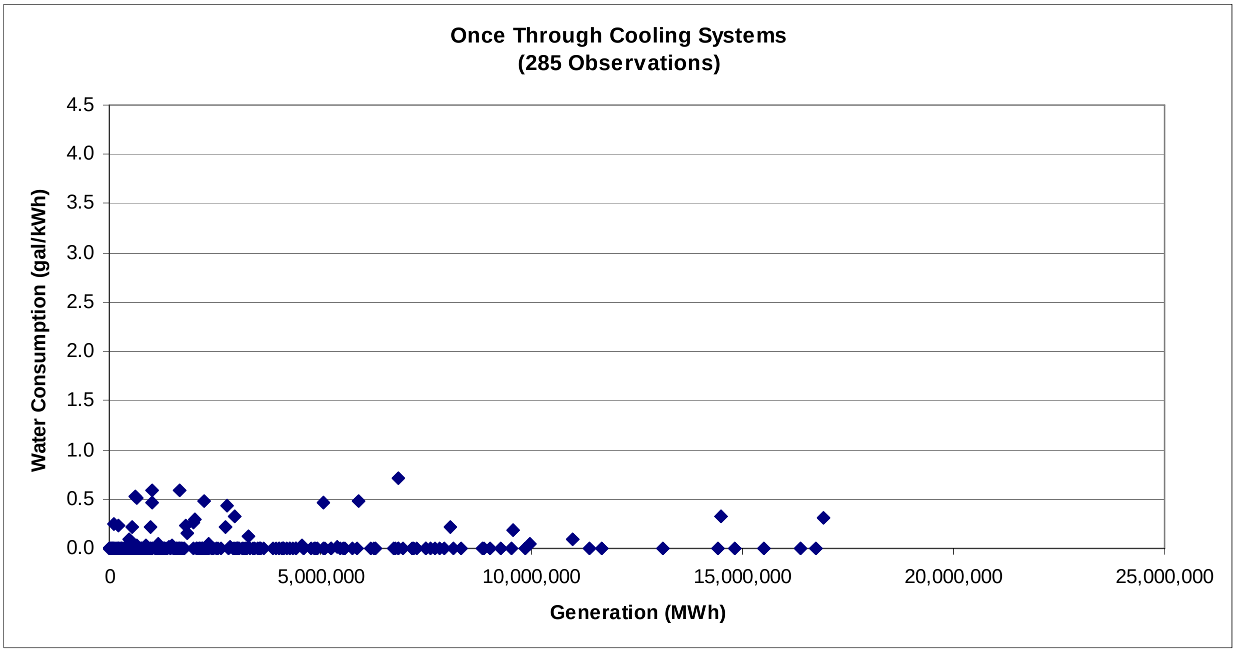
Exhibit 4-2: Water Withdrawal for Power Plant Cooling Water

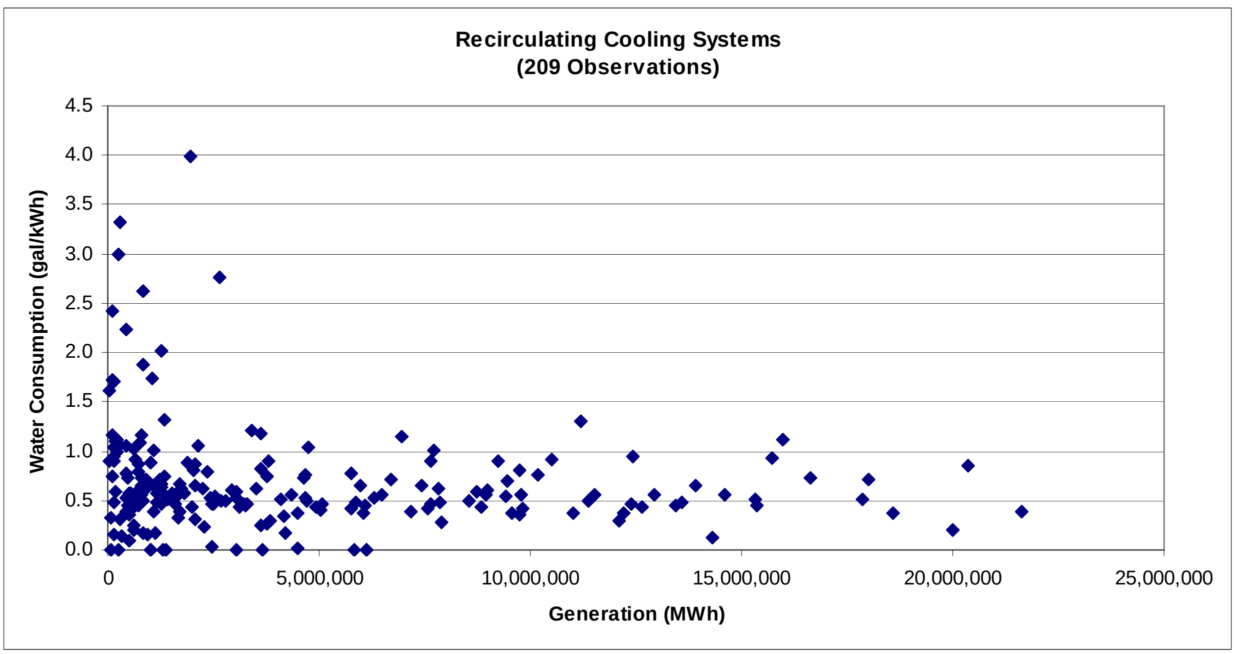




Source: Analysis of EIA Form 767 data for 2002 (EIA, 2004).

Exhibit 4-3: Water Consumption for Power Plant Cooling Water





Source: Analysis of EIA Form 767 data for 2002 (EIA, 2004).

Exhibit 4-3 shows that recirculating systems consume more water than once-through systems. As shown in the exhibit, recirculating systems typically consume about 0.5 gallons per kWh, while nearly all the once-through systems are substantially below that level. Summary statistics for the available data include:[15]

- Once-through systems:
  - The average water consumption rate is about 0.11 gallons per kWh. This average is influenced heavily by the relatively small number of observations with non-zero consumption rates: 86 percent of the observations report no water consumption (all the water withdrawn is reported as being discharged).
  - The median rate of water withdrawal is 54 gallons per kWh. The 25th and 75th percentile values are 36 and 87 gallons per kWh, respectively.
  - Total electricity production from the plants in the data set was about 915 million MWh in 2002, or about 24 percent of the national total.
  - The estimates are based on data for 285 power plants with only once-through cooling systems and valid and complete data for purposes of performing the calculations.
- Recirculating systems:
  - The average water consumption rate is 0.75 gallons per kWh. The median consumption rate is 0.55 gallons per kWh. The 25th and 75th percentile values are 0.39 and 0.88 gallons per kWh, respectively.
  - The median rate of water withdrawal is 0.81 gallons per kWh. The 25th and 75th percentile values are 0.57 and 1.9 gallons per kWh, respectively. These withdrawal rates are on the order of 1.5 to 2.2 percent of the withdrawal rates for once-through cooling systems.
  - Total electricity production from the plants in the data set was about 990 million MWh in 2002, or about 26 percent of the national total.
  - The estimates are based on data for 209 power plants with recirculating cooling systems and valid and complete data for purposes of performing the calculations.

These water withdrawal and consumption figures for cooling water are consistent with recent estimates by CEC and EPRI (see Exhibit 4-4).

Because these values apply to steam condensing, they do not reflect the water intensity of electricity production using combined cycle power plant configurations. Typically, the total generating capacity of a combined cycle plant is two-thirds from combustion turbines and one-third from steam turbine generation. Because the combustion turbines use no cooling water to condense steam, the total cooling water consumption is associated only with the steam turbine portion of the plant. As a result, water withdrawal and consumption per kWh for the complete combined cycle plant is about one-third the value for the steam portion alone.

For example, a combined cycle plant may produce 480,000 MWh in a year, with 320,000 MWh coming from the combustion turbine and 160,000 MWh coming from the steam turbine. If the cooling water requirement for the steam cycle is 0.6 gallons per kWh, then the total cooling water consumption would be 0.6 gallons/kWh x 160,000,000 kWh = 96 million gallons. This cooling water requirement would then be divided by the total plant output of 480,000 MWh to

[15] Note that the data for 2002 do not include nuclear power plants.

calculate the total water consumption per kWh for the entire plant, which would be 0.2 gallons per kWh.

The total cooling water consumption for all electric power production in the U.S. depends on the mix of generating technologies used and the mix of cooling systems used. Unfortunately, the data needed to match cooling system use to actual power generation is lacking (EPRI, 2002, p. 4-5). As demonstrated above, there is wide variation in water consumption among plants and between once-through and recirculating cooling systems. Additionally, the portion of power produced by combustion turbines and combustion turbines in combination with steam turbines (combined cycle) influences the average rate of water consumption.

Exhibit 4-4: Cooling Water Withdrawal and Consumption for Steam Plant Cooling

	This Paper Median (25^{th} to 75^{th} percentile)	**CEC (2002)**	**EPRI (2002)**
Once-through Cooling			
Withdrawal Rate (gallons/kWh)	54 (36 to 87)	30 to 45	20 to 50 (fossil) 25 to 60 (nuclear)
Consumption Rate (gallons/kWh)	0 (0 to 0)[a]	Negligible	About 1% of withdrawal[b]
Recirculating Cooling			
Withdrawal Rate (gallons/kWh)	0.81 (0.57 to 1.9)	0.6 to 0.9	0.5 to 0.6 (fossil) 0.8 to 1.1 (nuclear)
Consumption Rate (gallons/kWh)	0.55 (0.39 to 0.88)	0.72	0.48 (fossil) 0.72 (nuclear)

[a] 86 percent of the observations reported no water consumption.
[b] Includes increased evaporation from the receiving body of water due to temperature increase in the cooling water.
Values reported for steam cycle only. Not applicable to combined cycle power plant cooling. See text.
Estimates for this paper from analysis of EIA Form 767 data (EIA, 2004).

Recognizing these data limitations, EPRI estimated total cooling water consumption at approximately 2,300 to 3,000 million gallons per day (mgd) for the year 2000 (EPRI, 2002, p. 6-3).[16] Given total annual electricity generation of about 3,800 million MWh in 2000 (EIA, 2007a), the average rate of water consumption is about 0.2 to 0.3 gallons per kWh. This estimate is a total average across all electricity production, including electricity that does not require cooling water (such as hydroelectric power and electricity from combustion turbines).

As discussed above, evaporation from streams and lakes may be increased by the higher temperature of the water discharged from once-through cooling systems. For once-through cooling the amount of evaporation may be on the order of 0.3 gallons per kWh, or about one percent of the water withdrawal for this type of cooling (EPRI, 2002, p. 3-2). This figure is included in the EPRI estimate of water consumption. Increased evaporation is not expected for recirculating cooling systems because the water is cooled prior to its discharge (see Exhibit 4-1).

[16] The EPRI (2002) estimate is for freshwater consumption. Saline water consumption for cooling water is expected to be very small because coastal cooling systems are typically once-through designs. Consequently, the estimate of freshwater consumption is taken as total consumption.

The cooling water consumption requirements of newly constructed power plants can vary substantially. Given that once-through cooling for steam cycles is not expected to be used, the options for new plants may include:

- combustion turbine with no cooling water consumption;
- combined cycle power plant with a recirculating cooling system consuming about 0.2 gallons per kWh; and
- steam plant with a recirculating cooling system consuming about 0.6 gallons per kWh.

Additionally, dry cooling systems are emerging as an alternative (see below). The relative environmental attributes of each of the options is undergoing examination and debate (see, e.g., CEC, 2002 and USEPA, 2001c).

4.2.2 Other Uses of Water

The other uses of water are typically much smaller than cooling water consumption. CEC estimated these other uses for various configurations of power production, including (CEC, 2000, p. 1-4):

- Stand alone steam plant: 0.03 gallons per kWh for evaporation, blowdown, and other uses. This water use is about 5 percent of the average water use per kWh for recirculating cooling water systems at steam plants.
- Combustion turbine: 0.15 gallons per kWh for inlet air cooling, emissions control, and other uses. No cooling water is used at these plants.[17] This rate of water usage is about 25 percent of the average recirculating cooling water use at steam plants.
- Combined cycle power plant: 0.11 gallons per kWh, computed as 2/3 times the rate for the combustion turbines plus 1/3 times the rate for steam plants.[18] This rate of water use is about 50 percent of the use for recirculating cooling water estimated for these plants.

Water may also be used for coal gasification at some facilities. Although not in wide use, EPRI estimates water consumption at about 0.15 gallons per kWh for gasification when used in combined cycle configurations (EPRI, 2002, p. 3-7).

As combustion turbines and combined cycle power plants account for an increasing share of future total electricity production in the U.S., these water uses will take on increasing importance in overall water consumption. Because steam plants currently dominate total electricity production, these uses remain minor.

4.3 Dry Cooling

Dry cooling is emerging as a technical option for reducing water withdrawal and consumption by electric power plants. As shown in Exhibit 4-5, steam is condensed in an air cooled condenser that uses no water. The air cooled condenser is similar to an enormous automobile radiator. The steam is passed through pipes with fins over which air is blown. The air picks up the heat from the steam, thereby condensing the steam to water.

The principal concerns regarding dry cooling are its cost and its decline in capacity during hot weather. The decline in cooling capacity causes a reduction in the amount of power that can be produced, and is called an “energy penalty.” Unfortunately, it is precisely during hot weather that

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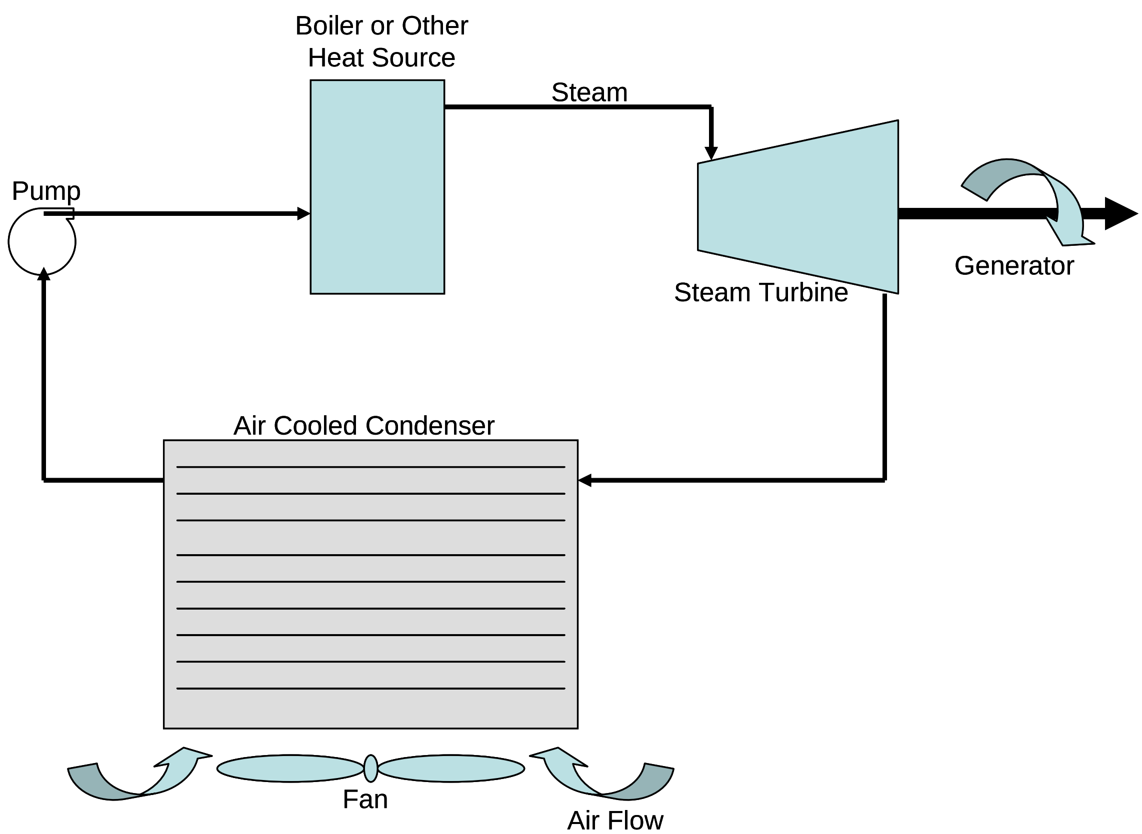
[17] The water consumption for inlet air cooling at combustion turbines was estimated to be about 0.036 to 0.072 gallons per kWh for those turbines that use it (CEC, 2002, p. 6-3).

[18] The calculation is: 0.03 / 3 + 0.15 x 2 / 3 = 0.11.

a reduction in production capacity is generally most unfavorable. The severity of this concern regarding cooling capacity depends on the temperature profile of the site. More hours of high temperatures translate into greater concern over loss of capacity.

USEPA (2001) estimated the magnitude of the energy penalty for a range of conditions. Exhibit 4-6 summarizes the estimates for average load conditions and peak load conditions during hot summer weather. As shown in the exhibit, current expectations are that the reduction in generating capacity can be significant when using dry cooling.

Exhibit 4-5: Typical Dry Cooling Configuration



These energy penalties are not inevitable, however. To overcome this problem with cooling capacity, the size of the air cooled condenser can be increased so that under high ambient temperature conditions the system has adequate cooling capacity. Increasing the size increases capital and operating costs. A larger facility also requires more land, and may be taller, making it more visible. Another option for addressing this problem is to operate a combined or "hybrid" wet and dry cooling system. The wet portion of the cooling system would only be used when high temperature conditions were encountered. A hybrid system also adds capital and operating costs, as well as operating complexity. Micheletti and Burns (undated, p. 12) indicate that the operational complexities could be significant.

Given that the energy penalties can be addressed through system design, the primary issue to be considered for dry cooling is not energy penalties, but rather cost. At this time, the construction and operating experience with dry cooled systems is extremely limited in the U.S. (Micheletti and Burns, undated, p. 9), and the available literature contains little quantitative cost information (CEC, 2002, p. 3-3). The optimal tradeoff among design capacity and operating parameters for a full range of ambient temperature conditions has not been defined. Consequently, the increased costs of dry systems, and the cost-optimal tradeoff between energy penalty and capital and operating costs, are not known precisely.

CEC (2002) summarizes the history of the use of dry cooling in the U.S. and around the world. We do not repeat the information here but note that dry cooling has been used more frequently in Europe and South Africa than in the U.S., particularly in areas where cooling water is not available. Its first large U.S. installation (330 MW power plant) was at a coal mine in Wyoming in 1977 where water supplies were limited (CEC, 2002, p. 3-5). Very few plants were built in the U.S. using dry cooling through the 1980s and 1990s.

Increasingly, dry cooling power plants are starting to be proposed and built to address water supply and environmental concerns. Maher (2002) summarizes dry power plant cooling activity in southern Nevada, showing that the majority of new capacity is proposed with dry cooling. Dougherty discusses dry cooling power plants proposed and built in Massachusetts, including the conclusion that dry cooling is being recognized as the best alternative for avoiding permitting impasses in the state (Dougherty, 2002, p. 17). Despite these recent trends, power generation capacity on dry cooling remains limited in the U.S. (CEC, 2002, p. 3-6).

Exhibit 4-6: National Average Energy Penalty by Cooling System Type

	Nuclear Power		Combined Cycle		Fossil Fuel	
Cooling Type	**Average Load**	**Peak Load**	**Average Load**	**Peak Load**	**Average Load**	**Peak Load**
Recirculating versus Once Through	1.7%	1.9%	0.4%	0.4%	1.7%	1.7%
Dry Cooling versus Once Through	8.5%	11.4%	2.1%	2.8%	8.6%	10.0%
Dry Cooling versus Recirculating	6.8%	9.6%	1.7%	2.4%	6.9%	8.4%

Average Load = 67% capacity.

Peak Load = 100% capacity during hot weather.

Estimates are national averages. Results vary by location.

Source: USEPA (2001), p. 3-2.

Because the design and cost of dry cooling systems are sensitive to site-specific temperature conditions, CEC (2002) examined four California locations to compare the costs and benefits of alternative cooling options. For a 500 MW gas-fired combined cycle power plant that is typical of the new plants proposed for California, the incremental capital costs of dry cooling over a recirculated cooling water system was about $15 million to $44 million (CEC, 2002, p. 9-3). The range is driven by the temperature conditions across the four sites. The higher incremental costs are expected for the desert study site that has high ambient temperatures for a large number of hours. The lower costs are for a Bay area location that rarely experiences high temperatures. No incremental operating and maintenance costs were identified. For purposes of comparing the alternative cooling systems, the cooling systems were designed to enable the power plant to perform at the level that would be achieved using a typical recirculating water cooling system.

The total initial capital cost for a gas-fired combined cycle power plant in California is on the order of $600 per kW (CEC, 2003c, p. C-3 and CEC, 2000, p. 36), making the approximate total cost for the CEC example about $300 million. The incremental capital cost of the dry cooling systems adds about 5 percent to 15 percent to these capital costs. Because the capital costs are only a portion of the total levelized cost for a new power plant, the percent impact of the increased capital costs on total levelized costs per kWh will be less, possibly on the order of 1 percent to 7 percent.

An analysis by the Hewlett Foundation estimates an increase in capital costs of about 3.5 percent for dry cooling, with an impact on total annualized costs of about 0.19 cents per kWh over and above the costs for a typical recirculating cooling system (Hewlett Foundation, 2003, p. 12). This impact on total annualized cost is consistent with the range developed from the CEC analysis.

Given the relative lack of design and operating experience for dry cooling systems in the U.S., much remains to be learned regarding the cost and performance tradeoffs under the diverse operating conditions encountered across the country. As the competing needs for water supply and electricity production are addressed, dry cooling may take on increased importance, particularly in arid and semi-arid locations. In areas with adequate water supply, such as Massachusetts, dry cooling systems may be considered as a means of reducing overall impacts on water resources.

4.4 The Water Impacts of Energy Efficiency

National, regional, and local energy efficiency programs promote energy-efficiency products, processes, and practices. The programs are designed to reduce overall energy costs for consumers, as well as prevent pollution associated with the production and use of energy. By improving energy efficiency and reducing energy production, water consumption associated with electricity production is also reduced. Section 7.2 presents several examples of the key relationships between energy efficiency and water efficiency opportunities.

5. Residential Water Consumption

Residential water is supplied primarily by two sources: public water supply systems and self-supply from groundwater wells. As discussed in Section 2, public supply systems accounted for about 10.6 percent of annual water withdrawals in 2000, while self-supply accounted for about 0.9 percent. Together, these two sources are the third largest sector for withdrawals, after power plant cooling and irrigation (USGS, 2004, p. 7). Residential water use accounts for about two-thirds of the water use in this sector, or about 7 percent of annual withdrawals. The remaining one-third of the water is used for commercial, institutional, and other uses.

Also referred to generally as “urban water use,” these withdrawals amounted to about 46,900 million gallons per day (mgd) of freshwater in 2000. A substantial portion of this withdrawal is consumed, estimated at about 19 percent or about 8,000 mgd in 1995 (USGS, 1998, p. 19). Consumption includes landscaping irrigation, conveyance losses (leaks), evaporation, and water consumed by drinking. In 1995, this water consumption was second only to water consumed for irrigation. The urban water that is not consumed is typically treated in a wastewater treatment plant (see Section 3) and discharged to a receiving body of water.[19]

Although withdrawal and consumption are small compared to water used for irrigation, urban water use is typically highly visible. Population growth and economic development depend critically on continued access to high quality, reliable sources of water. Consequently, states and community water systems work to ensure adequate supply and delivery to meet evolving needs. Recognizing the importance of protecting drinking water quality, the 1996 Amendments to the Safe Drinking Water Act (SDWA), required states to develop comprehensive Source Water Assessment Programs (SWAP) that:

- identify the areas that supply public tap water;
- inventory contaminants and assess water system susceptibility to contamination; and
- inform the public of the results (USEPA, 1997a).

All 50 states have had their SWAPs approved by EPA (USEPA, 2001b).

As discussed above in Section 3, about 161,000 public and private water supply systems provide potable water throughout the United States, serving residential, commercial, institutional, and industrial customers. Community water systems serve a population of more than 273 million, and approximately 3,900 large and very large community water systems (those serving more than 10,000 people) serve a total of about 221 million. Most people in the U.S. receive their water from these large community systems.

This section reviews residential end uses of water and summarizes opportunities for improved efficiency. The impact of water rates and billing on consumption is discussed briefly. This section concludes with a discussion of the links between residential water and energy efficiency programs.

5.1 Residential End Uses

Residential water uses are generally familiar, and include both indoor and outdoor uses. Indoor water use is typically defined by the fixtures that use the water, including:

- toilets;

[19] Of note is that in coastal communities, the treated wastewater is often discharged to the ocean, so that the treated water is not available for freshwater uses downstream. Consequently, although the water is discharged, it is not available for beneficial use by others and may be considered to be consumed.

- showers and baths;
- clothes washers (laundry);
- faucets;
- dishwashers; and
- other (e.g., evaporative coolers).

Outdoor water use is often considered as a single category, and includes irrigation for lawns and gardens, water for pools and spas, and other uses. Leaks are encountered both inside and outside residences, and may include leaking pipes and faulty valves (e.g., a leaking faucet or toilet).

This section focuses on indoor uses of water. This focus is not meant to imply that outdoor uses are not important. Outdoor use is highly variable, and in arid climates, outdoor residential water use can exceed indoor use. Examining the factors affecting outdoor use and the opportunities for improving efficiency, although beyond the scope of this report, are important topics worthy of investigation.

To aid in water supply and delivery planning, studies have been conducted to understand residential water use. Most recently, studies have examined opportunities to reduce water use, particularly indoor uses, through the use of water-efficient appliances and fixtures. The 1984 study by Brown and Caldwell for the Department of Housing and Urban Development (HUD) is an often referenced work that examined water use rates for selected residential appliances and fixtures (Brown and Caldwell, 1984 and Mayer, et al., 1999). Multiple studies in the 1980s and 1990s examined billing data and metered individual fixtures and appliances to better understand the pattern of residential water use.

In the mid-1990s a new method of examining residential end uses of water was developed, and subsequently deployed in a large scale study of 1,188 homes in 12 cities in the U.S. and Canada. The study, titled *Residential End Uses of Water* (Mayer, et al., 1999), provides the most complete picture of indoor residential water use available today (see Exhibit 5-1). Three follow-on studies were subsequently conducted using the same method that examined the impact of installing water-efficient appliances and fixtures on water use in the home.

Exhibit 5-2 presents the measured indoor water use by end use for each of the 12 study sites. As shown in the exhibit, the mean indoor water consumption in gallons per capita per day (gpcd) varied from 57.1 gpcd in Seattle to 83.5 gpcd in Eugene, with an overall average of 69.3 gpcd. Water use for toilets, clothes washers, and showers are the three largest uses in nearly all the cities. The data are shown graphically in Exhibit 5-3.

Mayer, et al. (1999) present a detailed analysis of each end use. Highlights include:

- <u>Toilets</u>: Water for toilet flushing is the largest use in 10 of the 12 locations. The cities with the lowest per capita toilet water use also had the lowest mean flush volume (gallons per flush) and the highest saturation of ultra-low flush (ULF) toilets as revealed by the measured flow data.[20] These data support the assertion that ULF toilets can reduce water usage in the home. Of note is that the mean flushes per capita per day did not increase for ULF toilets (Mayer, et al., 1999, p. 109).

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[20] Ultra-low flush toilets are defined as having a design flush rate of less than or equal to 1.6 gallons per flush. For purposes of the analysis in Mayer, et al. (1999), all flushes under 2.0 gallons were counted as ULF toilet flushes.

- Clothes Washers: The data in Mayer, et al. (1999) were collected prior to the significant adoption of resource efficient clothes washers. Consequently, little variation was found in the water use per capita per day. The average volume per load was 40.9 gallons and the average number of washer loads per capita per day was relatively constant at 0.37 across the study sites (Mayer, et al., 1999, pp. 95, 103).
- Showers: While there is variation in the amount of water used for showers across the study locations, the mean shower flow rate (in gallons per minute, gpm) was found to be relatively constant across all the locations. The variation in water use appears to be driven by the frequency of showers per person, which is probably correlated with the ages of the occupants. The average flow rates were all below the 2.5 gpm mandated under the Energy Policy Act of 1992 (EPAct), indicating that many users reduce their shower flow rates to under this level even though they do not have a low flow showerhead (Mayer, et al., 1999, p. 110).[21] However, only 15 percent of the homes studied had EPAct compliant flow rates exclusively. The majority of the homes (60 percent) had a mixture of pre-EPAct flow rates and EPAct compliant flow rates, and 25 percent of the homes had all their showers exceed the EPAct flow rate (Mayer, et al., 1999, p. 143). Consequently, although the average flow rate is less than 2.5 gpm, 85 percent of the homes have data showing that some or all of their showers have flow rates exceeding 2.5 gpm. The study was able to compare homes in which all showers taken had flow rates below 2.5 gpm (LF Homes) with those in which all showers taken had flow rates above 2.5 gpm (non-LF Homes). The LF Homes used about 4.5 gpcd less water for showers compared to non-LF Homes, despite taking slightly longer showers on average (Mayer, et al., 1999, p. 134).
- Leaks: The rate of leakage was highly variable. The median leak rate of 4.2 gallons per home per day (gphd) is well below the average rate of 21.9 gphd. Nearly 67 percent of the homes measured had leak rates below 10 gphd, and 5.5 percent of the homes had leak rates of more than 100 gphd ((Mayer, et al., 1999, p. 139). A small portion of the homes account for the majority of the leakage.

Mayer, et al. compare their results to previous studies (see Exhibit 5-4). The two largest studies, Mayer, et al. and the HUD study, have similar overall results (Mayer, et al., 1999, p. 128). While noting the general consistency of the various study results, it is important to recall that the study by Mayer, et al. was not meant to be statistically representative of cities generally. Demographic characteristics, such as age and time spent away from home (e.g., at work or school) have an impact on indoor water use in the home. Additionally, the price of water has been measured to have an impact on consumption, with higher prices for water and sewer services tending to reduce indoor water use. Nevertheless, the relative similarity of the results across the study sites provides some measure of confidence in the indoor use data despite potential regional differences.

[21] As of January 1, 1994, all newly manufactured shower heads were required by EPAct to have flow rates of 2.5 gpm or less at a water pressure of 80 pounds per square inch (psi). Complying shower heads are often referred to as “low flow” showerheads.

Exhibit 5-1: Overview of *Residential End Uses of Water*

Overview. *Residential End Uses of Water* presents a comprehensive measurement and analysis study of residential water use in 12 cities in North America. The objective of the study was to provide specific data on the end uses of water in residential settings, and to develop predictive models to forecast residential water demand. Funded by the American Water Works Association Research Foundation (AWWARF), the study was led by Aquacraft, Inc. and was conducted with the cooperation and assistance of the local water utilities and their customers.

Water use was measured at 1,188 homes in 12 cities. Individual end use data were obtained for two two-week periods at each house. Demographic data for each house were also obtained from the occupants, along with billing data from the utilities.

Measurement Method. This study was the first large scale deployment of a new measurement technique that enabled end use data to be collected in a cost-effective manner. A data logger was installed on each home's water meter that recorded cumulative water use every 10 seconds. The data loggers provided two weeks of virtually continuous flow data for each of two measurement periods for each home. The signature flow pattern of each end use appliance and fixture was identified using pattern recognition software, so that the total flow could be segmented into each end use. The segmented flow data provide the detailed flow measurements by end use. Both the accuracy of the data loggers and the segmentation of the total flow into individual end uses were verified. For example, the signature flow pattern for each toilet in the house was determined and then detected in the data. The number of times each toilet was flushed, and the amount of water used for each flush, were then able to be calculated.

Results. *Residential End Uses of Water* provides detailed measurements of water use by end use in each of the 12 study locations. The 12 locations were not selected to be statistically representative of all cities in North America. Nevertheless, the indoor uses of water show consistent patterns across the cities. The average indoor water use was 69.3 gallons per capita per day (gpcd), with toilets, clothes washers, and showers accounting for 65 percent of the total indoor use. Total indoor water use was correlated with the number of residents in the home. Outdoor use was highly variable, depending on weather, lot size, and other factors.

Availability: The study is available from the American Water Works Association (AWWA) bookstore at: http://www.awwa.org/bookstore/productlist.cfm?cat=0.

Source: Mayer, et al., 1999.

Exhibit 5-2: Indoor Residential Water Use by End Use and Study Site (gallons per capita per day)

Study Site	# Obs	People/ House	Toilet	Clothes Washer	Shower	Faucet	Leak	Other	Bath	Dish-washer	Mean	Median	Std Dev
Seattle, WA	99	2.8	17.1	12.0	11.4	8.7	5.9	0.0	1.1	1.0	57.1	54.0	28.6
San Diego, CA	100	2.7	15.8	16.3	9.0	10.8	4.6	0.3	0.5	0.9	58.3	54.1	23.4
Boulder, CO	100	2.4	19.8	14.0	13.1	11.6	3.4	0.2	1.4	1.4	64.7	60.3	25.8
Lompoc, CA	100	2.8	16.6	15.3	11.1	9.9	10.1	0.9	1.2	0.8	65.8	56.1	33.4
Tampa, FL	99	2.4	16.7	14.2	10.2	12.0	10.8	0.3	1.1	0.6	65.8	59.0	33.5
Walnut Valley WD, CA	99	3.3	18.0	14.1	11.7	12.3	7.6	2.3	1.0	0.8	67.8	63.3	30.8
Denver, CO	99	2.7	21.1	15.6	12.9	10.5	5.8	0.5	1.6	1.2	69.3	64.9	35.0
Las Virgenes MWD, CA	100	3.1	15.7	16.8	11.4	11.2	11.2	1.1	1.3	0.9	69.6	61.0	38.6
Waterloo & Cambridge, Ont.	95	3.1	20.3	13.7	8.3	11.4	8.2	6.0	1.9	0.8	70.6	59.5	44.6
Phoenix, AZ	100	2.9	19.6	16.9	12.5	9.6	14.8	2.2	1.2	0.8	77.6	66.9	44.8
Scottsdale & Tempe, AZ	99	2.3	18.4	14.5	12.6	11.2	17.6	5.0	0.9	1.1	81.4	63.4	67.6
Eugene, OR	98	2.5	22.9	17.1	15.1	11.9	13.6	0.1	1.5	1.4	83.5	63.8	68.9
12 Study Sites	**1188**	**2.8**	**18.5**	**15.0**	**11.6**	**10.9**	**9.5**	**1.6**	**1.2**	**1.0**	**69.3**	**60.5**	**39.6**

Source: Mayer, et al. (1999).

Distribution by end use for the 12 Study Sites:
(CW = clothes washer; DW = dishwasher)

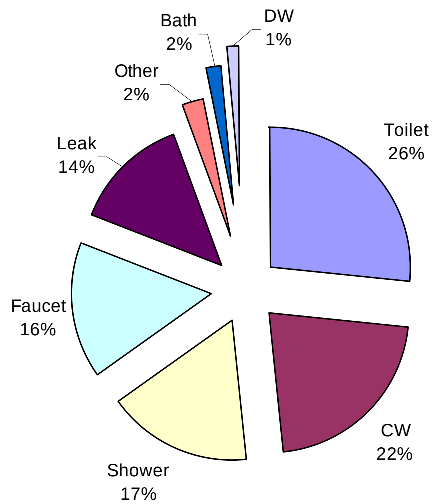
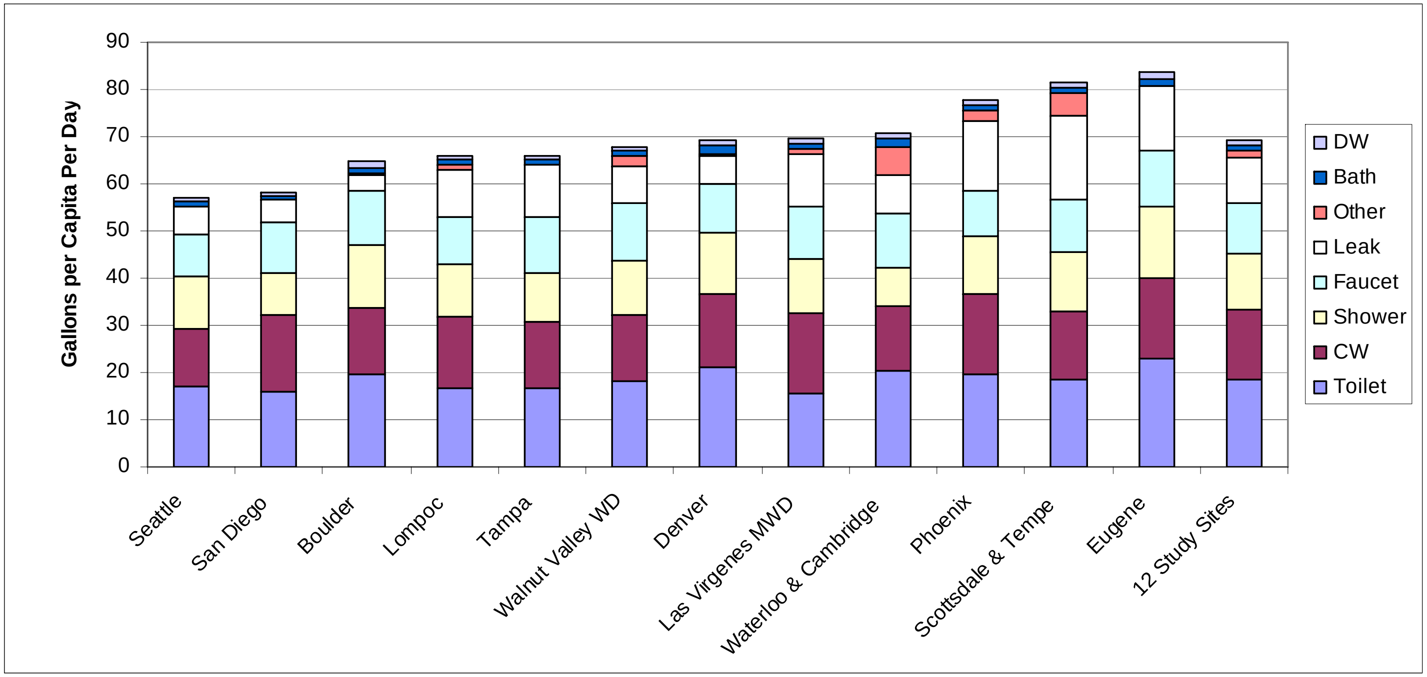


Exhibit 5-3: Indoor Residential Water Use by End Use and Study Site



Source: Mayer, et al. (1999).

CW = clothes washer; DW = dishwasher

Exhibit 5-4: Comparison in Indoor Water Use Measurements Among Studies (gpcd)

Fixture	1984 HUD Study	1991 East Bay MUD (CA)	1993 Tampa (FL)	1994 Heatherwood (CO)	1995 Westminster (CO) pre-1977 housing	1995 Westminster (CO) post-1984 housing	1998 Data 12 cities Mayer, et al.
Toilet	24.3	12.8	13.7	15.1	18.4	14.1	18.5
Shower & Bath	18.9	13.5	11.0	11.1	14.1	14.1	12.8
Laundry	12.6	--	--	14.4	14.7	13.0	15.0
Faucets	10.4	--	--	9.1	6.7	5.3	10.9
Dishwasher	--	--	--	1.9	0.8	0.7	1.0
Other	--	13.7	26.0	--	7.3	0.1	1.6
Leaks	--	--	--	7.2[a]	1.5[a]	3.3[a]	9.5[a]
Total	**66.2**	**40.0**	**50.7**	**58.8**	**63.5**	**50.6**	**69.3**
# of homes	210	25	25	16	20	20	1,188

[a] Leakage includes indoor and outdoor leaks.

Source: Mayer, et al. (1999), p. 129.

Sources cited: Brown and Caldwell (1984); Aher, at el. (1991); Anderson, et al. (1993), Aquacraft (1994) and Aquacraft (1996).

5.2 Opportunities to Improve Residential Water Use Efficiency

There has been considerable research and investigation into opportunities to improve water efficiency and reduce residential water use. The available data strongly support the conclusion that indoor water use can be reduced significantly using cost-effective retrofit fixtures and appliances. The WaterSense program is developing a series of product specifications for high performing, high-efficiency fixtures that exceed the EPAct water use requirement. Products that meet these specifications are currently available on the market or can readily be brought to market. Accelerated retirement of old fixtures and replacement with new WaterSense labeled fixtures is cost effective in most cases (see discussion on cost effectiveness in section 5.2.2).

5.2.1 Measured Water Savings

Numerous water conserving "tips for consumers" are available that describe both behavioral options and opportunities for replacing appliances and fixtures.[22] The water saving tips from the U.S. Environmental Protection Agency are available at USEPA (2007a), and the "water saver home" profile is hosted by CUWCC (2006). The Federal Energy Management Program (FEMP) has developed recommendations for using domestic water conservation technologies and practices in government facilities, including housing, hospitals, and office buildings (FEMP, 2002). Landscaping styles and irrigation alternatives that are suitable for local conditions are often promoted. In many cases, efforts to promote efficiency are emphasized during drought conditions (e.g., PDEP (2003) and Massachusetts (2004)). Recommendations for saving water typically address the major residential uses of water, as summarized in Exhibit 5-5.

[22] An Internet search on "tips for saving water" yields numerous sites. Examples from around the U.S. include: CUWCC (2006), LCRA (2008), American Water (2008), GDNR (2004).

Exhibit 5-5: Typical Tips for Saving Water

End Use	Behavioral Recommendations	Appliance/Fixture Recommendations
Toilet	Check for leaks and replace leaking flapper valves.	Replace old toilets with new WaterSense labeled high efficiency toilets (HETs) or models that comply with the EPAct limits of 1.6 gallons per flush.
Shower	Take shorter showers (during drought conditions). Reduce flow rate during showers.	Replace shower heads with showerheads that comply with the EPAct limits of 2.5 gpm maximum.
Faucets	Do not allow the water to run unnecessarily (e.g., while shaving or brushing teeth).	Install faucet aerators or replace faucets to with WaterSense labeled faucets or faucet accessories when available or models that comply with the EPAct limits of 2.2 gpm (kitchen) and 2.2 gpm (lavatory) maximums.
Clothes Washer	Wash full loads.	Replace standard washers with ENERGY STAR qualified clothes washers.
Dishwashers	Wash full loads.	Replace standard dishwashers with resource-efficient dishwashers (that carry the ENERGY STAR label) that save water and energy.
Irrigation	Limit watering to late evenings to reduce evaporation. Only apply the amount of water needed by the plants. Check for and repair leaks. Do not allow the water to run unnecessarily.	Install WaterSense labeled irrigation products when available or irrigation timers. Use WaterSense certified irrigation professionals or modify landscaping to require less water.

The water savings achievable, particularly with appliance and fixture retrofits, have been measured and documented in multiple studies. In addition to documenting the savings under laboratory conditions, field studies have demonstrated the effectiveness of water conserving technologies under typical operating conditions in homes. Most recently, several retrofit studies have been conducted to measure the savings using the following method:

- Select Homes: Homes are selected for the study and data are collected for each, including demographic data and past billing data.
- Measure a Baseline: Baseline water use is measured under typical conditions for a period such as two weeks.
- Install New Appliances and Fixtures: New appliances and fixtures, such as clothes washers, toilets, and shower heads, are installed in the homes included in the study.
- Measure Post-Installation Water Use: Following a period of adjustment (such as several months), water use is measured under typical conditions.
- Estimate Savings: The water savings are estimated as the difference between the post-installation use and the baseline use. A control group of homes that did not receive the retrofits may be used to examine potential changes in use unrelated to the retrofit installations.

This method can provide estimates of the impact of specific retrofit technologies on actual water use under field conditions. Impacts on residential irrigation use are not typically assessed using this method because irrigation requirements vary substantially during the year, and brief measurements (e.g., for two weeks at a time) cannot quantify the impact of changes in practices.

With funding from the U.S. EPA and others, Aquacraft, Inc. recently conducted retrofit studies in three locations: Seattle, Washington, East Bay Municipal Utility District (EBMUD, Oakland, California), and Tampa, Florida. The studies examined water savings from retrofitting toilets, clothes washers, shower heads, and faucets. The study participants were selected to represent customers with indoor use of more than 60 gpcd, which as a group puts the participants above the average use in these three areas. Baseline water use reasonably corresponded to expectations, as shown in Exhibit 5-6. One difference identified was that the leakage rates in Tampa and EBMUD were significantly higher than the rates found in Mayer, et al. (1999) (see Exhibit 5-2).

Exhibit 5-6: Baseline Water Use from Aquacraft Retrofit Studies (gallons per capita per day)

End Use	Retrofit Studies			REUW
	Tampa	**EBMUD**	**Seattle**	
Bath	2.6	3.0	3.7	1.2
Clothes Washer	14.7	13.9	14.8	15.0
Dishwasher	0.6	1.0	1.4	1.0
Faucet	9.4	10.5	9.2	10.9
Leak	18.9	25.7	6.5	9.5
Shower	12.7	12.0	9.0	11.6
Toilet	17.9	19.9	18.8	18.5
Other	0.5	0.1	0.2	1.6
Total	**77.2**	**86.2**	**63.6**	**69.3**
# Homes	26	33	37	1,188
People/Home	2.91	2.55	2.54	2.80

REUW = *Residential End Uses of Water* study by Mayer, et al. (1999).
Source: Aquacraft, 2004, p. 29.

The results of these three retrofit studies confirm that indoor water use can be reduced significantly using readily available retrofit technologies. The technologies examined were:

- Toilets: Replace pre-1994 toilets with ultra-low flush (ULF) toilets that comply with the 1.6 gallon maximum flush requirements in EPAct.
- Clothes Washers: Replace standard clothes washers with ENERGY STAR qualified clothes washers.[23]
- Showerheads: Replace pre-1994 showerheads with low-flow (LF) showerheads that comply with the 2.5 gallon per minute maximum flow rate in EPAct.
- Faucets: Install aerators on kitchen and bathroom faucets or replace faucets with models that comply with the EPAct maximum flow requirements.

The results of the studies show that ULF toilets can save approximately 10 gpcd and resource efficient clothes washers, including ENERGY STAR models, can save about 5 to 7 gpcd. There

[23] See Section 7.6 for ENERGY STAR clothes washer saving opportunities.

was more variability in the savings from low-flow showerheads and faucets that comply with EPAct flow rates (see Exhibit 5-7).

Of note is that the retrofits also reduced leaks, primarily from toilets. As shown in Exhibit 5-7, leaks were reduced in all three study locations, by significant amounts relative to the baseline leak rates in each location. These leak reductions were primarily associated with the elimination of leaking toilets through the retrofits with new toilets. When the reductions from the appliances and fixtures are added to the reductions from the leaks, the overall impact on indoor residential water use is a reduction of about 35 percent to 50 percent. This amount of reduction is achieved using current technologies that are widely available. In the case of the ULF toilets, faucets, and low-flow showerheads, these performance levels are required by EPAct in all new products. The studies demonstrate that pre-EPAct products continue to be in widespread use.

Exhibit 5-7: Measured Water Use Reductions in Retrofit Studies (gallons per capita per day)

Study	ULF Toilets	CW	SH	Faucets	Total: Toilets, CW, SH & Faucets	Leaks	Reduction[a] (% of Baseline)
Aquacraft Retrofit Studies							
Tampa (2003)	10.1	6.9	3.5	3.2	23.7	15.2	50%
EBMUD (2003)	10.1	5.2	1.3	0.0	16.6	16.8	39%
Seattle (2000)	10.9	5.6	0.3	1.2	18.0	4.3	35%
Comparison Retrofit Studies							
SWEEP (2001)		5.3					
Mayer, et al. (1999)	10.5		4.5				
Westminster (1999)		4.6					
Bern, Kansas (1998)		7.2					
Heatherwood (1996)	2.6	10.9					
MWD (1992-94)	11.4						
Tampa (1993)	6.1		3.6				
EBMUD (1991)	5.3		1.7				

ULF Toilets = Ultra Low Flush Toilets. Retrofit is a toilet complying with EPAct maximum of 1.6 gallons per flush. Some retrofits included dual flush modes, with partial flush volumes (for liquid wastes) of less than 1.0 gallon per flush.

CW = Clothes Washer. Retrofit is one of several ENERGY STAR labeled clothes washers.

SH = Showerheads. Retrofit is a showerhead complying with EPAct maximum flow of 2.5 gallons per minute.

[a] Reduction = Reduction from toilets, clothes washers, showerheads and faucets and leak reduction divided by total baseline (from Exhibit **5-6**).

Source: Aquacraft (2004), pp. 56, 60, 65.

Sources cited: Brown and Caldwell (1984); Aher, at el. (1991); Chesnutt, et al. (1992); Anderson, et al. (1993), Aquacraft (1994); Aquacraft (1996); and Tomlinson and Rizy (1998), Sullivan, et. al. (2001).

Aquacraft (2004) compares the results from the three studies to previous studies and finds similar water savings from these appliances and fixtures. In addition to the studies identified in Exhibit 5-7, additional studies provide supporting evidence for the water savings estimates.[24] Two examples are as follows:

[24] Gleick, et al. (2003) discusses additional evidence for water saving estimates.

- A study focusing on clothes washers was conducted by Oak Ridge National Laboratory in Boston in 2000 (Durfee and Tomlinson, 2001). The savings reported for 50 condominiums was calculated to be about 4.1 gpcd. This value is less than the approximately 5 to 7 gpcd found by Aquacraft. A portion of the difference appears to be accounted for by the fewer loads of laundry per person found in the Boston study (0.32 loads per person per day) compared to the results from the Aquacraft studies (0.32 to 0.42 loads per person per day). Of note is that the average age of the Boston study participants was above 50 (Durfee and Tomlinson, 2001, p. 6).
- The Jordan Valley Water Conservancy District evaluated the savings from replacing 275 residential toilets with three models of ULF toilets (Mohadjer, 2003). The average water savings for the 42 toilets with flow measurements and flush counters was 8.1 gpcd (Mohadjer, 2003, p. 9). Additionally, the authors noted that the replacements reduced toilet leaks by a comparable amount (Mohadjer, 2003, p. 10).

In addition to these technologies, resource-efficient, including ENERGY STAR, dishwashers have also been examined for their water savings. The Save Water and Energy Education Program (SWEEP) found a 39 percent reduction in dishwasher water use when ENERGY STAR labeled dishwashers replaced existing dishwashers in 50 homes in two Oregon communities (Sullivan, et al., 2001, p. 34). Overall, this study found a 25 percent reduction in indoor water use from retrofitting toilets, clothes washers, and dishwaters (leaks were not measured) (Sullivan, et al., 2001, p. 26).

While all these data point to significant savings, the measurements were typically performed within several months of retrofit installation. The persistence of the savings remains to be assessed. Water savings from clothes washers, faucets and showerheads would be expected to remain so long as the appliance or fixture remains in place. However, there has been some concern that water savings from ULF toilets may not be maintained. Over time, toilet flapper valves wear out and need to be replaced.[25] Replacement flapper valves tend to increase the flush volumes of toilets, in some cases significantly (NAHB Research Center, 2002). Additionally, leaks from flapper valves (the primary source of leaks), may reappear due to valve deterioration over time. Consequently, attention to replacement flapper valves and how they affect water use is a high priority. To address this issue, trim durability and marking requirements were incorporated into ASME Standard A112.19.5–Trim for Water-Closet Bowls, Tanks, and Urinals. Meeting this standard is a requirement for HETs carrying the WaterSense Label.

Lack of consumer acceptance or changes in consumer behavior can also affect the savings achieved. The Aquacraft, Boston, and Jordan Valley studies each examined customer satisfaction. In all cases, customer satisfaction was higher for the newly retrofitted products than it was for the original fixtures and appliances. Although possible concerns have been raised regarding the performance of ULF toilets, the studies reviewed here did not find customer dissatisfaction problems with ULF toilets. The Jordan Valley study noted that one of the three ULF toilet models used in that study performed less well compared to the others, with only 69 percent of recipients recommending it to others, while the other models were recommended by 92 percent and 96 percent of recipients (Mohadjer, 2003, p. 5).

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[25] Most residential toilet designs use a flapper valve to effectuate the flushing of the toilet. The activation of the flush handle lifts the flapper valve, which allows water to flow from the tank into the bowl for the flush. As the flapper valve wears, it may not seal completely, causing the toilet to leak. Replacement flapper valves are often different configurations from the original designs, such that the average flush volume is increased. See NAHB Research Center (2002) and Gauley and Koeller (2003) for additional information on replacement flapper valves.

Recently, increased attention has been paid to the performance of toilets, including developing improved test methods that better reflect field conditions (Gauley and Koeller, 2003).[26] Tests show a wide range in the performance of ULF toilets, in terms of the amount of solid waste that is cleared reliably in a single flush (Gauley and Koeller, 2003, pp. 7-8). The high satisfaction with the retrofit toilets in the above studies appears to be due to the use of models that generally perform well. The one model that was a concern in the Jordan Valley study was not rated highly by Gauley and Koeller. With release of the WaterSense HET specification and the labeling of these products, consumers will have assurances on the performance and water saving potential of these products.

Based on a review of the available data, the evidence supports strongly that water conserving fixtures and appliances are effective in reducing water use under realistic field conditions. In a comprehensive review of water supply and conservation options, Western Resource Advocates (2003) estimated water use for homes equipped with a range of fixtures and appliances. Based on their analysis, we can identify water use patterns of three types of homes:

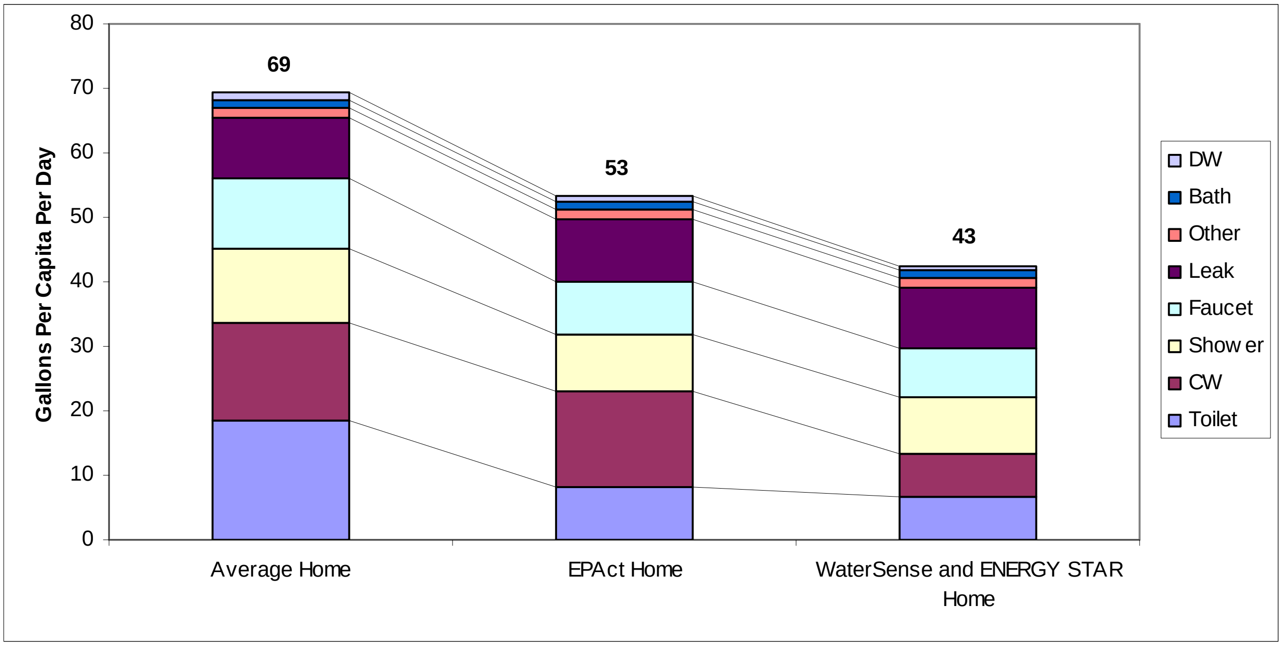
- Average Homes that use water according to the estimates in Mayer, et al. (1999).
- EPAct Homes that include fixtures and appliances that comply with EPAct standards, including ULF toilets, LF shower heads and LF faucets.
- WaterSense and ENERGY STAR Homes that include WaterSense labeled high-efficiency toilets and faucets, that go beyond EPAct requirements and reduce leaks an additional 2 gpcd beyond EPAct Homes. Additionally, these homes include ENERGY STAR clothes washers and dishwashers, which combined generate a savings of approximately 9 gpcd beyond EPAct Homes.[27]

Exhibit 5-8 presents the estimates for these three configurations. As shown in the exhibit, the total water use per capita per day can be reduced significantly using these measures. By switching from pre-EPAct to currently available EPAct compliant plumbing fixtures and appliances, consumers can realize savings of over 20 percent. Additionally, by investing in ENERGY STAR and WaterSense products, consumers could save an additional 15 percent. Combined these measures have the potential to reduce water consumption by approximately 40 percent or about 27 gpcd compared to average home water consumption.

[26] Performance tests for ULF toilets that meet the EPAct maximum flow requirements were adopted by industry. However, some have commented that the standards are not adequately rigorous such that some poorly performing models have reached consumers (GAO, 2000, p. 26). GAO (2000) summarizes the history of performance testing standards for ULF toilets.

[27] ENERGY STAR clothes washers are 55 percent more efficient and ENERGY STAR dishwashers are 33 percent more efficient than conventional units. Water savings based on the following water usage estimates: ENERGY STAR clothes washer uses 5,748 gallons per year; a conventional clothes washer uses 12,741 gallons per year; an ENERGY STAR dishwasher uses 860 gallons per year; and a conventional dishwasher uses 1,290 gallons per year (ENERGY STAR, 2008a, ENERGY STAR, 2007b).

Exhibit 5-8: Water Use at Three Representative Home Types



Not included in these assessments of residential water efficiency options are techniques for reducing the loss of water down the drain while a person waits for hot water to reach the point of use (such as the faucet, shower, or tub). Such losses can be on the order of one to three gallons each time a fixture is used (Ally, et al., 2002, p. 1). Tankless water heaters that are located at the point of use (e.g., the shower) can provide hot water on demand, thereby reducing or eliminating this water loss. Hot water recirculating systems are also being considered for residential applications (Ally, et al., 2002). These recirculating systems return water from the hot water line back to the hot water tank until the water reaching the fixture reaches the desired temperature. Once the temperature is reached, a valve opens so that the hot water can flow to the fixture. Additionally leaks, which consume 9.5 gpcd on average, can by identified and reduced through home audits.

The components for recirculating systems can be obtained from retail stores (Ally, et al., 2002, p. 1). A key design element for the system in residential applications is that the recirculation pump only runs briefly (typically less than 30 seconds) when the hot water is turned on. One system, developed initially through the Department of Energy's Inventions and Innovation grant program, has reportedly been implemented widely in multifamily and commercial applications (Moore, et al., 2004, p. 6-265).

While not examined in detail in this paper, outdoor residential water use is significant in some areas. Mayer, et al., report that outdoor use per home varied from 7,800 gallons per year to 213,200 gallons per year (Mayer, et al., 1999, p. 114). Factors affecting the rate of use include climate, irrigable area, and application rate. During periods of drought, restrictions are often put in place to reduce outdoor water use. Improved irrigation practices, including recommendations listed in Exhibit 5-9, can improve water use efficiency on a more permanent basis.

Landscape design and maintenance have a significant impact on irrigation requirements. The choice of turf and garden plants is important, as is the decision regarding the sizes of areas covered by turf, plants, and hardscape (such as patio areas). Through the systematic application of xeriscaping principles, water conservation can be promoted. The California Urban Water Conservation Council summarizes xeriscape principles as (CUWCC, 2006):

- planning and design;
- soil improvements;
- efficient irrigation;
- zoning of plants;
- mulches;
- turf alternatives; and
- appropriate maintenance.

Gleick, et al. estimate that residential outdoor use can be reduced 25 to 40 percent in California (Gleick, et al., 2003, p. 2). We do not examine further the potential water savings from outdoor use in this paper.

The cost effectiveness of the opportunities to reduce indoor water use is discussed next.

Exhibit 5-9: Water Efficient Landscape Irrigation Recommendations

Drip Irrigation: Drip irrigation, also called trickle or micro-irrigation, applies water slowly and directly to the roots of plants through small flexible pipes and flow control devices called emitters. Drip irrigation uses 30 to 50 percent less water than sprinkler irrigation and usually costs less to install. Since water is applied directly to the root zone, evaporation and runoff are minimized.

Drip irrigation is recommended for use on trees, shrubs, and flowers in the high- and moderate-water-use zones of the landscape to maximize efficiency. Several types of drip irrigation systems can be adapted to suit a variety of applications, from watering individual trees and shrubs to beds of annuals, herbaceous perennials, ground covers, or mixed borders.

Hand Watering: Hand watering can be an effective and efficient way of applying water to selected plants that show signs of stress during dry periods. The direct application of water to the base of the plant, provided it is applied slowly enough to be absorbed by the soil, uses less water and is more efficient than sprinkler irrigation. To avoid runoff when using a hand-held hose, use a nozzle that divides the spray into rain-size droplets. Some nozzles have built-in spray pattern adjustments.

Operating Sprinklers at Night: The best time to irrigate with sprinklers is after 9 p.m. and before 9 a.m. During this time there is generally less wind, a lower temperature, and less sunlight, resulting in less water loss to evaporation. Drip irrigation systems can be operated at any time of day because the foliage stays dry and therefore evaporative water loss is not a problem.

An automatic controller attached to the irrigation system turns the system on and off and controls the water flow through the various zones according to a pre-set time clock. It allows you to set the length of time each zone operates as well as the days of the week and time of day. The controller should be reprogrammed frequently during the growing season because water needs change from week to week.

Advanced Controllers: Advanced controllers can help match water application rates to actual plant requirements. A rainfall sensor detects rainfall and prevents the irrigation system from operating if significant rainfall has occurred. Another type of sensor measures soil moisture and overrides the system when soil moisture is adequate. More sophisticated systems that allow irrigation to be adjusted based on weather conditions were recently evaluated in California (MWD, 2004). These systems match water application rates to estimated evapotranspiration (ET), which is a measure of the rate at which plants lose water through evaporation and transpiration. Advanced ET-driven controllers appear to have the potential to improve irrigation efficiency significantly. WaterSense is in the process of developing specifications for irrigation control technologies.

Irrigation Professionals: Up to 50 percent of water used for landscape irrigation is lost due to over-watering, evaporation, or bad irrigation system design or maintenance. WaterSense labeled certification programs:

- Verify professional proficiency in water-efficient irrigation system design, performance audits, and installation and maintenance.
- Test designers, installation/maintenance professionals, and/or auditors on their water efficiency knowledge through examinations.
- Certify only experienced irrigation system designers and installation/ maintenance professionals.
- Require independent oversight.
- Require that professionals periodically renew their certification to demonstrate awareness of recent technology and innovations.

Source (unless otherwise noted): NCCES, 1996.

5.2.2 Cost Effectiveness

The cost effectiveness of water saving fixtures and appliances can be examined from the consumer perspective and the water utility perspective. The Aquacraft retrofit studies examined costs and benefits from the consumer's point of view. The typical cost of the product and its installation were compared to a consumer's expected water and sewer bill savings. Energy savings were also included for hot water savings. The results showed that the payback to consumers can be relatively short for ULF toilets, LF showerheads and aerators.

The payback time for ULF toilet replacement in Tampa, Florida, was estimated to be less than two years (see Exhibit 5-10). The incremental toilet cost, including installation, was estimated at $285, and the annual savings per toilet were estimated at $143.68 (Aquacraft, 2004, p. 88). The payback period estimated for EBMUD was higher due to lower water costs. Also, in addition to the replacement toilet costing $285, a second replacement toilet was also evaluated with an incremental cost of $470 (Aquacraft, 2003, p. 93-94).

The payback periods for resource efficient clothes washers are estimated based on combined savings from water and energy. The Tampa, Florida, estimates use a range of incremental costs for the clothes washer of $450 to $550, yielding a payback period of about 5.5 years (Aquacraft, 2004, p. 90). The payback period for EBMUD is estimated to be shorter, despite lower water rates, because the incremental costs of the clothes washers were estimated to be lower. In the EBMUD estimates, the incremental costs ranged from $61 to $199 (Aquacraft, 2003, p. 97).

For low flow showerheads, both studies used $25 per showerhead as the incremental cost. The differences in payback times are due to differences in water costs as well as differences in measured water savings associated with low flow showerheads in each location. Energy savings associated with reduced hot water usage were not included in the estimates.

Exhibit 5-10: Simple Payback for Water Saving Fixtures and Appliances

Fixture or Appliance	Tampa (FL)	EBMUD (CA)
Value of Water Savings[a]	$3.98 - $5.32 / 100 cubic feet ($5.32 - $7.11 / 1000 gal)	$2.20 / 100 cubic feet ($2.94 / 1000 gal)
ULF Toilet	2 years	3.7 – 6.4 years
Resource Efficient Clothes Washer[b]	5.5 – 5.7 years[c]	1.1 – 2.9 years[c]
LF Showerheads	1.6 years	3.5 years
Faucet Aerators	0.8 years	--

[a] Value to consumer based on reduced water and sewer bills.
[b] Payback for clothes washer calculated for incremental costs over a standard model.
[c] Includes energy savings for reduced hot water use.
Sources: Aquacraft (2003), pp. 93, 94, 97, 98. Aquacraft (2004), pp. 87, 88, 90, 91, 92.

Based on the payback periods reported for these products, the replacement of pre-EPAct toilets and showerheads is cost effective. When a clothes washer needs to be replaced, it is cost effective to replace it with a resource efficient model. This result is consistent with the labeling of clothes washers by the ENERGY STAR program. The program only labels cost-effective technologies that conform with a set of labeling principles, including: the resource savings must be cost effective, so that the savings outweigh incremental product costs; the performance of the labeled product must be as good or better than standard products; the labeled products must be available from multiple sources; the energy savings must be significant; and the label must convey useful information to consumers who would otherwise be unaware of the labeled product's resource-saving characteristics.

Gleick, et al. (2003) took the alternative view of cost effectiveness, comparing the net cost of the product and its installation to the marginal cost of obtaining new water supply. The incremental cost of additional supply in California was estimated to be at least $600 per acre-foot, or about $1.38 per 100 cubic feet (ccf) (Gleick, et al., 2003, p. 115). Compared to this cost, the accelerated replacement of LF showerheads was found to be cost effective, and the accelerated installation of ULF toilets was found to be approximately equal to the marginal cost of additional water supply (Gleick, et al., 2003, p. 120). These results are consistent with the observation that water utilities often provide rebates or other promotions for retrofitting these two fixtures.

5.3 Water Prices and Billing

Water prices and billing practices are important for water efficiency for two reasons. First, water prices should be set to provide the proper incentive to adopt water conserving technologies and practices. Second, in order for the prices to have their desired impact, they must be billed to consumers.

Water pricing and billing policies have evolved in the United States. Historically, the costs of water supply were recovered in property taxes or similar government collections. Under these circumstances, water use was not metered and consumers did not pay for water based on the amount they used. Because the marginal cost of water was zero to customers, there was no incentive to use water efficiently.

Metering of most individual water customers became the norm in the U.S. after the 1950s. With metered accounts, individual consumers started to pay for water on the basis of the amount they used. This "volumetric billing" approach provides an incentive for consumers to use water efficiently. To promote overall efficiency, the price charged to customers must reflect the actual cost of supplying the water. Gleick, et al. (2003) discuss the importance of setting water rates to include the short term cost of water delivery as well as the long term cost of increasing supply capacity (Gleick, et al., 2003, pp. 149-153).

The topic of water pricing is beyond the scope of this paper. However, we note that water pricing varies significantly across jurisdictions. As a result, there are varying incentives for adopting water conserving practices and products. Residential water rates typically include a monthly connection (or meter) charge, on the order of $5 to $15 per month, as well as a volumetric rate for the water actually used. The volumetric rate may take several forms:

- a flat water rate is a constant rate per unit of water, such as $2.00 per 1,000 gallons;
- a seasonal water rate incorporates different prices for different seasons;
- an increasing block water rate has a rate that increases with the amount of water used so that customers who use more water pay a higher rate for their marginal consumption;
- a decreasing block water rate has a rate that declines with the amount of water used so that customers who use more water pay a lower rate for their marginal consumption; and
- target water rates have prices that typically increase for customers that exceed their target amount of water use, such as exceeding 120 percent of use in the same month in the previous year.

The payback analysis conducted by Aquacraft shows the variation in pricing in two jurisdictions (see Exhibit 5-10). Mayer, et al. (1999) summarize water rates in their 12 study locations. As shown in Exhibit 5-11, both flat rates and increasing block rates were observed. The flat rates and the rate for the first block of water use are primarily less than $2.00 per 1,000 gallons in these data. The highest rates in the increasing block rates can exceed that level, and can exceed $5.00 per 1,000 gallons.

An analysis of data from 658 water suppliers in the AWWA Water Stats Survey (AWWA, 1996) indicates that 42 percent of the respondents had increasing block rates. The average rate for the initial blocks was about $1.85 per 1,000 gallons. Flat rates were observed in about 26 percent of the systems, with a similar average rate. Of note is that the rates across systems vary significantly, consistent with the observations reported by Mayer, et al.

The Utah Division of Water Resources reports that water rates in Mountain States range from about $1.16 per 1,000 gallons in Utah to about $2.66 per 1,000 gallons in New Mexico, with a national average for the U.S. of about $1.87 (Utah, 1997). The USEPA Community Water System Survey reports that the revenue from residential customers averages about $3.11 per 1,000 gallons across all water systems (USEPA, 2002a, Table 55, p. 86). This figure includes the monthly connection charge, and consequently is higher than the volumetric rate. Based on this review, a representative volumetric water rate for residential customers is on the order of about $1.90 per 1,000 gallons of water.

Exhibit 5-11: Water Rates Observed in 12 Study Locations

Location	Water Rate	Rate per 1,000 Gallons
City of Boulder, CO	Increasing block rate in three blocks	$1.20 to $2.85
Denver Water Department, CO	Increasing block rate in two blocks	$1.25 to $1.50
Eugene Water and Electric Board, OR	Flat water rate	$0.76
Belleview: Seattle Public Utilities, WA	Increasing block rate in four blocks	$1.51 to $4.36
Highline: Seattle Public Utilities, WA	Flat water rate	$2.58
Northshore: Seattle Public Utilities, WA	Increasing block rate in four blocks	$1.47 to $3.74
San Diego Water Department, CA	Increasing block rate in two blocks	$1.89 to $2.07
Tampa Water Department, FL	Increasing block rate in two blocks	$1.20 to $1.95
Las Virgenes Municipal Water District, CA	Increasing block rates in four blocks across five tiers of users	$1.58 to $5.98
Walnut Valley Water District, CA	Flat water rate	$1.93
City of Phoenix, AZ	Increasing block rate in two blocks	$0.00[a] to $1.59
Scottsdale, AZ	Increasing block rate in two blocks	$1.22 to $1.95
Tempe, AZ	Increasing block rate in six blocks	$0.79 to $1.13
Waterloo, Ontario	Flat water rate	$1.87
Cambridge, Ontario	Flat water rate	$1.64
City of Lompoc, CA	Flat water rate	$2.18

[a] The rate for the first block of 4,490 gallons per month is reported as $0.00. The rate for use above this amount is $1.59 per 1,000 gallons.
Source: Mayer, et al., 1999, pp. 56-57.

Wastewater treatment costs are also significant for many residential customers. As with water supply rates, wastewater treatment rates may include several components, including a fixed monthly cost, a volumetric rate, and a rate (tax) based on property value. The Association of Metropolitan Sewerage Agencies (AMSA) survey conducted in 2001 and published in 2002 found that the most common wastewater treatment rate structure was a connection charge plus a volumetric rate, accounting for 43 percent of the 114 respondents to this portion of the survey (AMSA, 2002, p. 85). About 34 percent reported using volumetric rates only, and 12 percent reported using fixed connection charges exclusively. The remainder reported using tax assessments either alone or in combination with other charges.

For those agencies that use volumetric rates, the water volume may be measured as all of the metered water usage by the customer, or in some cases as less than all the metered usage, to reflect water used for irrigation that does not enter the wastewater treatment system (AMSA, 2002, p. 82). When used in combination with a connection charge, the volumetric rates reported ranged from $0.82 to $4.10 per 1,000 gallons, with a mean value of $2.27 (AMSA, 2002, p. 87). When used alone, the volumetric rates ranged from $0.59 to $7.83 per 1,000 gallons, with a mean value of $3.00. Wastewater treatment rates, therefore, are as important as water supply rates in terms of economic incentives to consumers to use water efficiently.

There is one customer segment that has generally not faced water prices in the U.S.: residents of multifamily buildings. In most cases, multifamily buildings are "master metered" for water, meaning that a single water meter serves the entire building. Under these circumstances, water costs are recovered in rent payments and residents face a marginal cost of water of zero. Until recently, building owners were deterred from billing customers individually for water because effectively they were required to become mini-water distribution companies if they installed sub-meters for purposes of billing tenants individually. As such, they would be required to comply with water supply system regulations and reporting.

This sub-metering policy was changed in December 2003 (Federal Register, 2003). Under the new policy, building owners may install sub-meters for purposes of charging tenants for their individual water use without becoming a water supply distribution company. Various studies have estimated the impact that this policy change could have on water use (see, e.g., Koplow and Lownie (1999) and Goodman (1999)), showing that significant reductions in water use can result. For purposes of promoting water use efficiency, billing water directly to consumers will provide an incentive for those consumers to pay more attention to their water using behaviors.

5.4 Linkage Opportunities with Energy Efficiency Programs

There are several potential links between residential water use efficiency and energy efficiency initiatives including:

- residential products that use both energy and water directly; and
- residential products that use water directly and indirectly require energy for water supply and treatment.

These linkages are discussed in Section 7, including new program strategies for leveraging energy-efficiency activities to improve water efficiency and vice versa.

6. Commercial and Institutional Water Consumption

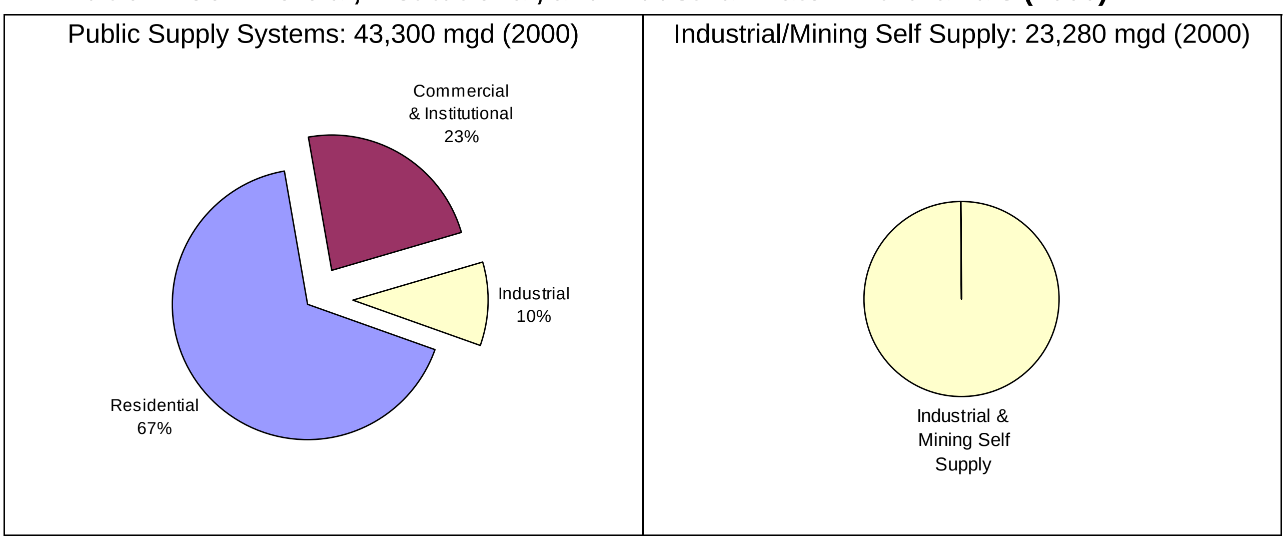
Public water supply systems are the principal source of water for commercial and institutional customers. As discussed in Section 2, public supply systems accounted for about 10.6 percent of annual water withdrawals in 2000, which is the third largest sector for withdrawals, after power plant cooling and irrigation (USGS, 2004, p. 7). Non-residential use, including commercial, institutional and a portion of industrial water use, accounts for nearly one-third of the public water supply sector nationally, or about 3.5 percent of annual withdrawals. In 2000, this water use totaled about 14,400 million gallons per day (mgd).

The relative importance of non-residential water use varies significantly across communities, depending on the types and sizes of commercial, institutional, and industrial activities that are present. These water users are highly diverse, with widely varying water use intensities. Commercial and institutional water customers include: office buildings; hotels/motels; warehouses; education; laundries; and many others. Industrial water users are equally diverse, with use often driven by process-specific requirements. Large industrial water users typically have their own water supply and treatment systems, and are not supplied by public water supply systems. USGS estimated that in 1995 only about 17 percent of water used by industrial customers was supplied by pubic water systems (USGS, 1998, p. 19). The industrial customers that are served by public supply systems account for about 10 percent of the public supply water use.

Exhibit 6-1 shows the relationship among the sources of water for these customers. As shown in the exhibit, commercial and institutional customers are served by public supply systems. Industrial customers are served both by public supply systems and through their own self supply.

This section reviews the water uses that are common across many of the commercial and institutional customers served by public supply systems. Opportunities to improve water use efficiency are discussed.

Exhibit 6-1: Commercial, Institutional, and Industrial Water Withdrawals (2000)



Percentages are national approximations. Distributions vary significantly across communities (see text).
Sources: USGS, 2004, p. 7 and USGS, 1998, p. 19.

6.1 Commercial and Institutional End Uses

Commercial and institutional (C&I) water users are highly diverse. Because there is no universally adopted set of customer definitions among water utilities, aggregate data on water use and use intensity are not readily available. A recent review and analysis of C&I water use by Dziegielewski, et al. (2000) summarizes the available data. Using data from USEPA (1997b), they estimated the relative water use among 21 customer categories. The data, shown in Exhibit 6-2, are from 12 cities in Texas, New York, California, Florida, Oregon, and Minnesota for various years from 1992 through 1995.

Exhibit 6-2: Relative Water Use Among Commercial and Industrial Customer Categories

Commercial/Institutional Customer Category	Percent of C&I Use			# Cities Reporting
	Average	Low	High	
Utilities and infrastructure	22.8%	0.7%	73.0%	10
Hospitality	14.8%	5.5%	34.9%	12
Warehousing	12.4%	3.0%	30.8%	10
Offices	9.2%	5.7%	15.8%	11
Health care	7.3%	3.5%	17.2%	10
Irrigation	6.2%	0.3%	21.9%	10
Education	5.9%	0.3%	11.4%	10
Miscellaneous	5.7%	0.1%	31.1%	4
Grocery/Other Sales	5.5%	3.0%	18.2%	12
Services (miscellaneous)	2.4%	0.2%	13.1%	10
Laundries	1.7%	1.1%	5.9%	8
Vehicle dealers and services	1.2%	0.2%	4.8%	12
Meeting and recreation	1.1%	0.0%	9.6%	11
Church	0.7%	0.2%	2.8%	11
Communication and research	0.7%	0.1%	7.8%	10
Non-profit service org.	0.7%	0.2%	2.3%	7
Landscape	0.6%	0.1%	2.3%	7
Transport and fuels	0.4%	0.0%	1.4%	7
Car Wash	0.3%	0.2%	2.5%	9
Military	0.3%	0.0%	2.4%	3
Passenger terminals	0.2%	0.0%	2.3%	9

Based on an analysis of data for 12 cities. Average is weighted across the 12 cities. Low (High) is the lowest (highest) reported value across the 12 cities. Not all categories are reported by all 12 cities (see text).
Source: Dziegielewski, et al., 2000, pp. 15-16.

As shown in the exhibit, the customer categories with the largest average use are:

- Utilities and infrastructure accounted, on average, for about 23 percent of C&I water use. These customers include police and fire stations, public works/utilities, electric steam, natural gas, gas production and distribution, sanitary collection and disposal, construction, fumigating, and septic tank cleaning.
- Hospitality customers accounted for nearly 15 percent of C&I water use. These customers include overnight accommodations (hotels and motels), restaurants/bars, and other group shelters.

- Warehousing operations accounted for about 12 percent of C&I water use.
- Offices buildings of all types accounted for more than 9 percent of C&I water use. Buildings include those for finance, insurance, real estate, and government.

The Low and High values listed in the exhibit emphasize that there is considerable variability in the importance of each of the customer categories across cities, including those with the highest water use. For example, although Warehousing has the third largest use on average, one city reported that this category accounted for only 3 percent of C&I water use. Of the 12 cities included in the data, two cities did not report water use for this category at all. The number of cities reporting for each customer category is listed in the exhibit.

Within each of these customer categories, water is used for a variety of purposes, which can be summarized generally in the following categories:

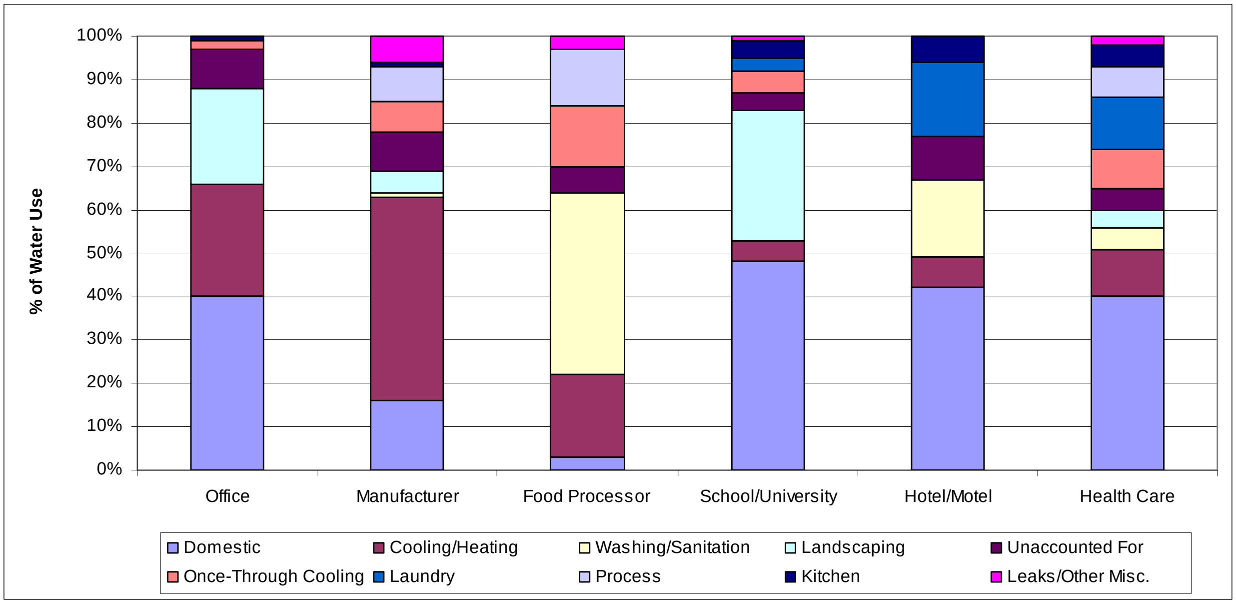
- Domestic water use:
  - toilets, faucets, baths/showers, and general cleaning;
  - kitchen water use: food preparation, dishwashing, ice machines, other activities;
- Space cooling and heating:
  - cooling water for air conditioners;
  - boiler water for heating;
- Outdoor uses, for landscaping, pools, and other purposes; and
- Process-specific uses, such as: process rinses, photographic processing, car washing, laundry, process cooling, other.

Based on a review of available data and analyses of water measurements at 24 locations, Dziegielewski, et al. found wide variations in water use by different customer types across these categories. Similar variation in use is also reported in the water balance data presented by the North Carolina Department of Environment and Natural Resources (NCDENR). Despite this variation, a common theme of the estimates is that domestic water uses are significant among nearly all of the C&I customers examined. Exhibit 6-3 shows the water balance estimates from NCDENR. As shown in the exhibit, domestic water uses comprise an important portion of use for four of the six categories of customers. Water use for cooling and heating is also considerable, such that these two uses together account for more than 45 percent of the total use among five of the six customer types shown. Not surprisingly, washing/sanitation is a significant use among food processors, and laundry is a significant use among hotels and motels.

Mayer (undated) presents similar estimates from a 2001 study in Westminster, Colorado. As shown in Exhibit 6-4, these data also show that domestic uses are significant. However, these data show less importance for cooling/heating and greater importance of landscaping. Among restaurants, kitchen uses of water dominate, accounting for more than 50 percent of water use at restaurants.

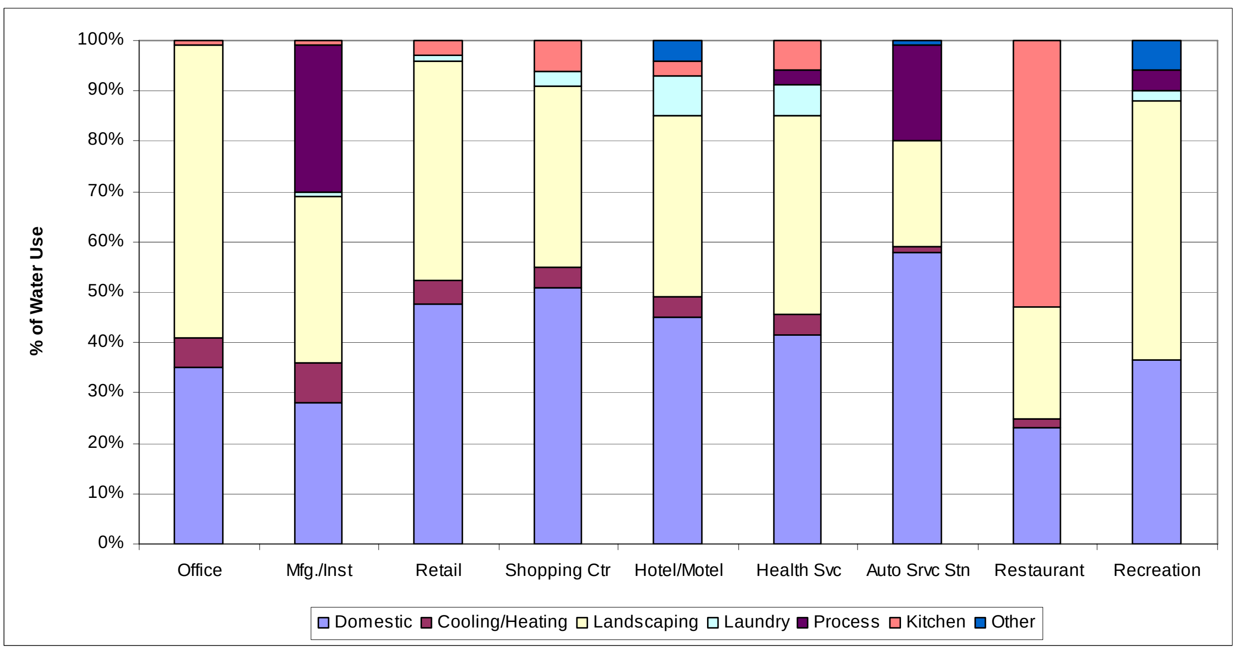
Gleick, et al. (2003) reviewed data on water supplied to non-residential customers in California, and examined eight C&I customer groups and nine industrial customer groups in detail. The average water balance for all sectors showed that landscaping was the largest use, followed by process water, domestic use, and cooling applications (see Exhibit 6-5). Gleick, et al. agree with other authors that the ability to characterize C&I water use is hampered by a lack of comprehensive data and standard definitions for customer types and water uses (Gleick, et al., 2003, p. 88). Nevertheless, the data indicate overall that domestic uses and cooling water are significant uses across C&I customers. Also, process water requirements are highly variable and specific to individual customer groups.

Exhibit 6-3: Water Balance for Common Commercial and Institutional Customer Types



Source: NCDENR, 1998, pp. 18-19.

Exhibit 6-4: Water Balance for Commercial and Institutional Customers in Westminster, Colorado



Source: Mayer (undated).

Exhibit 6-5: Water Balance for Commercial and Industrial Customers in California

Water Use	% of Total
Landscaping	35%
Process Water	17%
Domestic Water Uses (restrooms)	16%
Cooling Water	15%
Other Uses	9%
Kitchen	6%
Laundry	2%

Source: Gleick, et al., 2003, p. 83.

6.2 Opportunities to Improve Commercial and Institutional End Use Efficiency

Recognizing the diversity of water use in the C&I sector, there is no single technology or practice for improving water efficiency among these customers. Particularly when process-related uses are significant, a systematic assessment of facility operations is warranted. The California Department of Water Resources (CDWR) recommends that large water users conduct water inventories and audits to identify opportunities to improve water management, including (CDWR, 1994, pp. 22-30):[28]

- Audit Preparation: Assemble utility records, plumbing diagrams, and previous surveys. Define the scope of the audit, including describing the site(s) and processes included.
- Facility Survey: Identify all water-using equipment and processes. Confirm plumbing configurations and quantify current flow rates and quality needs. Target: cooling and heating systems; process equipment; and domestic use.
- Determine Full Cost of Water: Identify all charges associated with using water, including water purchases, treatment costs, wastewater discharge fees, and energy used to heat or pump water. Calculate the unit costs of using water.
- Identify and Evaluate Opportunities: Assess current water use and identify opportunities to cost-effectively improve water management efficiency.

  ➢ Minimum water requirements: Identify the minimum water requirements to accomplish each task. Examine both behavioral and equipment options for improving efficiency.

  ➢ Recirculation and Reuse: Recirculate water within a process when possible. Cooling and heating water should be recirculated in nearly all cases. Assess how water quality limits the ability to recirculate water, and estimate the amount of recirculation that stays within the necessary quality parameters. Examine options for treating the water to enable additional recirculation or reuse in other processes.

  ➢ Cost Effectiveness: Evaluate the cost effectiveness of management improvements to identify the options that save the most water and are most cost effective. The full lifecycle costs and benefits of the options should be examined, including co-benefits or costs associated with changes in energy use, production quality, and labor requirements.

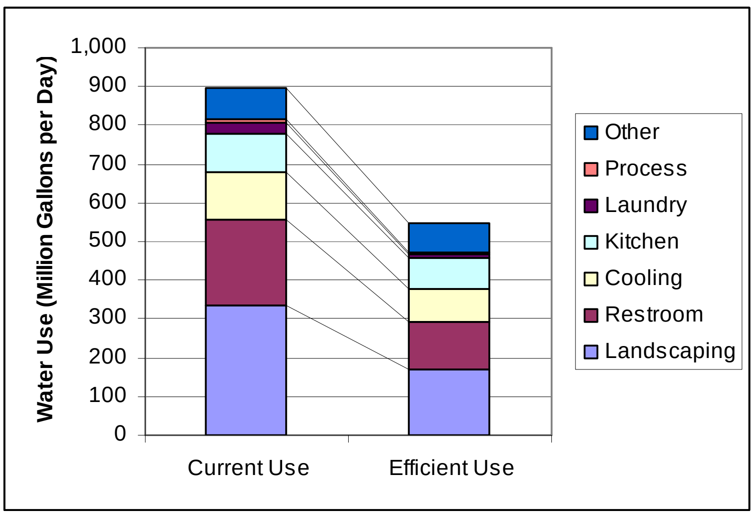
[28] NCDENR (1998) presents a similar approach. See pp. 20-29.

To be successful, the audit and evaluation must be followed by an action plan to implement the cost-effective opportunities. CDWR lists examples of projects that completed audits and improvements, as well as estimates of potential savings at a wide variety of C&I customers. Several of the completed projects include (CDWR, 1994, pp. 48-77):

- Automotive Paint Manufacturer: Reduced wastewater discharge through the installation of an ultrafiltration/reverse osmosis treatment system that enabled process water recycling. Installation costs were $454,000 and annual net savings were $205,000. The improvements saved 3.6 billion Btu and 380,000 gallons of water annually.
- Food Processor: Reduced excess boiler blowdown through analysis of steam purity requirements. Installation costs were $45,000 and first year savings of energy, water and treatment costs totaled $186,000.
- Commercial Laundry: Installed water treatment and recycling system to reduce wastewater discharge. Installed costs were $37,137 and annual savings were $28,345. The improvements saved 11 million gallons of water annually, plus energy.

Gleick, et al. conducted assessments of water efficiency improvements for each of nine sectors in California, considering the end uses in each sector and the cost-effective opportunities to improve efficiency. Overall, the estimated savings were found to total about 39 percent of current baseline use. Exhibit 6-6 shows the current use by end use and the estimated use if currently available cost-effective measures were implemented. Results for each of the nine sectors are summarized in Exhibit 6-7

Exhibit 6-6: Potential Water Savings in Nine C&I Sectors in California (2000)



Source: Analysis of data in Gleick, et al. (2003), Appendix E.

6.2.1 Landscaping

Savings from landscaping contribute most to the reduction in use. These landscaping results are driven in part by the California climate, and consequently cannot be generalized nationally. The primary approach for reducing water use for landscaping is to reduce the over-application of water using improved controls and sensors (Gleick, et al., 2003, Appendix D, p. 12).

6.2.2 Restrooms

Water savings in restrooms is the largest opportunity to save water among indoor uses. These savings are important in all the sectors examined. Significant water savings can be realized by replacing older toilets with toilets that meet the 1.6 gallons per flush performance requirements of the Energy Policy Act of 1992 (EPAct). Gleick, et al. estimate that accelerated toilet replacement is cost effective for toilets that are flushed 15 times or more per day (Gleick, et al., 2003, p. 141), which is common in C&I customer facilities.

Exhibit 6-7: Potential Water Savings in Nine C&I Customer Groups in California (2000)

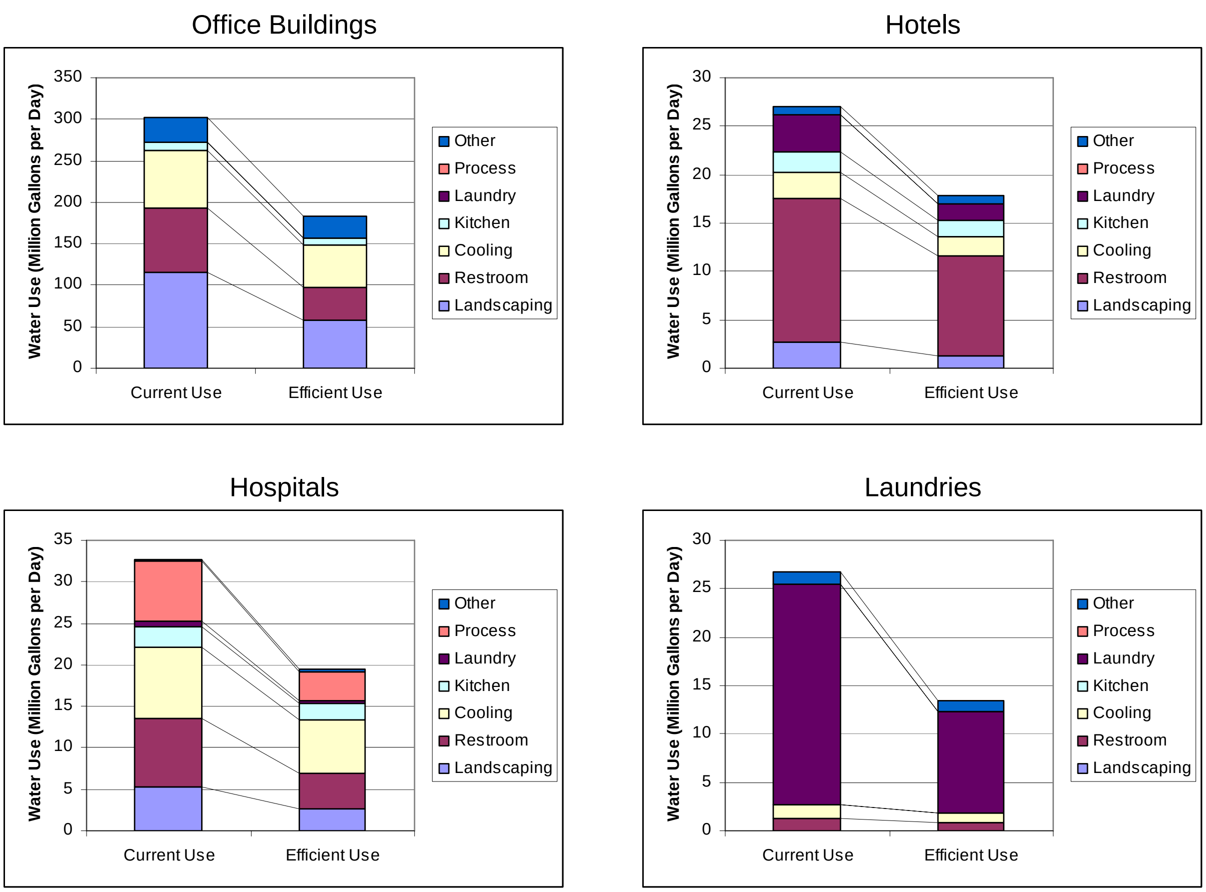


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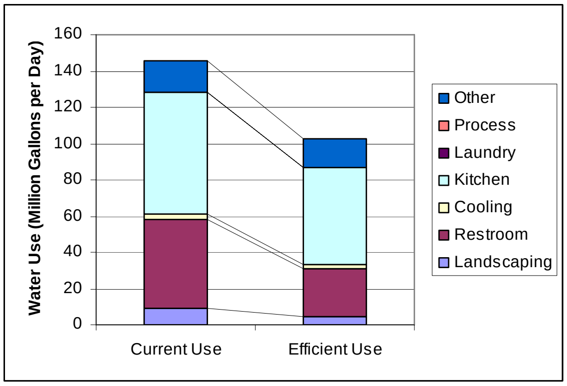
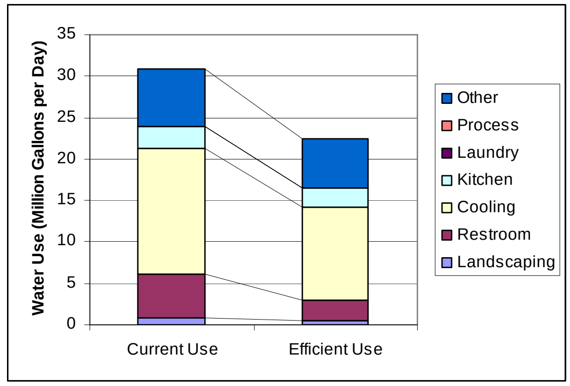
Exhibit 6-7: Potential Water Savings in Nine C&I Customer Groups in California (2000) (continued)

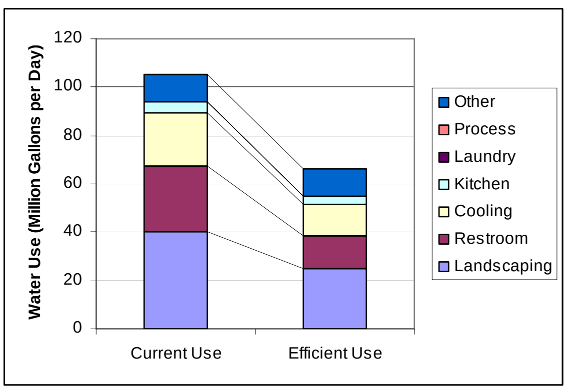
Restaurants



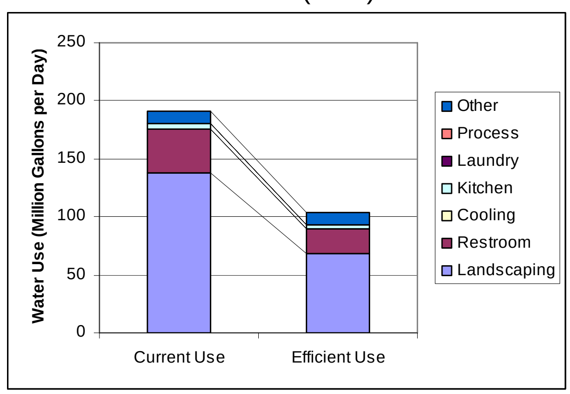
Groceries



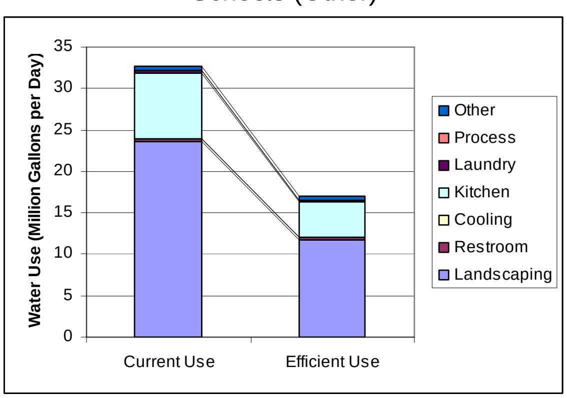
Other Retail



Schools (K-12)



Schools (Other)



Source: Analysis of data in Gleick, et al. (2003), Appendix E.

The extrapolation of the restroom savings estimate to a national figure can only be done approximately. The Gleick, et al. estimate considers the baseline use of toilets and other EPAct compliant products by customer type. The baseline nationally may not correspond to the estimates for California. Nevertheless, the 50 percent reduction in this use can be applied to the portion of C&I use in this category, which is on the order of 15 to 30 percent, to estimate potential savings of 750 to 1,500 mgd.[29] Efforts to promote toilets that are more efficient than those that meet the standard could make an important contribution to these savings.

Urinals are another opportunity for significant savings. The national standard for urinals is 1 gpf. High Efficiency Urinals (HEU), defined as flushing at 0.5 gpf or less, have existed in the marketplace for the past 15 years. Today, manufacturers are developing and refining urinal models that flush at 0.5-gpf and below, some with as little as 1-pint of water.

Zero water urinals, first introduced in the early 1990s, use no water at all. Instead, they use a "trap" that separates the sewer line from the indoor space. Conventional plumbing fixtures (including urinals) use a u-shaped pipe that stays filled with water as the trap that prevents sewer gases from escaping into the room. Flush water is required to move wastes through the conventional trap. In zero water urinals, a mini-trap is used that provides a seal using a specially designed liquid that floats on top of the waste. The waste flows through the mini-trap and down the drain without the aid of flush water.

Relative to an EPAct compliant urinal, a zero water urinal can save about 7,800 gallons per year (assuming 30 flushes per day for 260 days per year). However promising, the zero water urinal has raised some concerns, including issues of maintenance requirements, questions about the life expectancy of the liquid seal (or cartridge), concerns over build-up of urine solids in the drainlines behind these fixtures, and, questions about the cost-effectiveness of zero water urinals in areas where water and sewer charges are low. Further research and testing of zero water urinals is ongoing.

6.2.3 Cooling Water

Improved operation of cooling systems is the second largest opportunity identified by Gleick, et al. among indoor water C&I uses. Although water is used for a variety of cooling needs, in the C&I sector it is primarily used as part of the heating, ventilation and air conditioning (HVAC) system that provides space cooling. When water is used for this purpose in a commercial building, it is typically the largest use of water in the building. Water may also be used to provide cooling for refrigeration as well as industrial processes.

Water use for cooling purposes is sufficiently important to warrant providing some detail on it here. Water provides cooling by acting as a sink for excess heat. By flowing water through a heat exchanger, heat is transferred from its source to the water. As a result, the water temperature increases. Examples of equipment that use cooling water include:

- air conditioners that transfer heat from inside the building to the cooling water;
- refrigeration systems that transfer heat from inside the refrigerated space to the cooling water; and
- compressors that transfer heat from the compressed air or other fluid to the cooling water.[30]

After the water is heated, it may be discharged. However, this "once-through" cooling is considered to be particularly wasteful. To save water, it is preferred to *recirculate* the cooling

[29] Total C&I use is about 14,400 mgd x 70 percent (from Exhibit 6-1) = 10,080 mgd. Of this use, restroom use is about 15 to 30 percent, or 1,500 to 3,000 mgd. A 50 percent savings would be 750 to 1,500 mgd.
[30] Air heats up when compressed. To maintain the compressed air at an acceptable temperature, cooling water is often used.

water so that it is used multiple times. Before it can be reused, however, the cooling water itself must be cooled, which is typically accomplished using a *cooling tower*.

The cooling tower is critical to the recirculation of the cooling water. After it flows through the heat exchanger, the heated water is pumped to the cooling tower where it is sprayed downward, forming small droplets. As the droplets fall, air is blown up through the tower, so that the droplets contact the air. Some of the water droplets evaporate, causing the air to absorb heat, and thereby reducing the temperature of the remaining water. The evaporation of the water in the cooling tower is the primary mechanism by which the water is cooled prior to its recirculation to the heat exchanger. The evaporation also reduces the quantity of the cooling water, so that additional cooling water must be added. Some droplets also drift out of the cooling tower without evaporating, creating an additional loss of water.

The proper design, operation, and maintenance of cooling towers and cooling water systems have received considerable attention because of the impact they have on both water and energy use. If the cooling water system is not functioning properly, the efficiency of the air conditioner or refrigeration system may suffer, resulting in increased energy costs. Additionally, a poorly operating cooling water system can waste substantial quantities of water.

Of note is that water-cooled air conditioning systems are more energy efficient than air-cooled systems. Residential air conditions, and small commercial air conditioners, do not typically include water cooling. For larger systems, however, the energy savings from increased energy efficiency more than offset the cost of installing water cooling equipment. Consequently, shifting from water cooling to air cooling is not recommended for larger systems as a means of saving water. In fact, in California newly installed systems above 300 tons are required to be water cooled systems.[31]

Recognizing the opportunity to improve cooling tower operations, particularly on commercial buildings, the San Jose Environmental Services Department (SJESD) developed guidelines for managing water in cooling systems. The objective of their guidelines is to reduce water use and discharge to the San Jose/Santa Clara Water Pollution Control Plant, one of the largest advanced wastewater treatment facilities in California (SJESD, 2002, p. iv).

The most effective method of reducing the amount of water used in a cooling system is to ensure that the water is recirculated as many times as possible. The number of recirculation cycles that can be used is limited by the build up of dissolved solids and salts in the water. Because a portion of the water evaporates in the cooling tower, the concentration of solids and salts increases in the remaining water. When the concentration reaches a level that can damage the cooling system or cause scale to build up on system components, the water must be discharged and replaced with freshwater.

Exhibit 6-8 displays the amount of water used as a function of the number of cycles of concentration of the cooling water (cycles of concentration refers to the number of times the water is recirculated). As shown in the exhibit, the water requirements per ton-hour of air conditioning are reduced with increased cycles of concentration. It is not uncommon for cooling towers to be operated in the range of two to four cycles of concentration. Substantial reductions in water use can be achieved by increasing the cycles of concentration to the range of four to six. This can typically be accomplished through the use of chemical treatments for the water, as well as through better cooling water quality monitoring and water discharge control. Gleick, et al. estimated that overall a 39 percent improvement in cooling water efficiency is possible in

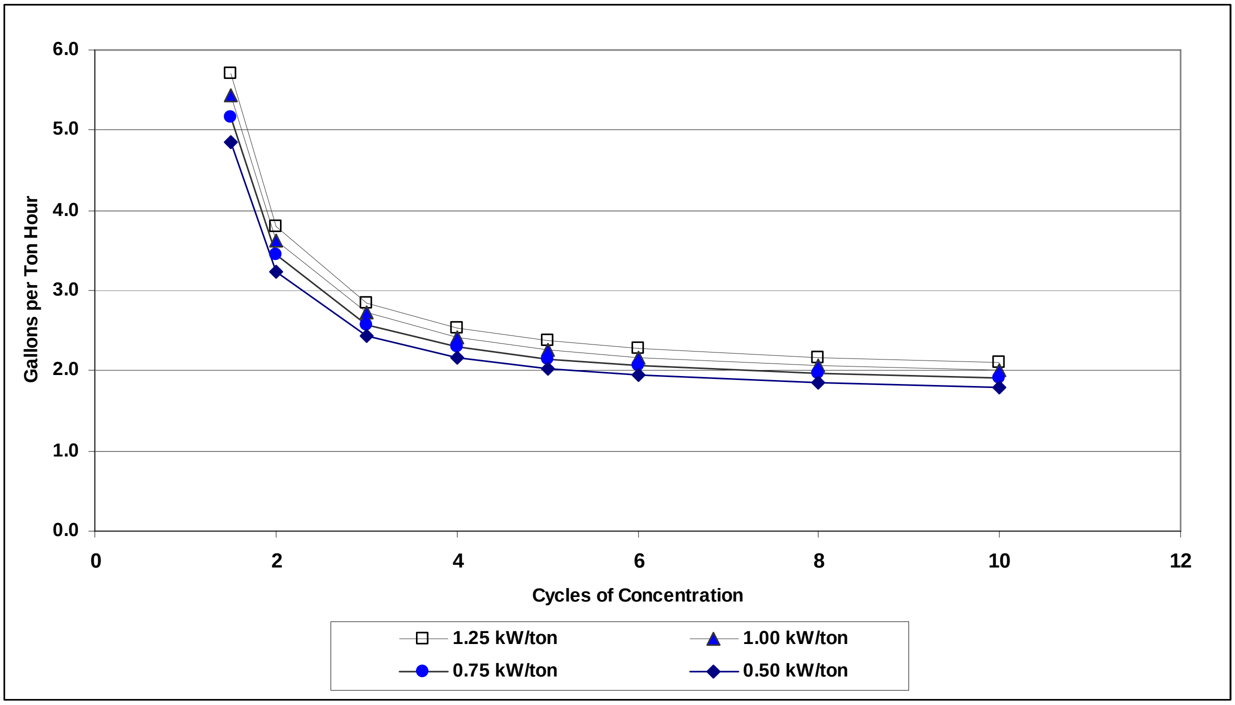
[31] "Tons" is used to describe the amount of cooling provided by an air conditioning system. One ton of cooling is the ability to remove 12,000 Btu of heat per hour.

California, which includes replacing once-through cooling with recirculated cooling in some applications.

Although no national data are available that describe water use in cooling towers, an approximate value can be developed for water use in air conditioning of commercial buildings using data from CBECS (1999).

- Buildings with Cooling Towers: Buildings over 50,000 square feet with central chillers or district chilled water are assumed to use cooling towers. The total inventory of these buildings was 14,256 million square feet in 1999 (CBECS, Table B7).
- Tons of Air Conditioning: As an approximation, we assume one ton of cooling per 350 square feet of space.
- Water Use: Recognizing that the water consumption varies with the manner in which the cooling tower is operated, we adopt assumptions of water circulation of 3 gallons per minute per ton of cooling and a water use rate of 1.5 percent. These values imply 2.7 gallons of water use per ton-hour of cooling, which represents about three cycles of concentration (see Exhibit 6-8).
- Cooling: On average, the air conditioning system is assumed to run 26 weeks per year, 5.5 days per week, 12 hours per day at half load on average, yielding 858 hours of equivalent full load operation.

Exhibit 6-8: Water Requirements for Cooling Towers as a Function of Cycles of Concentration



Note: kW/ton of cooling values represent a range of air conditioner efficiencies. More efficient systems (lower kW/ton) require less cooling system water. A "Ton Hour" is one ton of cooling operating for one hour, which is equal to 12,000 Btu of cooling.

Using these assumptions, total national cooling water use for air conditioning is roughly 260 mgd. While Gleick, et al. estimate a 39 percent reduction in cooling water use, we can assume conservatively a 10 percent reduction, implying a savings of 26 mgd. To put this figure into context, we recall that retrofitting a home with ULF toilets saves about 10 gallons per capita per day (gpcd). This savings of 26 mgd is equivalent to having 2.6 million people's homes retrofitted with ULF toilets.

6.2.4 Other Water Savings Opportunities

Additional water efficiency improvements are possible among C&I customers. One customer segment that has received attention is restaurants, which have relatively high water use intensities. Resource-efficient commercial dishwashers, pre-rinse spray valves,[32] and other options are available. For example, despite the diverse and fragmented nature of the restaurant sector, the California Urban Water Conservation Council (CUWCC) has implemented a successful program to replace pre-rinse spray valves in food service establishments in California. In its first phase (October 2002 through December 2003), the program replaced 16,896 high-flow pre-rinse spray valves with more efficient models, and estimates it will replace an additional 24,700 in 2004 and 2005 (CUWCC, 2004, p. 1).

The annual savings for each retrofit was measured at about 57,000 gallons (CUWCC, 2004, p. 9), less than the expected savings of about 65,000 gallons per retrofit.[33] Annual energy savings were 336 Therms per retrofit for facilities with gas hot water and 7,629 kWh per retrofit for electric hot water sites (CUWCC, 2004, pp. 10-11). The savings from the nearly 17,000 replacement pre-rinse valves is therefore about 2.6 mgd. The CUWCC estimates that there are more than 130,000 high-flow pre-rinse spray valves being used in California alone (CUWCC, 2003, p. 3). Nationally, the water and energy savings associated with promoting these products can be substantial.

[32] Pre-rinse spray valves are handheld devices commonly used by commercial kitchens (e.g., in restaurants, hospitals, educational institutions, and government facilities) to rinse dishware before it enters a dishwasher. The valves generally consist of a spray nozzle, a squeeze lever to control water flow, and a dish guard bumper.

[33] The water savings achieved in the CUWCC pre-rinse spray valve program reportedly fell below expectations because the food service facilities served by the program were smaller on average than originally planned. See CUWCC (2004, p. 8).

7. Leveraging Efficiency Programs to Improve Energy and Water Use Efficiency

This section presents opportunities for leveraging existing energy and water efficiency programs to improve resource efficiencies for both energy and water. Saving the two resources at the same time provides several benefits, including:

- Cost Effectiveness: The combined benefit of saving both energy and water improves the cost effectiveness of the efficiency measures as well as program implementation.
- Resources: By addressing both energy and water together, the resources of energy and water organizations can be brought together and leveraged for larger impact. In particular, the established program implementation infrastructure of efficiency programs can be leveraged to promote both energy and water use efficiency.

First, an overview of energy efficiency programs is provided, in particular the national ENERGY STAR program, followed by a description of the impacts of energy efficiency on water use in power generation. The recently launched WaterSense program and other water efficiency programs are described next, followed by a description of the energy savings associated with water efficiency initiatives. These two sections provide approaches for assessing the indirect benefits of energy efficiency and water efficiency programs. The next sections focus on opportunities for improving energy and water efficiency together by leveraging existing energy efficiency programs for three key sectors: water supply and wastewater utilities; residential; and commercial. These sections primarily focus on opportunities to leverage existing programs. Finally, estimates of joint water and energy savings potential are summarized.

7.1 Energy Efficiency Programs

Energy-efficiency programs focus on reducing the energy intensity of products and processes while maintaining or enhancing the level of services derived from them. Through improved engineering and innovation, the energy intensity of various products and processes may decline over time as part of a natural trend. At the same time, new energy-using products and processes are introduced that increase energy use. Energy-efficiency strategies focus on accelerating reductions in energy intensity, so that energy use is less than what otherwise would have been the case. Energy efficiency is typically achieved using cost-effective technologies and practices.

In the 1980s and 1990s, energy-efficiency programs were included in integrated resource planning (IRP) activities performed by electric utilities under state regulation. With the advent of restructuring of the electric industry, IRP was abandoned in many states. Energy-efficiency programs are now implemented by utilities and other organizations based on two underlying rationales:

- *Public Good*: Promoting energy efficiency is considered a “public good” that is best provided through a government-directed process. Typically the goal is to obtain the greatest energy savings possible with the available resources, with the level of funding set as a matter of policy. The Public Good approach has generally been adopted during the process of electric industry restructuring.
- *Resource Acquisition*: Energy-efficiency resources may be procured within the context of a resource procurement process. Under this view, the cost of procuring energy efficiency is assessed relative to the incremental cost of energy supply, typically within a regulatory framework.

The American Council for an Energy-Efficient Economy (ACEEE) provides a list of states with funding for energy efficiency programs as shown in Exhibit 7-1. These 29 states budget nearly $3 billion of public benefit funds annually for energy-efficiency programs. The seven states with the largest budgets account for the majority of these expenditures, totaling almost $2 billion annually.

Exhibit 7-1: Public Benefit Funding for Energy Efficiency Programs

State	Funding Rate		Annual Budget (millions)
	Mills/kWh	Notes	
Arizona	0.71	LI, R	$27.7
California	4.81	LI, R	$913.2
Colorado	0.69	R	$29.0
Connecticut	4.00	LI, R	$125.9
Delaware	0.27	LI, R	$2.5
District of Columbia	0.90	LI, R	$10.0
Florida	0.64	LI	$110.4
Idaho	0.84		$16.0
Iowa	1.00	LI	$32.0
Illinois	0.60	LI, R	$80.0
Maine	1.98	LI	$22.1
Massachusetts	3.00	LI, R	$147.6
Michigan	0.61	LI, R	$60.0
Minnesota	1.80	R	$101.7
Montana	1.12	LI, R	$14.0
Nevada	1.80	LI, R	$53.0
New Hampshire	3.00	LI	$33.1
New Jersey	1.90	LI, R	$154.1
New Mexico	0.01		$1.0
New York	1.73	LI, R	$218.1
North Carolina	0.03		$3.8
Ohio	0.82	LI, R	$117.0
Oregon	1.90	LI, R	$61.7
Pennsylvania	0.91	LI, R	$132.0
Rhode Island	2.30	LI, R	$18.4
Texas	1.00	LI	$244.0
Vermont	4.21	LI	$24.8
Washington	2.20		$66.4
Wisconsin	2.80	LI, R	$162.5
Total			**$2982.0**

LI = includes some funding for low income assistance.
R = includes some funding for renewable energy.
Source: ACEEE, 2007. http://www.aceee.org/briefs/mktabl.htm. (Last updated September, 2007).

These public benefits funded activities do not include utility-specific programs that are undertaken for procurement purposes or as directed by public utilities commissions. For example, in California, the investor owned utilities are currently implementing energy-efficiency programs with procurement funding that is in addition to the public benefit funding, and nearly as large. Similarly, We Energies in Wisconsin implemented a $43 million four-year energy efficiency program, as part of an agreement with the Public Service Commission of Wisconsin. The $43 million runs through 2008, after which We Energies will continue to spend up to $12 million per year pending development and approval of a new plan.

Regional initiatives, such as the Northwest Energy Efficiency Alliance, Northeast Energy Efficiency Partnership, Midwest Energy Efficiency Alliance, and the Southwest Energy Efficiency Partnership are also active. These organizations often coordinate or harmonize activities across utilities or states. Some of these regional organizations also implement programs using public benefits funding from the states or utilities.

National organizations, such as the Consortium for Energy Efficiency (CEE), the Alliance to Save Energy, the American Council for an Energy-Efficient Economy (ACEEE) and others play important roles in the specification and promotion of energy efficiency programs. Electric Power Research Institute (EPRI) and state organizations, such as the California Energy Commission and the New York State Energy Research and Development Authority (NYSERDA), also contribute significantly to the analysis and research of energy efficiency opportunities.

As the largest energy consumer in the country, the federal government has a significant responsibility to use energy efficiently. The Department of Energy's Federal Energy Management Program (FEMP) works to advance energy efficiency and water conservation at federal facilities (USDOE, 2006). FEMP provides technical assistance and guidance for: new construction; retrofits; equipment procurement; operation and maintenance; and utility management.

The largest national energy efficiency program in the United States is the ENERGY STAR program, led by the U.S. Environmental Protection Agency and the Department of Energy. ENERGY STAR is a voluntary program that gives businesses, institutions, and government agencies the power to reduce the pollution that causes global warming while enhancing their financial value. ENERGY STAR uses multiple strategies to promote efficiency: labeling of consumer products and homes; labeling of commercial (i.e., business) products; residential home performance; commercial building energy performance rating; and sector focus for commercial and industrial customers. Many of the state and regional energy efficiency programs leverage resources provided by ENERGY STAR, including product specifications and analysis tools. Most typically, the state and regional programs promote ENERGY STAR labeled products and adopt ENERGY STAR targets for homes and buildings. By partnering with ENERGY STAR, organizations gain access to information, tools, and resources for improving energy and environmental performance (USEPA, 2004b).

Activities that are motivated by energy-efficiency objectives can promote water use efficiency both directly and indirectly. Given the resources and infrastructure dedicated to promoting energy efficiency nationally, regionally, and locally, opportunities to leverage energy efficiency activities to achieve water use efficiency benefits should be explored. A recent example is the ruling by the California public utilities commission for electric and water utilities to form partnerships in developing pilot programs. The adjacent textbox provides additional details on this rulemaking. The following sections describe approaches for capturing joint water and energy efficiency benefits from energy-efficiency programs.

California Rulemaking by Public Utilities Commission

On October 16, 2006, the Assigned Commissioner to the energy efficiency proceeding (Rulemaking 06-04-010) issued a ruling soliciting investor-owned utility applications for an approximately $10 million one-year pilot program to explore the issue of counting embedded energy savings associated with water use efficiency. More specifically, the ruling asked the four largest investor owned energy utilities (IOUs), Pacific Gas and Electric, Southern California Gas Company, Southern California Edison, and San Diego Gas and Electric, to partner with one large water provider to implement a jointly funded program designed to maximize embedded energy savings per dollar of program cost. This pilot would focus on efforts that would:

a) Conserve water;
b) Use less energy-intensive water (gravity-fed or recycling versus groundwater, aqueducts or desalination); and
c) Make delivery and treatment systems more efficient.

Funding for these programs was to be separate from the 2006-2008 energy efficiency program cycle and as such, the utilities were directed that they may not get credit for these savings towards their 2006-2008 savings goals since the primary purpose of measuring such savings would be the understanding of program benefits, rather than affecting rewards or penalties.

The utilities filed applications on January 15, 2007 seeking approval of one-year pilot programs as directed in the October ruling. Following the submittal of the pilot applications the Commission held a pre-hearing conference at which various parties expressed an interest in having the Commission convene additional workshops to further understand and develop the pilot program proposals. Over the next several months the Commission held several workshops and developed a utility territory-specific calculator modeled on the E3 energy efficiency cost-effectiveness calculator to provide ex-ante cost-effectiveness values based on the programs the utilities submitted in their January applications.[a] The utilities were subsequently directed to serve supplemental testimony proposing revised pilot programs on June 14, 2007 and additional testimony on July 11, 2007.

On December 20, 2007, the CPUC approved modified pilot programs, through which the four largest energy IOUs will develop partnerships with water agencies, undertake specific water conservation and efficiency programs, and measure the results.[b] The Commission also approved funding for two additional state-wide foundational studies to develop the information needed to make meaningful decisions about the value of the programs. These studies will help the Commission to understand more accurately the relationship between water savings and the reduction of energy use, and the extent to which those reductions would vary for different water agencies. The first study is a Statewide/Regional Water-Energy Relationship Study designed to establish the relationship between annual climate and hydrology variation, regional and statewide water demand variations and statewide energy use by the water system. The second study is a Water Agency/Function Component Study which includes a redefined Load Profile Study designed to establish detailed annual and daily profiles for energy use as a function of water delivery requirements within the California water system.

As the Commission states: "The period for the pilot programs and studies will begin January 1, 2008, will run for 18 months, and will consist of three phases. First, the utilities will design their programs while the utilities and Energy Division retain consultants to undertake evaluations and studies. Second, the consultants will begin baseline studies, and work with the utilities to ensure that the pilot programs are likely to produce useful information. Third, the utilities will implement the approved pilot programs for one year, beginning July 1, 2008. If the Energy Division is able to obtain consultants and prepare for the commencement of programs prior to July 1, 2008, it will notify the utilities of this change, and provide an earlier date by which the utilities may begin their 12-month programs."

[a] E3 is CPUC's computational tool, which is used to calculate the energy-efficiency and cost-effectiveness of utility efficiency programs.
[b] Decision (D.) 07-12-050, "*Order Approving Pilot Water Conservation Programs Within the Energy Utilities' Energy Efficiency Programs"* in Application 07-01-024, et.al., available at: http://docs.cpuc.ca.gov/WORD_PDF/FINAL_DECISION/76926.

7.2 The Impact of Energy Efficiency on Water Use in Power Generation

The intensity of water use and consumption during electricity production is reviewed in Section 4.2. The principal water use in this sector is for cooling water to condense steam in steam generation electric power plants. Withdrawal for power plant cooling is the single largest use of water, accounting for about 48 percent of annual withdrawals in the United States. Water consumption at power plants is much smaller, however, because nearly all the cooling water is returned to a receiving body of water. Consequently, power plant cooling accounts for only about 5 percent of annual water consumption.

By improving energy efficiency and reducing energy production, energy-efficiency programs can reduce water consumption associated with electricity production. The size of the impact of these programs on water consumption depends on how power generation is affected. If construction of new generating capacity is reduced or delayed by improved energy efficiency, the rate of water savings is driven by the amount of water that otherwise would have been used by the newly constructed power plant. The rate of water usage by new combined cycle power plants may be on the order of 0.2 gallons per kWh for cooling water, plus an additional 0.11 gallons per kWh for non-cooling uses, for a total of about 0.3 gallons per kWh. For new steam plants with recirculating water cooling, the water use is expected to be about 0.6 gallons per kWh. If a new plant is built with dry cooling, the water requirements could be reduced to 0.11 gallons per kWh or less.[34]

To the extent that energy efficiency reduces the operation of existing power plants, the impact on water usage depends on which plants are run less than otherwise would have been the case, and the water consumption rates per kWh at those plants. Unfortunately, the data required to assess precisely the marginal impact of energy efficiency on power generation by cooling system are not available. However, based on the estimates discussed above, a range can be developed.

The minimum water usage for electricity production today is for combustion turbines, which is about 0.15 gallons per kWh for non-cooling water uses. Although steam plants with dry cooling would use less water, these plants are not in common use today. Combined cycle power plants with recirculating cooling systems use about 0.3 gallons per kWh for cooling and non-cooling uses. This estimate is also the magnitude of the use estimated for once-through cooling systems for steam plants. Finally, a steam plant with recirculating cooling consumes about 0.6 gallons per kWh. Therefore, the marginal impact of energy efficiency on water consumption at existing power plants can be expected to be about 0.15 to 0.6 gallons per kWh.

The impact of energy efficiency on water use by power plants was assessed in a study of the southwest U.S. by the Hewlett Foundation (2002). Based on a review of power plant water consumption in Arizona, Colorado, Nevada, New Mexico, Utah and Wyoming, the authors estimated that water consumption in power plants would be reduced by about 21 billion gallons by 2010 through enhanced energy efficiency[35] (Hewlett Foundation, 2002, p. 3-24). This rate of savings computes to about 0.5 gallons per kWh, which is within the range of values presented here. The water usage rates in the study were similar to the values discussed above: 0.67 gallons per kWh for recirculating cooling at a steam plant and 0.33 gallons per kWh for a gas-fired combined cycle unit (Hewlett Foundation, 2002, p. ES-8).

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[34] The rate of water use and consumption by electric power plants is presented in Section 4.2.

[35] The study estimates total water savings of 24.7 billion gallons of which about 15 to 18 percent is estimated to be associated with resource-efficient clothes washers. The remainder of the savings is due to reductions in water use by electric power plants.

A similar estimate can be made for the energy efficiency savings realized by the ENERGY STAR program. The program estimates that it saved about 69 billion kWh in 2005 through its labeled products such as computers, office equipment, lighting and appliances. Using a water consumption rate of 0.45 gallons per kWh for power plant cooling and other uses (a middle figure from the range discussed above), the water savings associated with these energy savings are 31 billion gallons in 2005, or about 85 million gallons per day (mgd). To put this value in perspective, we can use the average per capita residential use of water of about 70 gallons per day for indoor uses (excluding landscaping – see Section 5.1). The water that is saved indirectly at power plants by the energy savings achieved through the ENERGY STAR program in 2005 is equal to the water used by about 1.3 million people. Because the ENERGY STAR's energy savings are forecasted to be increasing over time, the indirect water savings associated with reductions in power plant water consumption will also continue to grow.

This impact of energy-efficiency programs on water use in power generation is of interest in two ways. First, the water-saving benefits of energy-efficiency efforts can be included in the estimates of the benefits of investing in energy efficiency. These benefits can be important if cooling water availability is a factor constraining the ability to increase power production in a region. For example, Georgia Power lost a bid in 2002 to draw water from the Chattahooche and EPA ordered a power plant in Massachusetts to reduce water withdrawals (Hoffman, 2006, p. 19).

Second, the water savings associated with energy-efficiency efforts may be relevant for water resource planning purposes. The forecasted increases in water requirements for electricity production are sensitive to the expected rate of increase in electricity demand. Insofar as a portion of the increased demand for power can be satisfied through improved energy efficiency, the expected increase in water requirements could be reduced.[36]

7.3 Water Efficiency Programs

The growing population and aging water infrastructure of the United States are putting increasing stress on available water supplies, making water resource protection a national priority. Using water more efficiently helps preserve water supplies for future generations, saves money, and reduces stress on water systems and the environment. To protect and preserve these limited resources, water efficiency programs are encouraging governments, utilities, manufacturers, businesses, communities, and individual consumers to increase their water efficiency by purchasing water-efficient products and adopting water-efficient practices.

There are numerous state- and utility-run water-efficiency programs promoting the efficient use and conservation of water resources. Many of these programs focus on increasing the efficiency of individual household and business' water use by promoting use of high-efficiency, high-performing water-using products and processes. These efforts take the form of rebate programs for the installation of high-efficiency products and outreach and education on the value of conserving our water resources.

The WaterSense program seeks to promote water efficiency and enhance the market for water-efficient products and services at the national level. Fundamentally, the goal of WaterSense is

[36] In 2005, DOE launched the National Energy-Water Roadmap Program, as requested in Congressional appropriations in FY 2005. The purpose of the Roadmap is to assess the effectiveness of existing programs within the Department of Energy and other Federal agencies in addressing energy and water related issues, and to assist the DOE in defining the direction of research, development, demonstration, and commercialization efforts to ensure that energy and water related issues are being adequately and efficiently addressed, in particular, those issues associated with providing adequate energy and water supplies. Source: http://www.sandia.gov/energy-water/roadmap_process.htm.

to decrease indoor and outdoor non-agricultural water use through high-efficiency products and best management practices. The program helps consumers identify water-efficient products in the marketplace, while ensuring product performance and encouraging innovation in manufacturing. Through its product labeling efforts, WaterSense promotes and enhances the market for water-efficient products and services. As examples, WaterSense finalized its specifications for the certification of irrigation professionals in October 2006, high efficiency toilets in January 2007, and bathroom sink faucets in October 2007. Other products currently under review include showerheads; irrigation control technologies; drip irrigation; valve-type (commercial) toilets; and urinals.

7.4 The Impact of Water Efficiency on Electricity Usage at Water Supply and Wastewater Treatment Facilities

Actions that improve water efficiency have the potential to reduce the energy requirements for water supply and wastewater treatment. Consequently, water-efficiency programs can contribute to energy efficiency goals. The energy intensity of water supply and treatment can be expressed in terms of kWh of electricity used per million gallons of water supplied or treated. This electric energy is measured as the energy used on-site at the facilities.[37] For water supply systems, a representative energy intensity figure of about 1,500 kWh per million gallons of water supplied can be used, although the energy intensity varies with local conditions.[38] This electricity is used almost exclusively for pumping. The total electricity consumption for community water supply systems was estimated at about 30 billion kWh per year, which is about 0.75 percent of total national electricity sales in 2002 (EIA, 2007b, Table ES).

The energy intensity of wastewater treatment is divided into two pieces: electricity used for pumping and electricity used for aeration (see Section 3.2.2). A representative value of 150 kWh per million gallons of water can be used for pumping requirements at wastewater treatment plants, although, again, requirements vary with local conditions. Aeration requirements vary from about 500 to 1,000 kWh per million gallons of water treated in plants that use activated sludge treatment processes. Approximately 70 percent of the wastewater treatment flow is treated with activated sludge treatment, so the average energy intensity can be estimated at about 350 to 700 kWh per million gallons of water, or a middle value of about 525 kWh per million gallons of water treated. The total electricity consumption for wastewater treatment was about 1.7 billion kWh and 5.7 billion kWh per year for pumping and aeration respectively. These energy intensities are shown in Exhibit 7-2.

[37] The amount of energy used could also be expressed in terms of the primary energy used to produce the electricity that is used on site. The amount of primary energy required would reflect the efficiency of the electricity generation technology as well as losses from transmission and distribution.

[38] In some areas (such as California), the energy intensity of water supply has been estimated to be much larger. See Section 3.1.3.

Exhibit 7-2: Energy Intensity of Water Supply and Treatment

Activity	Energy Intensity (kWh/million gallons)[a]	Total Annual Electricity Use (billion kWh)	Percent of National Electricity Sales
Electricity Used in Water Supply	1,500	30.0	0.75%
Electricity for Pumping in Wastewater Treatment	150	1.7	0.04%
Electricity for Aeration in Wastewater Treatment	525	5.7	0.15%

[a] The energy intensity estimates presented here are within the range presented in the recently published AWWA RF Study (AWWA RF, 2007). However, due to the publication schedule for this report, the AWWA RF energy intensity data could not be used to revise energy intensity estimates used in this report. Energy intensity varies with local conditions, in some cases by substantial amounts. See section 3.

These intensity factors can be used to estimate the impacts of improving water efficiency on electricity use. For example, if a water conservation program can reduce residential water use by one million gallons per day (mgd), the electricity savings from reduced water supply can be estimated as: 1,500 kWh per million gallons x 1 mgd x 365 days per year = 547,500 kWh/year. If this same program also reduces wastewater flows by 1 mgd, the savings in wastewater pumping would be 150 kWh per million gallons x 1mgd x 365 days per year = 54,750 kWh/year. Electricity used for aeration at treatment plants may also be reduced if the water conservation program also reduces pollutant loading. The savings would be calculated in the same manner.

Combining the pumping energy savings, the total electric energy savings would be about 600,000 kWh/year. This electricity would power about 55 average residential customers each year.[39] This indirect energy efficiency benefit can be considered an added consequence of the water efficiency improvement.

7.5 Opportunities for Water Supply and Wastewater Utilities to Improve Energy and Water Use Efficiency Together

Electricity is an important input to the water supply system as well as for the treatment of wastewater in publicly owned treatment works (POTWs, or wastewater treatment plants). Both water supply and wastewater treatment are often provided by municipal governments. The energy required for these services is often the largest energy expenditure for a local government. The energy use in water supply and wastewater treatment facilities can be addressed in two ways. Water efficiency measures can reduce the demand for water supply and wastewater treatment, thereby reducing the energy requirements at these facilities. Additionally, energy efficiency measures can be implemented at these facilities.

While improving water use efficiency among customers provides the indirect energy benefits described in the previous section, improved operation of the water supply system and the wastewater treatment system can return substantial improvements in energy efficiency. As discussed above in Sections 3.1.3 and 3.2.3, case studies demonstrate substantial opportunities to improve efficiency through:

- improved pumping efficiency, including using more efficient motors, better controls, and pumping configurations that better match pump capacity to desired flow rates; and

[39] The average residential customer in the United States used about 10,800 kWh in 2003 (EIA, 2005b, Table 1a and Table 1b).

- improved aeration monitoring and controls at wastewater treatment plants.

Additionally, substantial opportunity exists to reduce leakage in the water supply sector. Reducing leakage simultaneously reduces energy and water consumption, thereby providing two sets of savings.

Recognizing that the water supply and wastewater treatment industries have untapped energy-efficiency potential, the ACEEE convened a workshop to initiate the development of a roadmap for improving energy efficiency in these two industries (ACEEE, 2005). This workshop found that there has not been a coordinated approach for capturing energy efficiency opportunities in this sector in the United States. Although individual energy-efficiency programs have been implemented in various locations, the workshop participants acknowledged the need for an over-arching initiative that would address a range of needs, including (ACEEE, 2005, p. vi):

- the development of best practice guidelines, particularly focusing on an overall systems approach to performance;
- data collection to support performance assessments relative to best practice guidelines;
- research and development; and
- information exchange to identify, collect, and disseminate information.

To address these needs, the U.S. Environmental Protection Agency is working with a broad group of stakeholders to build an energy-efficiency Focus in the water supply and wastewater industries. A Focus, implemented as part of the ENERGY STAR program, is a targeted effort to improve the energy efficiency within a specific industry or combination of industries.[40] Through this effort, EPA is working to provide the industry's managers with the tools to achieve greater success in their energy management programs, and create a supportive environment where energy efficiency ideas and opportunities are shared. Specific objectives include developing the following (USEPA, 2005):

- a strong network of partners (public and private drinking water organizations, POTWs/local governments, and related industry, national, and state associations);
- an energy performance rating system for each industry that is normalized for the appropriate variables such as weather, climate, plant/system characteristics, and regional differences;
- an Energy Efficiency Assessment and Opportunities Report for each industry that describes best practices to increase energy and water efficiency;
- Energy Management Guidelines to help organizations set goals and determine action steps; and
- innovative solutions to financing energy efficiency projects,

Through the summer of 2005, the ENERGY STAR Water and Wastewater Focus has involved a diverse set of stakeholders listed. Following progress in the initial industry Focus, EPA intends to expand the effort to all organizations in the water and wastewater sector.

Recognizing that a substantial portion of the water supply and wastewater treatment industries resides in local governments, the ENERGY STAR program has resources tailored to the needs

[40] An ENERGY STAR Focus is a targeted effort to improve energy efficiency in a specific industry. Each Focus creates momentum for continuous improvement in energy performance, providing tools and support, including energy performance evaluation tools and guidelines, financing information, and technical training. Recognition for improved energy performance is also an important program element.

of local governments. As of the Fall of 2007, ENERGY STAR lists 191 local governments and agencies as program partners in 39 states and the District of Columbia.[41] As shown in Exhibit 7-4, the 72 counties that are partners in the program have a total population of over 50 million. The program's extensive experience working with local governments provides a strong basis for developing the tools and methods for working with the water supply and wastewater treatment industries to improve energy efficiency.

Exhibit 7-3: Stakeholders Contributing to the Development of the ENERGY STAR Water and Wastewater Focus

The American Council for An Energy Efficient Economy (ACEEE)	National Association of Clean Water Agencies (NACWA)
Association of Metropolitan Water Agencies (AMWA)	National Association of Regulatory Utility Commissioners (NARUC)
Alliance to Save Energy (ASE)	National Association of Water Companies (NAWC)
AWWA Research Foundation (AwwaRF)	New York State Energy Research and Development Authority (NYSERDA)
California Energy Commission (CEC)	Oakridge National Laboratory (ORNL)
Consortium for Energy Efficiency (CEE)	Public Technology Institute (PTI)
Columbus (GA) Water Works	Water Environment Federation (WEF)
Electric Power Research Institute (EPRI)	Wisconsin Focus on Energy
Lawrence Berkeley National Laboratory (LBNL)	Washington Suburban Sanitary Commission (WSSC)
Los Angeles - Bureau of Sanitation	WateReuse Association
Metropolitan Council Environmental Services	

Source: Analysis of water and wastewater participants from: www.energystar.gov. Water and wastewater participant list: http://www.energystar.gov/ia/business/government/wastewater_participants.pdf

[41] Five local government program partners are water or wastewater treatment utilities: Central Contra Costa Sanitary District, California; Louisville & Jefferson Metropolitan Sewer District, Kentucky; West Point Treatment Plant, Washington; North Shore Water Commission, Wisconsin; and Oak Creek Water and Sewer Utility, Wisconsin. Based on activities motivated through the program, the Louisville & Jefferson County Metropolitan Sewer District (L&JC) reports saving 1.5 million kWh per year worth more than $600,000 annually (Cunningham, et al., 2001). The L&JC activities included: billing analysis that identified rate optimization opportunities of $120,000 annually; lighting upgrades, including T-8 retrofits, delamping, occupancy sensors; and LED exit sign retrofits; improved HVAC controls; improved specification of pump configurations to ensure efficiency during periods of low, average, and high flow; and high-efficiency pump and motor purchases based on detailed efficiency and payback analyses. L&JC also reports reducing energy consumption for aeration through process changes at their largest wastewater treatment plant (Cunningham, et al., 2001).

Exhibit 7-4: Populations in Counties that are ENERGY STAR Partners

State	# of Counties	Population	State	# of Counties	Population
Alabama	1	113,000	Missouri	1	664,000
Arizona	3	3,995,000	Nebraska	1	44,000
Arkansas	1	367,000	New Jersey	1	531,000
California	6	17,744,000	North Carolina	1	787,000
Colorado	3	1,386,000	Ohio	4	1,885,000
Delaware	1	526,000	Oregon	2	787,000
Florida	6	6,602,000	Pennsylvania	4	1,421,000
Georgia	4	1,907,000	Tennessee	1	94,000
Hawaii	1	910,000	Texas	1	493,000
Idaho	2	381,000	Utah	1	979,000
Illinois	2	981,000	Vermont	1	150,000
Iowa	3	501,000	Virginia	6	1,062,000
Kentucky	2	972,000	Washington	2	2,013,000
Maryland	2	1,720,000	West Virginia	1	24,000
Michigan	3	473,000	Wisconsin	3	669,000
Minnesota	2	254,000	**Total**	**72**	**50,435,000**

Source: Analysis of local government partner list from: www.energystar.gov.
Population data from: http://www.census.gov/popest/estimates.php (July 1, 2006 Estimates).

7.6 Opportunities for Residential Customers to Improve Energy and Water Efficiency Together

The key residential products that use both energy and water are: clothes washers; dishwashers; showers; and faucets. Two of these products, clothes washers and dishwashers, are eligible to earn the ENERGY STAR label; additionally, as of October 2007, faucets are eligible to earn the WaterSense label. The WaterSense program is in the process of developing specifications for high-efficiency showerheads, and these products may soon be eligible to earn the WaterSense label. The principal way in which these products save energy is through the reduction in their use of hot water. The combined water and energy savings achieved by these products make them cost effective for consumers. Product labeling and home audits are two strategies for capturing energy and water efficiency.

ENERGY STAR Labeling. Through 2006, the ENERGY STAR program is estimated to be responsible for cumulative sales of 11.4 million ENERGY STAR labeled clothes washers and 28.7 million ENERGY STAR labeled dishwashers. The annual direct water savings from these products are:

- clothes washers: 80 mgd;[42] and
- dishwashers: 59 mgd.[43]

[42] Annual water savings of an ENERGY STAR clothes washer over a conventional clothes washer is 5,608 gallons per year (gpy) for a 2004 specification unit (ENERGY STAR Clothes Washer Savings Calculator, last updated 10/11/2006) and zero gpy for a pre-2004 specification unit. Through 2006 6.16 million pre-2004 and 5.24 million 2004 specification units were shipped (Sanchez et al., 2007).

[43] Annual water savings of an ENERGY STAR dishwasher over a conventional dishwasher is 860 gallons per year for a 2004 specification unit (ENERGY STAR Dishwasher Savings Calculator, last updated 2/15/2005) and zero for a

These direct water savings are in addition to the indirect water savings achieved through energy efficiency.

Variability exists in the water consumption of some products. For example, the variability in clothes washer water use was reported in the retrofit studies discussed in Section 5.2. The ENERGY STAR program has taken steps to capture additional water savings within the ENERGY STAR product labeling framework. For example, the clothes washer specification for ENERGY STAR includes a water efficiency requirement that took effect January 1, 2007. The specification includes a maximum water factor, along with a minimum energy factor. The shaded area in Exhibit 7-5 shows the specifications for clothes washers and illustrates that some models use more water than others per unit of washer capacity. ENERGY STAR also revised specifications for dishwashers as of January 1, 2007.

Combining the energy and water specifications under a single label has several benefits. The single designation will clarify the choice of resource-efficient washers in the marketplace, simplifying purchase decisions for consumers. Using a single label simplifies participation for manufacturers, and enables energy and water utilities to adopt a uniform set of products to promote in local and regional energy and water efficiency programs. Additionally, combining water and energy specifications in a single program prevents unnecessary program duplication at the federal level.

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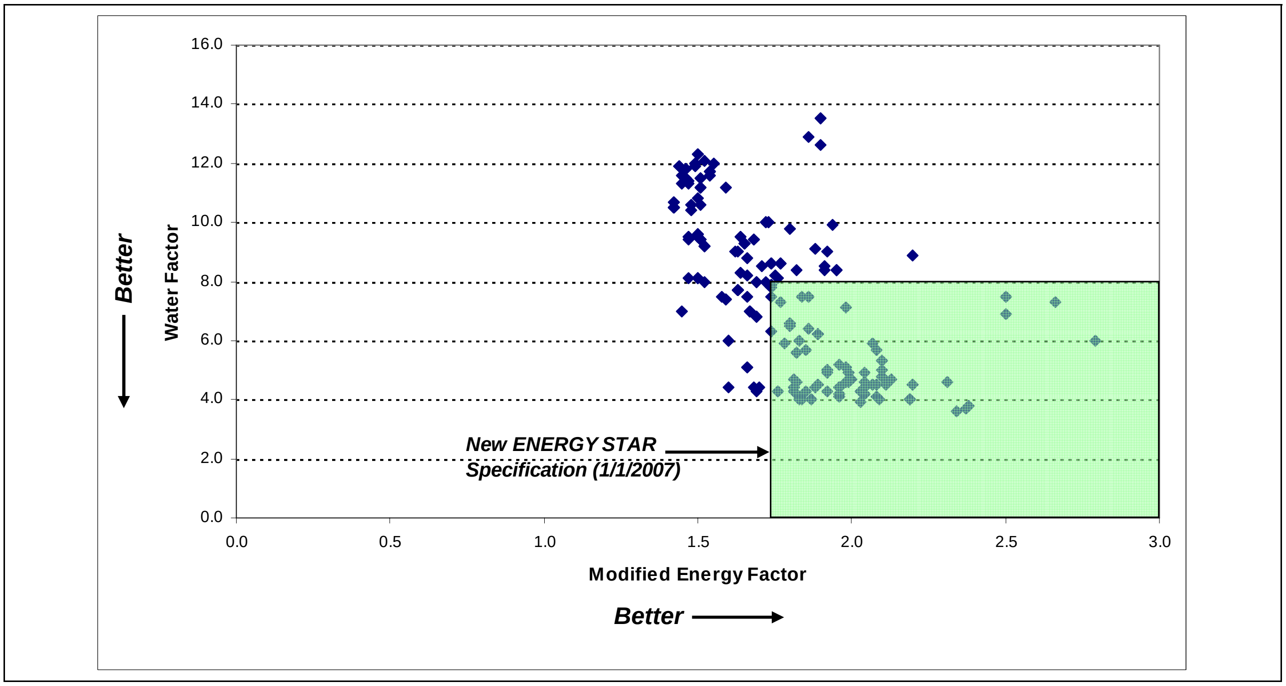
pre-2004 specification unit. Through 2006 3.57 million pre-2004 and 25.11 million 2004 specification units were shipped (Sanchez et al., 2007).

Exhibit 7-5: Variability in Water Use Among ENERGY STAR Labeled Clothes Washers Pre-2007



Modified Energy Factor = a measurement of the relative efficiency of the unit. Higher values represent greater efficiency.

Water Factor = water use per unit of washer capacity. Lower values represent greater efficiency.

ENERGY STAR specifications are: Maximum Water Factor of 8.0 and Minimum Modified Energy Factor of 1.72.

Data shown are for all ENERGY STAR labeled products listed on the ENERGY STAR website as of September 2005.

Source: ENERGY STAR (www.energystar.gov).

Home Performance with ENERGY STAR. "Home Performance with ENERGY STAR," an ENERGY STAR program that focuses on improving residential energy use, may provide an opportunity to promote water efficiency. As part of Home Performance, trained and certified home inspectors conduct detailed assessments of the way energy is used in homes. Through this branded service that leverages public recognition of the ENERGY STAR label, the objective is to make homes more comfortable with lower energy bills. Home Performance is now available in more than 15 states.

Home Performance implementers have identified water efficiency assessments as a value-added service that could potentially be incorporated into the program. EPA should examine the best approaches for achieving increased water efficiency in existing homes, including additional training and tools for ongoing water utility audit programs.

WaterSense labeling addresses the single largest opportunity to save water in the home, HET toilets. HET toilets do not save energy directly, however, the water savings associated with these products would save energy in the water supply and wastewater treatment sectors, as described in previous sections. Through the specification of performance characteristics based on accepted test methods, the program identifies HETs that can both perform well and use less water than required under EPAct.

Residential Rebate Programs. Water utilities have offered rebate programs for many years in order to promote efficient water use. Typically these programs consist of a financial incentive or rebate that is offered to residential customers to reduce the capital cost of purchasing and installing water efficient fixtures. These programs can be directed at retrofitting existing homes or encouraging builders of new homes to install high efficiency appliances. These programs cover a wide range of fixture types including showerheads, toilets, and clothes washers. Exhibit 7-6 below contains information on estimated water and energy savings in Southern California (MWD, 2006).

Exhibit 7-6:. Water Efficiency Rebate Programs and Associated Energy Savings for Residential Products

Device/Program	Water Savings per Year (Acre-Feet)	Lifetime Water Savings (Acre-Feet)	Lifetime Energy Savings (kWh)[a]
Residential Indoor			
High-Efficiency Toilet (HET)	0.04	0.85	3,574
HET Upgrade/New Construction	0.01	0.16	658
Ultra Low Flush Toilet (ULFT)	0.03	0.70	2,925
High-Efficiency Clothes Washer	0.02	0.23	986

[a] Assumes 4,200 kWh/acre-foot for indoor water use and 3,500 kWh/acre-foot for outdoor use.
Source: Metropolitan Water District of Southern California, 2006.

7.7 Opportunities Among Commercial Customers to Improve Energy and Water Efficiency Together

Strong links exist between water efficiency and energy efficiency among commercial customers. Opportunities to capture energy and water savings can be defined in terms of four strategies used to promote efficiency: systems-oriented building performance; product labeling; sector-specific assessments and commercial rebate programs. Each is discussed in turn.

Systems-Oriented Building Performance. Over the past 20 years, the energy efficiency community has worked with many organizations to refine and promote an effective energy management approach for commercial buildings. The preferred approach emphasizes the need to measure and improve buildings as a system, including the impacts of operations and maintenance. Additionally, the importance of corporate commitment to improving energy efficiency has been noted. In the ENERGY STAR program, the systems-oriented approach has been shown to deliver twice the energy savings for a given investment as alternative approaches (USEPA, 2004a), and it is essential to seeing progress in the energy efficiency of buildings over the next decades.

Fundamental to this systems-oriented approach is the ability to measure a building's total performance. Within the ENERGY STAR framework, the national energy performance rating system for buildings has been in use since 1999. The framework is based on the statistical regression analysis of national survey data (the Energy Information Administration's Commercial Building Energy Consumption Survey, CBECS). The system is currently capable of rating 13 building types (offices, bank branches, courthouses, financial centers, K-12 schools, acute care and children's hospitals, medical office buildings, hotels/motels, retail stores, supermarkets, residence halls/dormitories, warehouses, and wastewater treatment facilities). These building types account for more than half of all US commercial buildings. ENERGY STAR is continually looking for opportunities to expand the number of building types eligible for rating.[44]

As a front-end user interface to the energy performance rating system, the EPA designed the Portfolio Manager tool – a free-to-use online software program that allows building owners and operators to enter relevant building data and receive a 1-to-100 rating comparing their buildings' energy performance to that of similar properties across the United States. Buildings that rate a 75 or higher – indicating that they are performing in the top quartile of their building type nationwide – are eligible to apply for the ENERGY STAR label. Significant to note is the fact that these ratings are "normalized" for local weather conditions as well as key building characteristics such as size and occupancy – meaning that the energy performance of a small office building in Buffalo can be effectively compared to that of a skyscraper in Los Angeles. In addition, for building types that are not eligible to receive a 1-to-100 rating, Portfolio Manager can be used to determine the energy use intensity (expressed in $kBtu/ft^2$) of the building. Furthermore, for all buildings Portfolio Manager serves as an organizational tool, allowing users to actively track the performance of their properties – from single buildings to entire portfolios – in order to see the effects that energy efficiency improvements are having on their energy consumption, energy costs, related environmental impacts, and energy performance ratings if applicable. Collectively, this information can be used in key market transactions such as the assessment of the asset value of a building or lease price of building space. Exhibit 7-7 lists the current availability of Portfolio Manager by market segment, as well as the portion of each sector that has made commitments to improve performance under the ENERGY STAR program.

[44] From http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager.

Exhibit 7-7: ENERGY STAR Building and Product Offerings for Ratable Building Types (as of September 2007)

Market Segment	Current Rated Floor Space (% of market)	Availability of National Energy Performance Rating System (Portfolio Manager)	Primary ENERGY STAR Products Applicable to Building Type
Office • General • Courthouses • Banks • Financial Centers	3.2 billion (31%)	– available since 1999 – available since 2004 – available since 2004 – available since 2004	Office equipment Consumer electronics Appliances Water coolers Vending machines
Retail • All retail stores with the exception of stores in malls and electronics stores	Not yet available	– available since 2007	Office equipment Consumer electronics Appliances Water coolers
Education • K-12 • Higher Education (residence halls and dormitories) •	1.4 billion (22%) 42 million (6%)	– available since 2000 – available since 2004	Office equipment Consumer electronics Appliances Lighting
Healthcare • Acute Care Hospitals • Medical Office Buildings	864 million (52%) 50 million (5%)	– available since 2001 – available since 2004	Office equipment Vending machines
Lodging (Hotel and Motel)	561 million (21%)	– available since 2001	Office equipment Consumer electronics Appliances Lighting Vending machines
Food Sales • Grocery Stores	286 million (52%)	– available since 2001	Commercial food service equipment Office equipment Water Coolers Vending machines
Other • Warehouses • Wastewater Treatment Facilities	147 million (2%) N/A	– available since 2004 – available since 2007	Office equipment Consumer electronics Appliances Vending machines
TOTAL	**6.5 billion (21%)**		

Building water and energy efficiency have several direct links. For example, upgrading lighting systems and improving lighting design not only reduce electricity consumption, they also reduce heat load on the building. Similarly, improving building shell thermal performance, through the use of reflective roof materials, improved window products, and insulation, also reduces heat load. In buildings that include water-cooled air conditioning systems, these reductions in heat load reduce the amount of water required for cooling. Improving the efficiency of HVAC systems themselves also reduces water consumption. As shown in Section 6.2.3, more efficient HVAC units require less water for a given number of cycles of concentration. Tuning up and controlling an HVAC system to improve its energy efficiency from 1.0 kW/ton of cooling to 0.75 kW/ton saves about 5 percent of the water used for cooling.

Lelic and Blair (2004) identify one specific technology that improves both energy and water efficiency in cooling water systems. Through the use of variable speed drives (VSD) on cooling tower fans, fan speeds can be modulated to match heat dissipation requirements (Lelic and Blair, 2004, p. 3). By avoiding unnecessarily high fan speeds, water loss and electricity requirements are both reduced. Additionally, the temperature of the cooling water can be maintained more precisely so that the air conditioner itself operates more efficiently. Lelic and Blair report that code changes to require VSDs on cooling tower fans are being considered in some areas, and that the U.S. Green Buildings Council endorses their use (Lelic and Blair, 2004, p. 5).

By taking a comprehensive system-wide view of building performance, Portfolio Manager captures these interactions among heat load, air conditioner efficiency, and cooling water systems. Of particular importance is that no single component can be addressed in isolation: the combined performance of the total system is the important measure of building performance. Portfolio Manager has expanded its focus to monitor both energy and water performance in its existing framework.

In addition to the ENERGY STAR voluntary program described above, the Commercial Buildings Energy Consumption Survey (CBECS), implemented by the DOE, collects extensive building performance data for the entire collection of US commercial buildings. In the past the survey has collected comprehensive energy performance metrics on building size, age, principal activity, occupancy hours, energy sources and end-uses, and fuel, steam, and hot water usage. In the upcoming 2007 CBECS survey, the DOE is working with EPA's Office of Water to develop a set of water performance questions to be added to the existing energy related questions in the building survey.[45]

Products Labeling for Commercial Customers. While energy efficiency programs for the commercial and industrial sectors place a large emphasis on whole-building system improvements, there are opportunities to use efficient products as well. Products are typically defined as "plug loads," meaning that that are separate from building systems and plug into an outlet. Many such products, including office equipment and appliances, are already covered by the ENERGY STAR program, and offer significant energy savings within these sectors (see Exhibit 7-7).

Among the 22 ENERGY STAR labeled products available in this sector, four products use energy and water:

- coin-operated clothes washers (labeled in 2001)
- commercial steam cookers (labeled in 2003)
- ice makers (labeled in 2007)
- commercial dishwashers (labeled in 2007).

Additional products undergoing investigation that save both water and energy include: commercial clothes washers[46]; soft-serve machines; and autoclaves (steam sterilizers). Pre-rinse spray valves, used in restaurants and commercial kitchens, have also been identified as a significant opportunity to capture energy and water savings together. The recently enacted Energy Policy Act of 2005 sets a maximum flow rate of 1.6 gallons per minute for newly

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[45] Additional information on CEBCS can be found at: http://www.eia.doe.gov/emeu/cbecs/contents.html.

[46] Coin-operated clothes washers for use in multi-family housing qualified for the ENERGY STAR label in 2001. Commercial multi-load clothes washers for use in hotels, hospitals, sports facilities, etc. are undergoing investigation.

manufactured spray valves as of January 1, 2006. Replacing existing spray valves with more efficient models that comply with this new standard can return significant savings very cost effectively.

Sector-Specific Assessments. Energy-efficiency programs and initiatives often take a sector approach to promote corporate commitment and improved performance. This approach to commercial and industrial energy efficiency offers opportunities to promote water efficiency as well. Because water and energy are used jointly in many industrial processes, industry-specific metrics that examine both resources simultaneously should be the preferred approach.

For example, ENERGY STAR assembles sets of practices that reflect a wide range of efficiency opportunities for a sector. In the food service sector, the program promotes multiple sector-specific products: commercial fryers, hot food holding cabinets, solid door refrigerators and freezers, and commercial steam cookers. Expanding this product list to include commercial dishwashers, ice machines, and soft-serve ice cream machines would be an effective method of leveraging the existing program infrastructure.

Similarly, ENERGY STAR has multiple offerings in the hospitality (hotel/motel) and health care sectors. In both sectors, the program promotes whole building energy efficiency through the use of Portfolio Manager.[47] However, products and other practices may be bundled and promoted as well, again leveraging program resources and making use of existing outreach efforts to decision makers and energy managers.

Across these three program strategies, the ENERGY STAR framework provides an example of one option for promoting water efficiency along side energy efficiency to commercial and institutional customers.

Commercial Rebate Programs. Similar to the residential sector, water utilities have offered rebate programs for many years in order to promote efficient water use. Typically these programs consist of a financial incentive or rebate that is offered to commercial customers to reduce the capital cost of purchasing and installing water efficient fixtures. These programs cover a wide range of fixture types including pre-rinse spray valves and other equipment. Exhibit 7-8 below contains information estimated water and energy savings in Southern California (MWD, 2006).

[47] Portfolio Manager is an online tool that enables facility managers to track and manage the energy use of their buildings. It enables buildings to be benchmarked or compared to a similar building stock nationwide. This ENERGY STAR tool is available for commercial office buildings, hospitals, hotels, grocery stores, schools, and several other space types.

Exhibit 7-8: **Water Efficiency Rebate Programs and Associated Energy Savings for Commercial Sector**

Device/Program	Water Savings per Year (Acre-Feet)	Lifetime Water Savings (Acre-Feet)	Lifetime Energy Savings (kWh)[a]
Commercial			
High-Efficiency Toilet (HET)	0.03	0.61	2,546
HET Upgrade/New Construction	0.01	0.11	469
Ultra Low Flush Toilet (ULFT)	0.03	0.68	2,835
High-Efficiency Urinal (HEU)	0.06	1.23	5,153
HEU Upgrade/New Construction	0.02	0.31	1,289
Zero Water Urinal (ZWU)	0.12	2.45	10,307
ZWU Upgrade/New Construction	0.03	0.61	2,577
High-Efficiency Clothes Washer	0.12	0.93	3,898
Pre-Rinse Spray Valves	0.22	0.67	2,822
Water Brooms	0.15	0.46	1,698
Connectionless Food Steamers	0.25	2.50	10,500
Cooling Tower Controllers	0.32	3.22	13,524
PH Cooling Tower Controllers	0.97	9.72	40,824
Steam Sterilizer	1.30	19.50	81,900
X-Ray Recirculation	3.20	16.00	67,200
Landscape			
Commercial Water Based Irrigation Controllers (WBIC)	0.80	8.00	29,600
Rotating Nozzles for Pop-up Spray Heads	0.00	0.02	74

[a] Assumes 4,200 kWh/acre-foot for indoor water use and 3,500 kWh/acre-foot for outdoor use.
Source: Metropolitan Water District of Southern California, 2006.

7.8 Potential Water and Energy Savings Resulting From Leveraging Energy and Water Efficiency Programs

Dual savings strategies reduce the amount of both energy and water demanded by customers. The energy savings reduce the load on the relevant energy distribution systems, electric and/or gas. Similarly, the direct water savings reduce the amount of water that needs to be handled by community water supply and wastewater treatment systems.

In contrast to the dual savings strategies, many energy efficiency activities only save energy directly, so that water is only saved indirectly. The indirect water savings are realized through reduced cooling water requirements at power plants. For example, high efficiency residential lighting products reduce electricity generation requirements, and thereby indirectly reduce power plant cooling water needs. Although these indirect water savings at power plants do not reduce the water demands on community water supply systems and wastewater treatment plants, they have the potential to reduce the pressure on water resource requirements for power plant operations.

Each of the previous sections presents aspects of the relationship between water and energy use and opportunities for leveraging energy efficiency programs to improve water efficiency. This section summarizes these relationships and quantifies opportunities to save water and energy together. First, the water savings associated with the ENERGY STAR program is presented. Second, the potential energy savings from leveraging WaterSense program is presented. This section concludes with potential program strategies for promoting efficiency.

7.8.1 Potential Water Savings By Leveraging the ENERGY STAR Program

Exhibit 7-9 lists the direct and indirect water and energy savings estimated to be achieved by the ENERGY STAR program in 2006. The energy savings are reported under the ENERGY STAR Products program element and the Buildings element. These energy savings total 151,700 million kWh per year. The direct water savings are shown for clothes washers and dishwashers (as discussed in Section 7.6), totaling approximately 140 mgd. Improving the efficiency of cooling tower operations are also reported, amounting to about 1 percent of estimated cooling tower water use, or 2.6 mgd. This water savings is estimated based on 10 percent of the floor space of buildings with cooling towers having reduced energy consumption by 10 percent. Reaching this portion of large buildings is within the range of penetration of the current ENERGY STAR program (see Exhibit 7-7), and has probably been exceeded by the existing program activities.

The total direct water savings for 2006 from the ENERGY STAR program is about 140 mgd, which is equal to the residential indoor water use of about 2.0 million people. The indirect water savings at power plants is estimated at over 180 mgd.

The ENERGY STAR program is expected to grow over the next 9 years, approximately doubling its energy savings with currently planned activities.

Exhibit 7- 10 shows the estimated energy and water savings in 2015. In addition to the existing ENERGY STAR program elements, the exhibit lists the energy and water savings from potential new energy efficiency activities, including the following:

- <u>Intensified Residential Clothes Washer and Residential Dishwasher Initiatives</u>: ENERGY STAR labeled clothes washers are expected to account for about 40 percent of annual shipments of residential clothes washers by 2015. ENERGY STAR labeled dishwashers are expected to account for over 60 percent of shipments by 2015. Expanding the market share of resource-efficient clothes washers and dishwashers by another 6 percent would increase shipments so that 8 million additional clothes washers and 6 million additional dishwashers would be achieved over 10 years. The incremental direct water and energy savings associated with this intensified activity are about 130 mgd and 6.8 billion kWh per year.
- <u>Cooling Towers</u>: As discussed above in Section 6.2.3, a 10 percent improvement in the operation of cooling towers would save about 26 mgd. The direct energy savings that would accompany this water savings has not been estimated.
- <u>Water Supply and Wastewater Treatment Industry Focus</u>: As discussed in Section 7.5, the ENERGY STAR program is developing a focus on the water supply and wastewater treatment industries. Energy efficiency improvement targets for these sectors could include:
    - ➢ A 5 percent reduction in the energy intensity of water supply, achieved primarily through improved pumping efficiency, would yield annual energy savings of about 1,500 million kWh.

- ➢ A 10 percent reduction in the aeration energy requirements at activated sludge processes of treatment plants would save about 575 million kWh annually.
- ➢ A target of a 2 percent improvement in pumping efficiency at wastewater treatment plants would yield savings of 34 million kWh per year.

The total energy savings across these three activities is about 2,110 million kWh, shown in Exhibit 7-10.

- Other Industries: Additional efforts could be developed for other industries to save both water and energy. The potential savings from additional initiatives are not estimated at this time.

The potential expansion of energy efficiency efforts has the potential to achieve direct water savings of about 160 mgd by 2015. Combined with the direct water savings associated with the planned expansion of the existing ENERGY STAR activities, the total water savings are estimated to be about 750 mgd, or the residential indoor water use of over 10 million people. Of these water savings more than 95 percent are from planned and potential ENERGY STAR clothes washer and dishwasher promotional programs.

Considering the simultaneous savings of both water and energy improves the cost effectiveness of these efforts. The direct energy savings of the new energy efficiency activities listed in Exhibit 7-10, about 8,860 million kWh per year, are worth about $700 million annually. The value of the 160 mgd in direct water savings saved in residential and commercial use can be valued at $4.50 per 1,000 gallons to reflect both water and wastewater volumetric charges. These savings are worth about $260 million annually. The total value of the water and energy saved are together worth almost $1 billion annually.

7.8.2 Potential Energy Savings By Leveraging the WaterSense Program

WaterSense's market enhancement initiatives focus on promoting products and activities that save water directly. Energy may be saved indirectly through reductions in the requirements for supplying and treating water. Until recently, the primary strategies for saving water were to promote the accelerated installation of EPAct compliant bathroom fixtures and to improve the efficiency of outdoor water use. Now, the WaterSense program is promoting the use of high-efficiency, high performing fixtures that go beyond the EPAct standards to replace existing fixtures and install them in new construction.

Exhibit 7-11 presents opportunities to save both water and energy for existing and potential water saving strategies in 2015. Estimates for the projected annual water savings potential for the initial WaterSense program product areas—toilets, faucets, showerheads, irrigation controllers, and certification of irrigation professionals—is currently under development. These savings estimates will be based on the water savings per unit estimates described below and on models of the penetration rate of WaterSense products currently underway.

Listed below are the assumptions and methodologies used for estimating water savings for each of the activities listed.

Existing Water Saving Strategies

- Natural replacement of toilets with EPAct compliant toilets in the residential sector: Gleick, et al. estimate that in 2004, about 70 percent of the population in California did not have 1.6 gallon per flush toilets in their households (Gleick, et al., 2003, Appendix A, p. 6). This percentage is estimated to decline over a 10-year period (through 2015) to about 39 percent as the result of natural replacement and existing promotional programs in the state. Thus, about 31 percent of the population is expected to replace their non-compliant toilets by 2015. Using this replacement rate nationally, along with the projected U.S. population of about 312 million in 2015, the natural replacement rate amounts to about 95 million people. The direct water savings from this rate of replacement is substantial, totaling about 1,600 mgd, including both the direct savings from flushing and the reduced leakage from faulty flapper valves. This amount of reduction is about 3 percent to 4 percent of total water withdrawal for public supply in 2000. Annual indirect electricity savings of 980 million kWh would be realized due to reduced water pumping for water supply and treatment (no reduction in energy use is assumed for aeration during wastewater treatment).[48] The estimates are shown in Exhibit 7-11.

- Natural replacement of toilets and urinals with EPAct compliant toilets and urinals in the commercial sector: The installation of EPAct compliant toilets and urinals in the commercial sector is further along, with about 55 percent and 45 percent penetration respectively reported by Gleick, et al. for California (Gleick, et al., 2003, Appendix D, pp. 1 and 3). Insufficient information is available for estimating the continued natural installation rate of EPAct compliant toilets and urinals in commercial applications over the next 10 years.
- WaterSense high-efficiency toilets (HETs): Replacing EPAct compliant toilets with 1.28 gpf HETs saves 794 gallons per toilet per year. The current existing stock of 222 million toilets is a mix of older pre-EPAct models and EPAct compliant model. The national composition is estimated to consist of 5.0 gpf toilets, 3.5 gpf toilets and 1.6 gpf toilets (WaterSense, 2007a).
- WaterSense high-efficiency faucets: By replacing EPAct compliant bathroom sink faucets with WaterSense labeled faucets or retrofitting them with WaterSense labeled faucet accessories saves 292 gallons per faucet per year. EPAct compliant faucets have a maximum flow rate of 2.2 gpm. WaterSense labeled faucets and faucet accessories will have a maximum flow rate of 1.5 gpm (WaterSense, 2007b).
- WaterSense high-efficiency irrigation controllers: There currently are an estimated 25,000,000 installed controllers in the United States, 95 percent of which are candidates for replacement with higher-efficiency models (WaterSense, 2006). Based on analysis of data from six field studies, a 20 percent savings can be expected from using high-efficiency irrigation control technologies, which translates to approximately 10,000 gallons per controller per year (USEPA, 2007b).
- WaterSense certification program for irrigation professionals: Currently 6 programs have applied for WaterSense label and there are 260 WaterSense irrigation partners and the number of certified individuals is expected to grow each year. It is estimated that irrigation professionals certified through a WaterSense labeled program is approximately 15 percent more water efficient than systems handled by professionals without this certification (USEPA, 2007b).

Potential Water Savings Strategies

- Accelerated replacement of toilets with EPAct compliant units in the residential sector: In addition to the 95 million people expected to replace their non-compliant toilets to EPAct

[48] Replacing these toilets with WaterSense toilets instead of EPAct compliant toilets would produce direct water savings of 1,800 mgd and associated indirect energy savings of greater than 1 billion kWh (assuming that WaterSense toilets generate savings of 12.0 gallons per capita day (gpcd) above conventional, as compared to 10.3 gpcd savings for EPAct compliant toilets; both EPAct compliant and WaterSense toilets are assumed to generate savings of 6.3 gpcd from leak reduction compared to conventional toilets).

compliant units through natural replacement, accelerated replacement programs can be used to further increase savings. Gleick, et al.'s figures indicate that even in California, which has active water-conservation programs, there is considerable opportunity to further accelerate the installation of more efficient fixtures in residential applications (Gleick, et al., 2003). Nationally, the potential is likely larger. If an additional 25 million people replace their non-compliant toilets to EPAct units by 2015, the resulting additional direct water and indirect energy savings would total 430 mgd and 260 million kWh, respectively.

- Accelerated replacement of toilets and urinals with EPAct compliant units in the commercial sector: Accelerated replacement of an additional 2 million EPAct compliant toilets and urinals in the commercial sector would save about 200 mgd.[49] The annual indirect energy savings is estimated at about 120 million kWh.
- Reduced leakage in the water supply sector: Given that leakage is believed to be on the order of 10 percent of total water supply, a 10 percent reduction in leakage would mean a savings of about 1 percent of water supply, implying direct savings of 300 million kWh per year and 548 mgd. An aggressive national program effort could potentially achieve half this amount of savings, which is included in the exhibit. The largest single water saving opportunity is the reduction in real water losses by water supply systems, which warrants focused attention within any strategy to improve water and energy efficiency.
- Other Strategies: Landscaping, Irrigation, and Power Plant Cooling water efficiency programs: Improved efficiency in outdoor landscaping water use has the potential to save significant amounts of water, both in residential and commercial applications. The savings opportunities vary regionally, and have not been estimated in this report. Similarly, significant water savings may be achievable through improved irrigation efficiency on crops and substitution of dry cooling for recirculated cooling at power plants. In these two cases, increased energy usage may be associated with the water savings. Neither the water savings potential nor the possible increases in energy requirements are estimated here for crop irrigation and dry cooling.

The total water savings for the existing water saving strategies is over 1,600 mgd, which includes natural replacement of toilets in the residential sector with EPAct compliant toilets. Potential water savings strategies could save an additional 630 mgd through accelerated replacement of EPAct compliant toilets and urinals in the residential and commercial sectors; a value of over 1 billion dollars in savings per year. Moreover, a reduction in water loss during supply could result in avoided leakage of 270 mgd. Using the marginal cost of additional supply of $1.90 per 1,000 gallons as a representative value, the value of reduced water loss is about $180 million per year. The total direct and indirect energy savings for these potential water savings strategies are estimated at about 700 million kWh and are worth over $55 million per year. Combined the potential savings are worth over $1.2 billion per year. The savings estimates presented here are incomplete in that they omit WaterSense products and programs, residential and commercial landscaping options, irrigation options, and increased use of dry cooling at power plants.

[49] The savings per ULF toilet are estimated as 3 gallons per flush times 20 flushes per day for commercial applications. The savings per urinal are estimated as 2 gallons per flush times 20 flushes per day.

Exhibit 7-9: ENERGY STAR Program Energy and Water Savings in 2006

Activity	Direct Savings: Electricity (million kWh/yr)	Direct Savings: Community Water Supply and Wastewater Treatment (mgd)	Indirect Savings: Electricity (million kWh/yr)[b]	Indirect Savings: Power Plant Cooling Water (mgd)[c]	Total Savings[a]: Electricity (million kWh/yr)	Total Savings[a]: Water (mgd)
ENERGY STAR Products: 2006	75,200[d]	(estimated separately)	(estimated separately)	93	75,200	93
11.4 Million ES Clothes Washers: 2006[e]	(included above)	80[f]	48	(included above)	48	80
28.7 Million ES Dishwashers: 2006[e]	(included above)	59[g]	36	(included above)	36	59
ES Commercial Clothes Washers and Steam Cookers: 2006	(included above)	(under development)	(under development)	(included above)	(under development)	(under development)
ENERGY STAR Buildings: 2006	76,500 [h]	(estimated separately)	(estimated separately)	94	76,500	94
ES Buildings Reduced Water for Cooling: 2006	(included above)	3[i]	2	<1	2	3
ENERGY STAR in 2006	**151,700**	**142**	**86**	**187**	**151,786**	**329**

[a] Totals may not add due to independent rounding.
[b] Only water supply and wastewater pumping electricity savings will take place due to reduced water consumption. Water supply consumes 1,500 kWh/million gallons and wastewater pumping consumes 150 kWh/million gallons (Burton, 1996).
[c] Assuming a mid-range value of 0.45 gallons/kWh (see Sections 4.2 and 7.2). The impact of transmission and distribution losses on this factor has been ignored; however, the impact on the factor is minimal since transmission and distribution losses fall in the range of 5 to 10 percent.
[d] ENERGY STAR 2006 annual report, page 15. Available at: http://www.energystar.gov/ia/news/downloads/annual_report_2006.pdf.
[e] Cumulative shipments by specification (i.e., tier) due to ENERGY STAR program in 2006 (Sanchez et al., 2007). Through 2006 6.19 million pre-2004 specification (i.e., tier 1) and 5.24 million 2004 specification (i.e., tier 2) clothes washer shipments due the ENERGY STAR program, 3.57 million pre-2004 specification (i.e., tier 1) and 25.11 million 2004 specification (i.e., tier 2) dishwasher shipments due to the ENERGY STAR program, and 1.2 thousand pre-2004 specification (i.e., tier 1) steam cooker shipments due to the ENERGY STAR program. The weighted average ENERGY STAR clothes washer savings over a conventional unit in 2006 is 2,570 gallons per year.
[f] Annual water savings of an ENERGY STAR clothes washer over a conventional clothes washer is 5,600 gallons per year for a 2004 specification unit (ENERGY STAR Clothes Washer Savings Calculator, last updated 10/11/2006) and zero for a pre-2004 specification unit. Total water savings estimated using cumulative shipment values by specification for clothes washers as shown in footnote e (Sanchez et al, 2007). The weighted average ENERGY STAR clothes washer savings over a conventional unit in 2006 is 2,570 gallons per year.
[g] Annual water savings of an ENERGY STAR dishwasher over a conventional dishwasher is 860 gallons per year for a 2004 specification unit (ENERGY STAR Dishwasher Savings Calculator, last updated 2/15/2005) and zero for a pre-2004 specification unit. Total water savings estimated using cumulative shipment values by specification for dishwashers as shown in footnote e (Sanchez et al., 2007). The weighted average ENERGY STAR dishwasher savings over a conventional unit in 2006 is 753 gallons per year.
[h] ENERGY STAR 2006 annual report, page 15. Available at: http://www.energystar.gov/ia/news/downloads/annual_report_2006.pdf.
[i] Total cooling water consumption in commercial buildings is 260 million gallons per day (CEBCS,1999 & Perry's Chemical Engineering Handbook). Assuming Energy STAR buildings have a penetration rate of approximately 10 percent and have cooling towers with 10 percent greater efficiency than conventional cooling towers.

Exhibit 7-10: Potential Energy and Water Savings in 2015

Activity	Direct Savings		Indirect Savings		Total Savings[a]	
	Electricity (million kWh/yr)	Community Water Supply and Wastewater Treatment (mgd)	Electricity (million kWh/yr)[b]	Power Plant Cooling Water (mgd)[c]	Electricity (million kWh/yr)	Water (mgd)
Planned Growth in Existing ENERGY STAR Activities Through 2015						
ENERGY STAR Products: 2015	257,000[d]	(estimated separately)	(estimated separately)	320	257,000	320
29.1 million ES Clothes Washers: 2015[e]	(included above)	448[f]	270	(included above)	270	448
83.2 million ES Dishwashers: 2015[e]	(included above)	145[g]	87	(included above)	87	145
ES Commercial Dishwashers, Commercial Clothes Washers, Ice Machines and Steam Cookers: 2015	(under development)	(under development)	(under development)	(under development)	(under development)	(under development)
ENERGY STAR Buildings: 2015	89,900[h]	(estimated separately)	(estimated separately)	110	89,900	110
ES Buildings Reduced Water for Cooling: 2015	(included above)	3[i]	2	<1	2	3
Subtotal Existing Activities 2015	**346,900**	**596**	**359**	**430**	**347,259**	**1,026**
Potential New Energy Efficiency Activities Through 2015						
8 million additional ES Clothes Washers	4,960[j]	123[f]	74	6	5,034	129
6 million additional ES Dishwashers	1,790[k]	10[g]	6	2	1,796	13
Other ES Products: Commercial Dishwashers, Commercial Clothes Washers, Ice Machines and Steam Cookers	(under development)	(under development)	(under development)	(under development)	(under development)	(under development)
Improved cooling tower operations: 10% Improvement in Water Use	(not estimated)	26[l]	16	<1	16	26
Dry Cooling for Power Plants	(not estimated)	(not estimated)	(not estimated)	(not estimated)	(not estimated)	(not estimated)
Water Supply/Wastewater Treatment Industry Focus	2,110[m]	0	0	3	2,110	3
Subtotal New Activities in 2015	**8,860**	**160**	**100**	**11**	**8,960**	**170**
Total 2015 (New and Existing)	**355,760**	**756**	**459**	**441**	**356,219**	**1,196**

[a] Totals may not add due to independent rounding.
[b] Only water supply and wastewater pumping electricity savings will take place due to reduced water consumption. Water supply consumes 1500 kWh/million gallons and wastewater pumping consumes 150 kWh/million gallons (Burton, 1996).
[c] Assuming a mid-range value of 0.45 gallons/kWh (see Sections 4.2 and 7.2). The impact of transmission and distribution losses on this factor has been ignored; however, the impact on the factor is minimal since transmission and distribution losses fall in the range of 5 to 10 percent.
[d] Sanchez et al,, 2007.
[e] Cumulative shipments by specification (i.e., tier) due to ENERGY STAR program in 2015 (Sanchez et al., 2007). Through 2015 3.83 million pre-2004 specification (i.e., tier 1), 9.68 million 2004 specification (i.e., tier 2), and 15.61 million 2007 specification (i.e., tier 3) clothes washer shipments due the ENERGY STAR program, and 0.00 million pre-2004 specification (i.e., tier 1), 35.71 million 2004 specification (i.e., tier 2), and 43.50 million 2007 specification (i.e., tier 3) dishwasher shipments due to the ENERGY STAR program.
[f] Annual water savings of an ENERGY STAR clothes washer over a conventional clothes washer is 6993 gallons per year for a 2007 specification unit (ENERGY STAR clothes washer calculator, last updated 5/2007), 5600 gallons per year for a 2004 specification unit (ENERGY STAR clothes washer calculator, last updated 10/11/2006), and zero for a pre-2004 specification unit. Total water savings estimated using cumulative shipment values by specification for clothes washers as shown in footnote f (Sanchez et al., 2007). The weighted average ENERGY STAR clothes washer savings over a conventional unit in 2015 is 5,614 gallons per year.
[g] Annual water savings of an ENERGY STAR dishwasher over a conventional dishwasher is 430 gallons per year for a 2007 specification unit (ENERGY STAR dishwasher calculator, last updated 6/2007), 860 gallons per year for a 2004 specification unit (ENERGY STAR dishwasher calculator, last updated 2/15/2005), and zero for a pre-2004 specification unit. Total water savings estimated using cumulative shipment values by specification for dishwashers as shown in footnote f (Sanchez et al., 2007). The weighted average ENERGY STAR dishwasher savings over a conventional unit in 2015 is 635 gallons per year.
[h] G&A Sept 07 final (USEPA 2007c Climate Partnerships Protection Division)
[i] Assuming savings per building is the same in 2015 as in 2006.
[j] Average savings of 619.5 kWh/unit-year is based on weighted average savings of cumulative shipments due to ENERGY STAR program in 2015 (Sanchez et al., 2007).
[k] Average savings of 298.6 kWh/unit-year is based on weighted average savings of cumulative shipments due to ENERGY STAR program in 2015 (Sanchez et al., 2007).
[l] Total cooling water consumption at commercial buildings is 260 million gallons per day (CEBCS,1999 & Perry's Chemical Engineering Handbook). Assuming commercial buildings improve their cooling tower efficiency by 10 percent.
[m] Assuming energy efficiency improvements of 5 percent in water supply, 10 percent in wastewater treatment, and 2 percent in wastewater pumping. Water supply consumes 1500 kWh/million gallons, wastewater treatment consumes 525 kWh/million gallons, and wastewater pumping consumers 150 kWh/million gallons (Burton, 1996).

Exhibit 7-11: Potential Savings from Water Saving Strategies by 2015

Activity	Direct Savings		Indirect Savings		Total Savings[a]	
	Electricity (million kWh/yr)	Community Water Supply and Wastewater Treatment (mgd)	Electricity (million kWh/yr)[b]	Power Plant Cooling Water (mgd)[c]	Electricity (million kWh/yr)	Water (mgd)
Planned Growth in Existing Water Saving Activities Through 2015						
Natural replacement of toilets to EPAct compliant toilets (residential): 95 million people using EPAct toilets	0	1,620[d]	980	1	980	1,621
Natural replacement of urinals to EPAct compliant urinals (commercial)	(not estimated)	(not estimated)	(not estimated)	(not estimated)	(not estimated)	(not estimated)
WaterSense High Efficiency Toilets (HETS)	(under development)	(under development)	(under development)	(under development)	(under development)	(under development)
WaterSense High Efficiency Faucets	(under development)	(under development)	(under development)	(under development)	(under development)	(under development)
WaterSense High Efficiency Irrigation Controllers	(under development)	(under development)	(under development)	(under development)	(under development)	(under development)
WaterSense Certification for Irrigation Professionals	(under development)	(under development)	(under development)	(under development)	(under development)	(under development)
Subtotal Existing Activities 2015	**0**	**1,620**	**980**	**1**	**980**	**1,621**
Potential New Water Saving Activities Through 2015						
Accelerated replacement of toilets to EPAct compliant toilets (residential): An additional 25 million people using EPAct toilets	0	430[e]	259	<1	259	430
An additional 2 million EPAct toilets and 2 million EPAct urinals (commercial)	0	200[f]	120	<1	120	200
Intensified WaterSense High Efficiency Toilets, Faucets, Irrigation Controllers, and Irrigation Professionals Promotion	(not estimated)	(not estimated)	(not estimated)	(not estimated)	(not estimated)	(not estimated)
Reduce real loss by 0.5% of total water supply	150[g]	270	163	<1	313	270
Improvements in landscaping, irrigation, and power plant cooling operations.	(not estimated)	(not estimated)	(not estimated)	(not estimated)	(not estimated)	(not estimated)
Subtotal New Activities in 2015	**150**	**900**	**542**	**1**	**692**	**901**
Total 2015 (New and Existing)	**150**	**2,520**	**1,522**	**2**	**1,672**	**2,522**

[a] Totals may not add due to independent rounding.
[b] Only water supply and wastewater pumping electricity savings will take place due to reduced water consumption. Water supply consumes 1500 kWh/million gallons and wastewater pumping consumes 150 kWh/million gallons (Burton, 1996).
[c] Assuming a mid-range value of 0.45 gallons/kWh (see Sections 4.2 and 7.2).
[d] Assuming natural replacements results in 95 million people use EPAct toilets by 2015, which have savings similar to ULF toilets. The water savings from ULF toilets is 10.3 gallons per capital day, and the water savings from reduced leaks is 6.8 gallons per capita day (mid-range) (REUWS, 1999).
[e] Assuming an additional 25 million people use EPAct toilets, which have savings similar to ULF toilets. The water savings from ULF toilets is 10.3 gallons per capital day, and the water savings from reduced leaks is 6.8 gallons per capita day (mid-range) (REUWS, 1999).
[f] Assuming an additional 2 million EPAct toilets (commercial), with savings of 3.0 gallons per flush and 20 flushes per day, and an additional 2 million EPAct urinals (commercial), with savings of 2.0 gallons per flush and 20 flushes per day.
[g] Assuming a 0.5 percent reduction in real loss during water supply. In year 2000 total electricity consumption due to water supply was 30 billion kWh (EPRI, 2000, p. 2-4). A 0.5 percent reduction in real loss during water supply would save 150 million kWh of direct electricity ($0.005 \times 30 \times 10^9$ kWh). 1,500 kWh is used to supply a million gallons of water; therefore, 150 million kWh direct electricity savings during water supply correlates to a direct savings 270 mgd of water (150×10^6 kWh/year x 10^6 gallons/1,500 kWh x 1 year/365 days).

7.8.3 Summary of Potential Program Strategies: Linkage to Improving Water and Energy Efficiency

The strong linkages between water and energy, both direct and indirect, indicate that water and energy efficiency objectives can be approached simultaneously. Energy efficiency programs provide one option for a platform from which many of the water and energy strategies can be promoted to the general public, businesses, and industries. The existing energy-efficiency program infrastructure can be leveraged in the following areas.

- Product Labeling: Products that use both energy and water efficiently, and which meet the performance measures, can be promoted with a product label. As appropriate, either the ENERGY STAR or WaterSense product labeling program could provide consumers with a single label that communicates a good investment, and improved resource efficiency without sacrificing performance.

  A labeling approach should work for both consumer products (such as clothes washers and faucets) and business products (such as steam cookers). In particular, labeling business products enables utility-run and regional energy and water efficiency programs to leverage a common set of specifications in the design of their business-focused initiatives.

- Commercial Building Performance: The integrated-systems performance approach that has been applied to energy efficiency can be expanded to incorporate water efficiency in buildings. In particular, an integrated approach is required for building systems that use both water and energy, such as cooling towers. Metrics for water consumption in buildings can be added to the existing Portfolio Manager building rating tool so that a unified assessment of both energy and water can be conducted. Cost effective retrofits of WaterSense labeled restroom fixtures can also be added to the building performance recommendations to realize water savings benefits within the existing program structure. The first step of this strategy has been taken by adding water use tracking to Portfolio Manager and a number of organizations are now tracking water use through this system.

- Industry Focus: The water supply and wastewater treatment industries warrant additional attention to capture energy savings opportunities, which appear to be significant. A focus on reducing leakage deserves development as an opportunity to save both energy and water. The U.S. Environmental Protection Agency is well positioned to work with these industries, as there is a long working relationship between these industries and the agency. Using its existing industry framework, the ENERGY STAR program can contribute to focused outreach and assistance to the water supply and wastewater treatment industries.

  For the industries currently engaged by ENERGY STAR, industry-specific metrics that cover both energy and water can be developed so that a single message of overall resource efficiency can be promoted. The effectiveness of this combined approach should be assessed, and if appropriate applied to additional industries that are added to the program.

- Home Performance: To improve the efficiency of water use among residential customers, the Home Performance with ENERGY STAR program may provide a program strategy for promoting WaterSense-compliant plumbing fixtures, including high-efficiency toilets and faucets. EPA needs to study how best to expand water audits and efficiency upgrades.

Energy efficiency program resources do not currently extend to several strategies, including labeling plumbing fixtures, outdoor water use, and agricultural irrigation. Fortunately, the WaterSense program is developing labeling specifications for plumbing fixtures and irrigation control technologies. Promoting the retrofit of older fixtures with these high-efficiency fixtures is a method of promoting overall resource efficiency.

Promoting more efficient water use in urban landscaping, among both residential and commercial customers, requires expertise and tools that are outside the current capabilities of most energy efficiency initiatives. The WaterSense program recently released specifications for the certification of irrigational professionals and is in the process of developing specifications for irrigation control technologies and ultimately other technologies that will fill this void. Although the energy efficiency programs can conduct outreach to targeted decision makers, the expertise may need to be added to the programs or provided by another entity, such as the WaterSense program.

Promoting opportunities for improving irrigation efficiency on cropland would also fall outside the scope of most energy efficiency programs, and the ENERGY STAR program in particular. The ENERGY STAR program does not currently reach this audience, nor does it have the expertise needed to take an integrated approach to crop production. Because water ownership and water rights issues often must be considered, irrigation initiatives must incorporate not only technical options and their impacts on crop production, but the legal status of the "saved" water as well.

Finally, cooling water use by newly constructed power plants will be driven by the power generation technologies adopted. Dry cooling (or hybrid cooling) may be selected by a developer as one element of a siting strategy, with tradeoffs properly articulated between water use and plant efficiency. Siting and licensing decisions will likely continue to be made at the state and local level. Whether and how to promote dry cooling within this context remains to be determined.

The WaterSense program and other existing state and utility water efficiency programs can be leveraged to save energy through the product labeling process. The WaterSense program labels products that are at least 20 percent more efficient than the current standards require while performing as well or better than their less efficient counterparts. While WaterSense product specifications do not directly address energy consumption, all water savings realized through the use of WaterSense labeled products have a corresponding reduction in energy consumption as this report has demonstrated. Both commercial and residential water-using products will be addressed by the WaterSense labeling efforts. State- and utility-run rebate programs will be able to leverage this nationally recognized, EPA-backed product label to further their efforts and streamline their programs. The multitude of state- and utility-specific eligible product lists can be eliminated and replaced with a single list of products based upon the WaterSense label.

7.9 Conclusion

Given the inter-related nature of water and energy resources, increased attention is warranted for improving the efficiency of both resources simultaneously. Energy- and water-efficiency initiatives and the ENERGY STAR and WaterSense programs in particular, provide an opportunity for implementing some promising strategies. Both the ENERGY STAR and WaterSense programs have existing program infrastructures and methods for reaching decision makers involved in both water and energy. Some of Energy STAR's program tools and concepts, such as Portfolio Manager and Home Performance, can be extended to encompass water efficiency opportunities. Likewise, the water savings realized through WaterSense's product labeling efforts and its new home initiatives have inherent energy savings that can be emphasized along with the water savings.

Cooperative efforts between ENERGY STAR and WaterSense and all the various institutions involved in energy and water efficiency should be explored as a cost effective option for achieving resource efficiency. These entities should work together to promote and create a resource efficiency ethic across the nation.

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