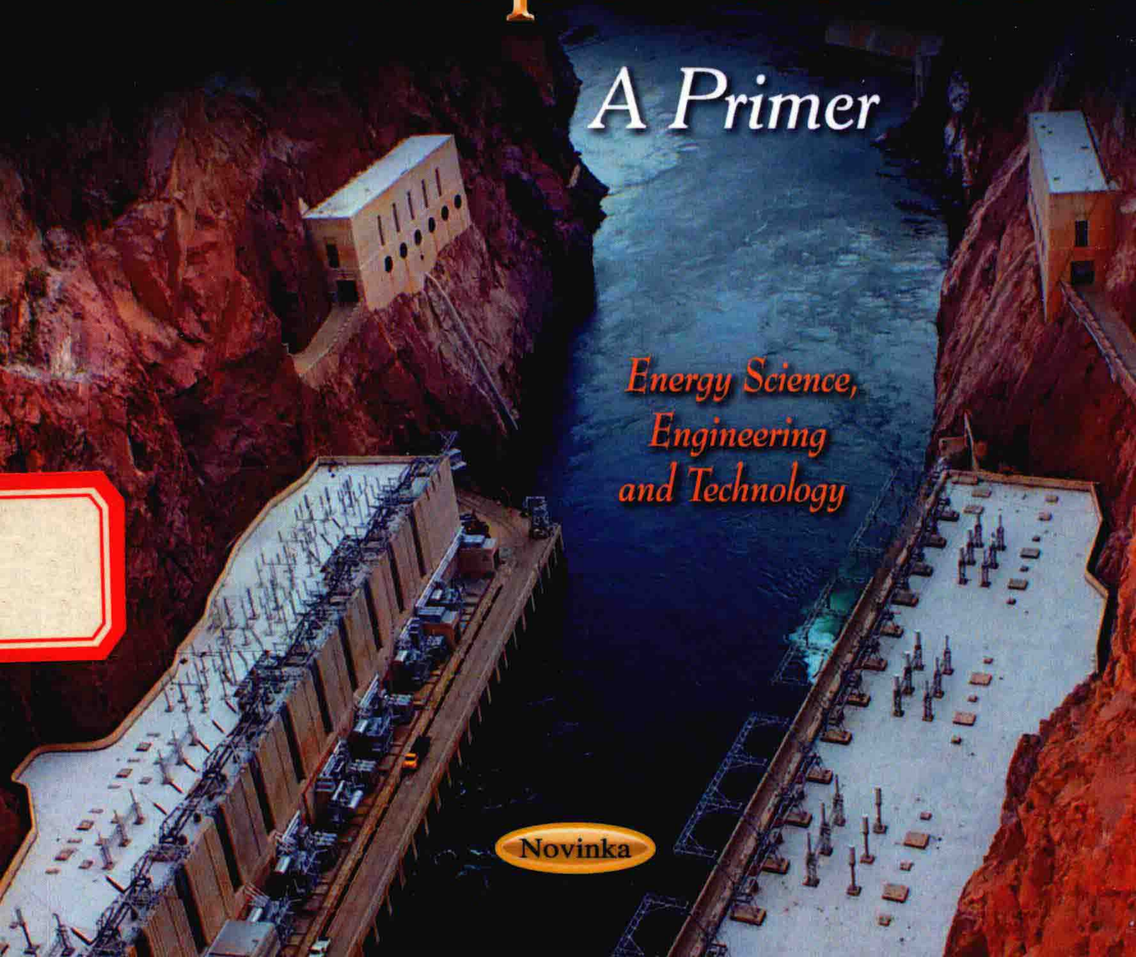
Wilfred D. Meadow
Editor

Energy and Water Sector Interdependence

A Primer

Energy Science, Engineering and Technology



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ENERGY SCIENCE, ENGINEERING AND TECHNOLOGY

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A PRIMER

WILFRED D. MEADOW
EDITOR

NOVINKA
New York

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ENERGY AND WATER SECTOR INTERDEPENDENCE

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PREFACE

This book provides background on energy for facilities that treat and deliver water to end users and also dispose of and discharge wastewater.

Chapter 1 – Water and energy are resources that are reciprocally and mutually linked, because meeting energy needs requires water, often in large quantities, for mining, fuel production, hydropower, and power plant cooling, and energy is needed for pumping, treatment, and distribution of water and for collection, treatment, and discharge of wastewater. This interrelationship is often referred to as the energy-water nexus, or the water-energy nexus. There is growing recognition that "saving water saves energy." Energy efficiency initiatives offer opportunities for delivering significant water savings, and likewise, water efficiency initiatives offer opportunities for delivering significant energy savings. In addition, saving water also reduces carbon emissions by saving energy otherwise generated to move and treat water.

This report provides background on energy for facilities that treat and deliver water to end users and also dispose of and discharge wastewater. Energy use for water is a function of many variables, including water source (surface water pumping typically requires less energy than groundwater pumping), treatment (high ambient quality raw water requires less treatment than brackish or seawater), intended end-use, distribution (water pumped long distances requires more energy), amount of water loss in the system through leakage and evaporation, and level of wastewater treatment (stringency of water quality regulations to meet discharge standards). Likewise, the intensity of energy use of water, which is the relative amount of energy needed for a task such as pumping water, varies depending on characteristics such as topography (affecting groundwater recharge), climate, seasonal temperature, and rainfall. Most of the energy used for water-related purposes is in the form of electricity. Estimates of water-related energy use range from 4% to perhaps 13% of the nation's electricity generation, but regional differences can be significant. In California, for example, as much as 19% of the state's electricity consumption is for pumping, treating, collecting and discharging water and wastewater.

Chapter 2 – Water and energy are critical resources that are reciprocally linked; this interdependence is often described as the water-energy nexus. Meeting energy-sector water needs, which are often large, depends upon the local availability of water for fuel production, hydropower generation, and thermoelectric power plant cooling. The U.S. energy sector's use of water is significant in terms of water withdrawals and water consumption. Thermoelectric cooling represented 41% of water withdrawn nationally, and the broader energy sector's water use (including biofuels) represented around 14% of water consumed nationally. Energy-related water consumption is anticipated to continue to increase in coming decades as the result of more domestic biofuel and unconventional onshore oil and natural gas production. Policy makers at the federal, state, and local levels are faced with deciding whether to respond to the growing water needs of the energy sector, and if so, which policy levers to use (e.g., tax incentives, loan guarantees, permits, regulations, planning, or education). Many U.S. energy sector water decisions are made by private entities, and state entities have the majority of the authority over water use and allocation policies and decisions.

For fuel production, water is either an essential input or is difficult and costly to substitute, and degraded water is often a waste byproduct that creates management and disposal challenges. U.S. unconventional oil and natural gas production has expanded quickly since 2008, and U.S. natural gas and coal exports may rise. This has sparked interest in the quantities of water and other inputs "embedded" in these resources, as well as the wastes produced (e.g., wastewaters from oil and natural gas extraction) and how they are reused or disposed (e.g., concerns over induced seismicity from disposal of oil and natural gas wastewaters). Much of the growth in water demand for unconventional fuel production is concentrated in regions with already intense competition over water (e.g., tight gas and other unconventional production in Colorado, Eagle Ford shale gas and oil in south Texas), preexisting water concerns (e.g., groundwater decline in North Dakota before Bakken oil development), or regions with abundant, but ecologically sensitive surface water resources (e.g., Marcellus shale region in Pennsylvania and New York).

Chapter 3 – The energy choices before Congress represent vastly different demands on domestic freshwater because water is used in varying amounts in most aspects of the energy sector. Transitions in the energy sector, such as the pursuit of greater energy independence and security, produce changes in how much and where the energy sector uses water. The energy sector is the fastest-growing water consumer in the United States, in part because of energy policies. Whether the federal government addresses the energy sector's rising water demand, and if so how, is one of the many energy decisions that may be considered by the 112th Congress.

Much of the growth in the energy sector's water demand is concentrated in regions with already intense competition over water. Whether the energy sector exacerbates or alleviates future water tensions is influenced by near-term energy policy and investment decisions. These decisions also may determine whether water will limit or harm U.S. capability to reliably meet the nation's energy demand. Part of the policy issue for Congress is identifying the extent of the federal role in responding to the energy sector's water use. Currently, the energy industry and states have the most responsibility for managing and meeting the energy sector's water demand.

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Chapter 1

ENERGY-WATER NEXUS: THE WATER SECTOR'S ENERGY USE*

Claudia Copeland

SUMMARY

Water and energy are resources that are reciprocally and mutually linked, because meeting energy needs requires water, often in large quantities, for mining, fuel production, hydropower, and power plant cooling, and energy is needed for pumping, treatment, and distribution of water and for collection, treatment, and discharge of wastewater. This interrelationship is often referred to as the energy-water nexus, or the water-energy nexus. There is growing recognition that "saving water saves energy." Energy efficiency initiatives offer opportunities for delivering significant water savings, and likewise, water efficiency initiatives offer opportunities for delivering significant energy savings. In addition, saving water also reduces carbon emissions by saving energy otherwise generated to move and treat water.

This report provides background on energy for facilities that treat and deliver water to end users and also dispose of and discharge wastewater. Energy use for water is a function of many variables, including water source (surface water pumping typically requires less energy than groundwater pumping), treatment (high ambient quality raw

* This is an edited, reformatted and augmented version of a Congressional Research Service publication, CRS Report for Congress R43200, prepared for Members and Committees of Congress, from www.crs.gov, dated January 3, 2014.

water requires less treatment than brackish or seawater), intended end-use, distribution (water pumped long distances requires more energy), amount of water loss in the system through leakage and evaporation, and level of wastewater treatment (stringency of water quality regulations to meet discharge standards). Likewise, the intensity of energy use of water, which is the relative amount of energy needed for a task such as pumping water, varies depending on characteristics such as topography (affecting groundwater recharge), climate, seasonal temperature, and rainfall. Most of the energy used for water-related purposes is in the form of electricity. Estimates of water-related energy use range from 4% to perhaps 13% of the nation's electricity generation, but regional differences can be significant. In California, for example, as much as 19% of the state's electricity consumption is for pumping, treating, collecting and discharging water and wastewater.

Energy consumption by public drinking water and wastewater utilities, which are primarily owned and operated by local governments, can represent 30-40% of a municipality's energy bill. At drinking water plants, the largest energy use (about 80%) is to operate motors for pumping. At wastewater treatment plants, aeration, pumping, and solids processing account for most of the electricity that is used. Energy is the second highest budget item for these utilities, after labor costs, so energy conservation and efficiency are issues of increasing importance to many of them. Opportunities for efficiency exist in several categories, such as upgrading to more efficient equipment, improving energy management, and generating energy on-site to offset purchased electricity. However, barriers to improved energy efficiency by water and wastewater utilities exist, including capital costs and reluctance by utility officials to change practices or implement new technologies.

Topics for research to better understand water-related energy use include studies of energy demands for water at local, regional, and national scales; development of consistent data collection methodology to track water and energy data across all sectors; development and implementation of advanced technologies that save energy and water; and analysis of incentives, disincentives, and lack of incentives to investing in cost-effective energy or water efficiency measures.

INTRODUCTION

Water and energy are critical resources that are reciprocally and mutually linked. Meeting energy needs depends upon the availability of water, often in large quantities, for mineral extraction and mining, fuel production, hydropower, and thermoelectric power plant cooling.[1] Likewise, energy is

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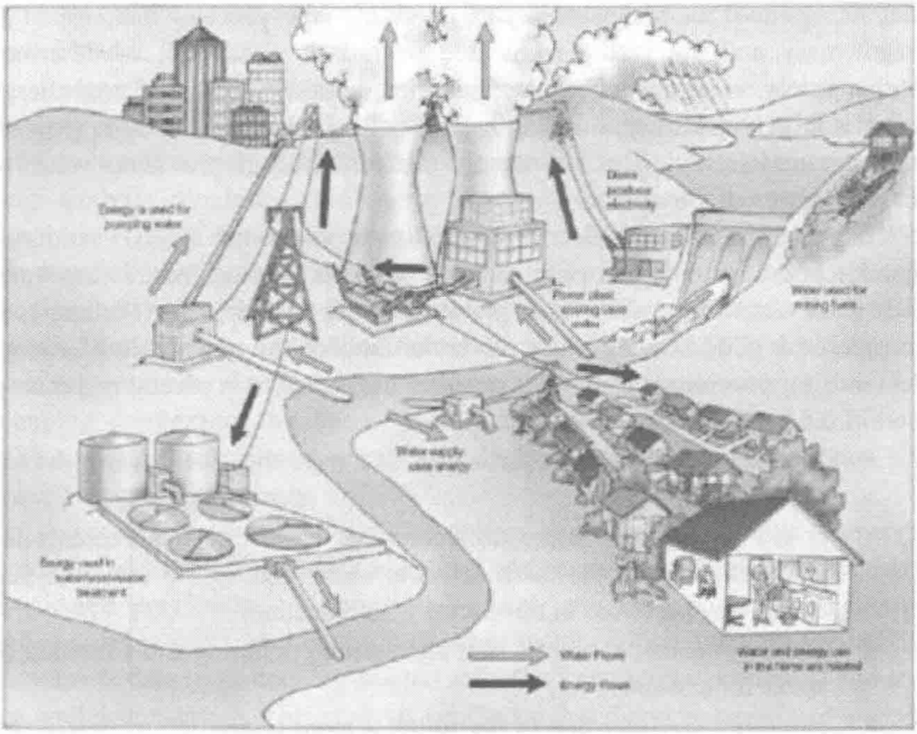
required for the pumping, conveyance, treatment and conditioning, and distribution of water and for collection, treatment, and discharge of wastewater. This interdependence, which is often described as the water-energy nexus, or energy-water nexus, is illustrated in the following graphic from a U.S. Department of Energy report.



Source: U.S. Department of Energy, Energy Demands on Water Resources, Report to Congress on the Interdependency of Energy and Water, December 2006, p. 13.

Figure 1. Examples of Interrelationships Between Water and Energy.

This report first discusses water-related energy use broadly and then energy for facilities that treat and deliver water to end users and also dispose of and discharge wastewater. There is growing recognition that "saving energy saves water," and the report describes options and impediments for energy efficiency by these facilities. It also identifies several areas of research and information needs concerning energy for water uses.

Energy for Water Use

In the United States, more than 400 billion gallons of water is withdrawn daily from surface and ground water sources of freshwater and saline-water to supply domestic uses, agriculture including irrigation, industry, mining, and thermoelectric power.[2] Information about the energy— especially electricity— that is needed to pump, transport, deliver, and process that water is fragmentary and not well documented overall. In particular, as described further below, energy needs for self-supplied domestic, industrial, and energy water is largely unknown, but are likely to be large. Interest has been growing in better understanding of the energy-related needs of providing water to diverse sectors of the economy.

In a 2002 report, the Electric Power Research Institute (EPRI) estimated that 4% of the nation's electricity use goes towards moving and treating water and wastewater by public and private entities.[3] Today that estimate is considered a good starting place for understanding the magnitude of energy demands for providing these water services, but deficient in several respects.

- It relied on secondary source data that were then well over a decade old.
- It did not include future projections of electricity requirements for water supplies in the thermoelectric sector (because it assumed that energy for water use in this sector would decline).
- It did not consider on-site heating, cooling, pumping and softening of water for end-use.
- It did not consider that in the future a large proportion of new water demands will be met by sources with greater energy intensities, such as groundwater pumped from greater depths and seawater desalination.

More recently, others have attempted to expand on the EPRI analysis, using additional and updated data from a variety of sources, to develop a baseline estimate of water-related energy use in the United States. These analyses suggest that energy for publicly supplied water and wastewater is a larger share of U.S. energy use than EPRI estimated. For example, a 2009 report by the River Network, a national advocacy group for freshwater conservation and watershed restoration, estimated that water-related energy use, including for heating in the residential and commercial sectors, was 52.1 billion killowatt hours (kWh), equivalent to 13% of U.S. electricity consumption in 2007.[4] National data can obscure differences in water-related energy use that are regional or state-specific, as reflected in a 2005 study by the California Energy Commission, which found that "water-related energy use [in California] consumes 19 percent of the state's electricity, 30 percent of its natural gas, and 88 billion gallons of diesel fuel every year – and this demand is growing." Pumps that move water from the San Joaquin Valley to southern California for domestic and irrigation water uses are the single largest power load in the state.[5]

Researchers at the University of Texas at Austin have attempted to quantify the energy embedded in the U.S. public water supply, which is the primary water source of residential, commercial, and municipal users. One such analysis concluded that energy use associated with the public water supply is 4.1% of the nation's annual primary energy consumption and 6.1% of national electricity consumption, but this analysis excluded energy requirements associated with water for agriculture, industrial, and self-supplied sectors (e.g., agriculture, thermoelectric, and mining). In this analysis, electricity consumption by public drinking water and wastewater utilities for pumping, conveyance, treatment, distribution, and discharge was 56.6 billion kWh, or 11.5% of primary energy and 21.6% of electricity consumption for water end-use, respectively, in 2009.[6]

A second analysis by these researchers looked more broadly at energy needs for water supply, adding industrial and thermoelectric sectors to others considered previously.[7] Water-related energy use throughout the economy varies across sectors, and analysis of some sectors is complex and limited by incomplete data (e.g., cooking-related activities vary across residences and are not well documented). This analysis concluded that direct water-related energy consumption was 12.6% of national primary energy consumption in 2010. This amount of energy, 12.3 quadrillion BTUs, is the equivalent of annual energy consumption of about 40 million Americans. It also estimated that energy losses at the point of electricity generation, transmission and distribution, and end-use represent 58% of the total primary energy that was consumed for water-related purposes, reflecting varying efficiencies of water heating and boiler technologies. The estimate of waste heat losses is subject to uncertainty, the researchers said.

Because of inadequate data and other factors, missing from some analyses is water-related energy for several important end-use sectors.

- Self-supplied water, which is a high percentage of power plant use and of some industrial uses such as mining. Some of this energy-for-water is in the form of electricity, but much of it is likely direct use of fuels on-site. Privately operated residential water supply wells also utilize energy for pumping, none of which is accounted for.

- Agricultural use of water for livestock and irrigation—second in volume only to water use for thermoelectric power, according to the U.S. Geological Survey—is generally omitted from these analyses, although substantial energy, which generally is self-supplied, is needed for pumping.
- The transportation sector, although the majority of energy consumed is for petroleum-based transportation fuels, which is presumably reflected in water-forenergy analyses.
- The bottled water industry, which is a substantial drinking water source in the United States and consumes energy to collect, treat, bottle, and distribute its products.

Energy use for water is a function of many variables, including water source (surface water pumping typically requires less energy than groundwater pumping), treatment (high ambient quality raw water requires less treatment than brackish or seawater), intended end-use, distribution (water pumped long distances requires more energy), amount of water loss in the system through leakage and evaporation, and level of wastewater treatment (stringency of water quality regulations to meet discharge standards). Likewise, the intensity of energy use of water[8] varies depending on characteristics such as topography (affecting groundwater recharge), climate, seasonal temperature, and rainfall. Focusing on national data can mask large variations, because the United States is a difficult country to generalize.

For example, the lifecycle energy-intensity of water in cities nationally is estimated to be 3,300-3,600 kWh per million gallons delivered and treated, but ranges from 2,700 kWh/million gallons in New York, New York, to 5,000 kWh per million gallons in Austin, Texas.[9] Energy intensity varies within states, as well. In California, the energy intensity of the water use cycle ranges from 4,000 kWh per million gallons in the northern part of the state to 12,700 kWh per million gallons in southern California, reflecting differences in the volume of water pumped, lifted, and transported hundreds of miles and over mountains from points of collection to points of need in the southern part of the state.[10] The energy intensity of a particular activity's water use, also described as the embedded energy of the activity, can have disproportionate impacts elsewhere.

For example, policies that promote the use of energy-intensive water supply such as pumping and distributing water over long distances, rather than policies that promote water conservation, water reuse, or aquifer recharge, adversely impact one sector to serve another.[11]

In every sector, there are opportunities for practices that would save energy and also save water. The Environmental Protection Agency's (EPA) WaterSense program promotes this concept by emphasizing that "saving water saves energy."[12]

Energy efficiency initiatives offer opportunities for delivering significant water savings, and likewise, water efficiency initiatives offer opportunities for delivering significant energy savings. In the commercial, industrial, and institutional sectors, potential water savings through energy efficiency and other measures could be 15-30% without reducing the services derived from the water. The potential for significant water and energy savings also exists in other sectors such as agriculture.[13]

Generating the energy associated with water use also produces carbon dioxide (CO_2) emissions that contribute to climate change. It has been estimated that water-related carbon emissions in 2005 were approximately 290 million metric tons, or 5% of all U.S. carbon emissions. Water-related CO_2 emissions were equivalent to the annual greenhouse gas emissions of 53 million passenger vehicles. By sector, water heating was responsible for 70% of the water-related carbon emissions, wastewater treatment was responsible for 18%, water supply was responsible for 8%, and agricultural activities were responsible for 6%.[14] Thus, saving water saves energy and also reduces carbon emissions.[15]

Energy for Water Supply and Wastewater Facilities

There are about 200,000 drinking water treatment systems in the country, of which about 52,000 are community water systems that serve 25 or more year-round residents.

Most U.S. drinking water is provided by relatively large community water systems. Nearly 85% of the U.S. population is supplied by about 5% of these systems; the remaining 95% include a large number of small and very small systems serving 3,300 persons or fewer.

Public agencies own and operate most community water systems; a small number are privately operated. Smaller utilities use more electricity and pay more per unit of water produced than do medium and large utilities, due to economies of scale. Nearly all of the energy consumed is electricity, about 80% of which is used by motors for pumping.

There are approximately 15,000 U.S. wastewater treatment plants. Most are publicly owned, and they serve more than 75% of the U.S. population. Nearly 70% of facilities are small, serving only 10% of the U.S. population. Approximately 22% are large (with flow greater than 1 million gallons per day) and serve over 85% of the population. Wastewater systems generally consist of collection systems (sewers and pumping stations), treatment facilities, and effluent disposal. Like water supply utilities, nearly all of the energy consumed is electricity. Wastewater aeration, pumping, and solids processing account for most of the electricity used in wastewater treatment.

For both types of systems, greater amounts of energy are required for more advanced treatment levels. Similarly, the age of the system and equipment are important: as systems age, equipment decreases in efficiency, resulting in an increase in electricity requirements.

According to EPA, community drinking water and publicly owned wastewater systems use 75 billion kWh per year—as much as the pulp and paper and petroleum industries combined, or enough electricity to power 6.75 million homes.[16] Energy is the second highest budget item for municipal drinking water and wastewater facilities, after labor costs, with utilities spending about $4 billion a year. Energy consumption by drinking water and wastewater utilities can comprise 30-40% of a municipality's total energy bill.

Water utilities are highly regulated entities whose primary goals are to meet regulatory requirements for protecting public health and the environment and to provide services for reasonable and fair rates. The energy efficiency of these utilities generally has not been a primary goal or considered as an element of rate determinations. Nevertheless, as populations grow and environmental requirements become more stringent, demand for electricity at drinking water and wastewater utility plants is expected to grow by approximately 20%.

Moreover, as electricity rates increase, energy conservation and efficiency are issues of increasing importance to many utilities. By some estimates, potential energy savings by drinking water and wastewater utilities are in the range of 15-30% per year.[17] Opportunities for efficiency exist in several categories.

- *Optimizing system processes*, such as modifying pumping and aeration operations and implementing monitoring and control systems through SCADA (supervisory control and data acquisition) systems to

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